AN EXHAUSTIVE, authoritative study of our oil resources, in terms of geographical knowledge, as well as of human resources—engineering and scientific learning, and private initiative and incentive. This highly important symposium by a number of authorities on the subject, supplies a complete accounting of oil up to the present time, with a timely appeal as it assumes increasing significance in international relationships.

The book demonstrates the indispensable role of petroleum in our daily life—traces the part of private enterprise in the development of U. S. oil resources, analyzes vital considerations such as conservation, the role of technology, oil, natural gas, coal and shale reserves, oil in public domain, naval reserves, capital employed in the petroleum and American oil industries — discusses the subject of American oil companies in foreign oil operations.

Eighteen outstanding authorities, and oil company executives, have contributed to this impressive symposium.

OUR OIL RESOURCES

This book is produced in full compliance

OUR OIL RESOURCES

EDITED BY

LEONARD M. FANNING

Author of "The Rise of American Oil"

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OUR OIL RESOURCES

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PREFACE

This volume presents the most exhaustive studies on our oil resources which have been attempted in recent years by highly qualified authorities. It is an impressive story of the petroleum industry of the United States, an industry that holds an indispensable role in our national life and strength.

America has led the world in petroleum production. This fact has been a basic reason for our unmatched industrial development. Americans accept as commonplace a voluminous, never-failing flow of low-cost oil products; most other nations have known nothing like it. The call of war found the American oil industry strong and ready to serve. How well it has discharged its duty is exemplified by the fact that two-thirds of all war materials shipped to the fighting fronts during the Second World War has been petroleum in one form or other. This country has supplied some 90 per cent of the petroleum requirements of all the United Nations.

Oil has been called a product of freedom. It is not found—it must be won from the earth. The history of petroleum over the world and the preeminence of the United States show that initiative and enterprise, with the spur of competition, are the real tools by which it is won. Moreover, the American petroleum industry performs an important part in developing oil reserves not only at home but also in foreign countries, as we show in this book.

Two previous studies have been published, similar in character and scope to the present volume: "American Petroleum Industry, 1935"[1] and "Petroleum Supply and Demand."[2] In this book a number of papers pertinent to the subject have been gathered together, most of them never before in print, although three or four were published in trade or technical journals. The authors are experts in the subjects they have covered, and

[1] American Petroleum Institute, New York, 1936.

[2] American Petroleum Institute Committee of Eleven, McGraw-Hill Book Company, Inc., New York, 1925.

in many cases have enlisted the aid of their technical staffs in exploring the basic facts about our petroleum resources. The result is an exhaustive and enlightening book that is also extraordinarily timely: oil resources figure high in the counsels of nations these days. The editor believes that for completeness and authoritativeness it will rank with the historic volumes mentioned above.

Never has petroleum played a more vital role in our national life than it does today. In the postwar years as truly as in the years before the war, when Americans owned more automobiles than the people of any other country and otherwise enjoyed the benefits of a natural resource turned to useful purpose, oil—its availability to all, its conversion into products of usefulness to mankind—will be a measure of our ability to build an even higher standard of living in America.

The supply of oil for the service of mankind is inextricably bound up with the establishment and maintenance of peace throughout the world. Hence the timeliness of this book now and in the immediate future. An accounting of our oil resources is given not alone in terms of geological knowledge but also in terms of human resources—engineering and scientific learning and application, and private initiative and incentive, which are the real keys to our future oil discoveries.

The editor wishes to express his thanks to the authors of the papers contained in this book for their cooperation in permitting their use, to *Chemical and Engineering News* for permission to republish Dr. Robert E. Wilson's papers, and to *Mining and Metallurgy* for permission to publish the papers of Mr. John M. Lovejoy and Messrs. Joseph E. Pogue and Frederick C. Coqueron.

LEONARD M. FANNING, *Editor.*

NEW YORK, N. Y.,
November, 1945.

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OUR OIL RESOURCES

CHAPTER I

THE ROLE OF PRIVATE ENTERPRISE IN THE DEVELOPMENT OF OIL RESOURCES[1]

By John A. Brown

Late President, Socony-Vacuum Oil Company, Inc.

Words express thoughts inexactly. We say private industry or free private enterprise, but we know that there is no absolute freedom for our lives or business, and little privacy for modern corporate enterprise.

Corporations exist by virtue of public approval through the laws of our states. Shares in their debts and their profits (when there are any), in the form of bonds and stocks, are owned by very large numbers of the general public. The public as a whole, through the tax laws (of which the Income Tax Law is but one), takes most of the corporate income left over after pay rolls, materials, and administration costs are paid for, and requires voluminous reports from management to public authorities. The money finally distributed to creditors as interest and to stockholders as dividends is again siphoned off in substantial degree for the general public by means of the income tax. Much of it goes to mutual insurance companies, educational institutions, hospitals, and socially valuable organizations.

Society pays an exceedingly low cost in net percentage of sales or capital investment to the ownership or management of business enterprise. We are already collectivist to a large degree. A drift to full collectivism is sure to cost more. We would have limitless power over our lives and fortunes placed in the political sphere. We would produce less to distribute. All of us would have far

[1] Address before The Economic Club of New York, Mav 9. 1944.

less freedom than we now enjoy, if indeed we could have any freedom whatever, and our mental and spiritual life would wither.

Our duty is to examine with anxious care all suggestions that government should assume some of the functions of business, or increase its control over it, or have a proprietary interest in it, or draw off too much of its substance by excessive taxation in peacetime, thus crippling its ability to improve products, lower costs, and expand to meet growing demand. The regulatory powers of government have been vastly extended in recent years; they need to be reexamined to see whether some of these extensions promote or retard the welfare of the people. An improvement in the organization of American government could contribute greatly to national progress. We need a highly trained, competent, and well-paid group of career civil servants working under sensible laws and holding their authority down to the minimum required for the public welfare. With such a truly modern government, modern business could work in harmony and reach new high levels of achievement.

Our petroleum industry started only 85 years ago with a shallow well in Pennsylvania, and lamp oil was its main product. The industry has kept pace with, and in great part made possible, the growth of motorized transportation and the airplane. Ever since gasoline in great volume became important, the industry has met the constantly growing demand, increased its underground inventory of raw material, paid better wages with shorter hours, continually improved its products, and lowered costs to the public.

Today, despite the failure of four out of five wildcat wells, each of which may cost from $20,000 to $100,000, we go on exploring and drilling; finding new crude oil and gas fields, producing oil from wells 2 to 3 miles deep in the ground, advancing the science of drilling, producing, and discovery, reducing the cost of transportation, and improving the technology of refining to derive more valuable fractions from each barrel of crude oil and to make products once thought impossible. No industry is more competitive. Thousands of aggressive companies and individuals are engaged in it, and no one company (according to prewar figures) sells quite 10 per cent of the branded gasoline distributed to the public of the United States. The industry was instrumental in winning the First World War. It is assuring victory in this war, which uses petroleum in quantities unimagined by Army and Navy men only 3 years ago, and which requires such variety and quality of products that our refineries and technicians have had to work miracles to produce them.

The record is one of marvelous achievement by private industry. Since the First World War we have quadrupled our crude-oil-producing capacity, found and put to use enormous volumes of gas, increased our yield of gasoline from a barrel of crude oil by 75 per cent, built 100,000 miles of pipelines, and not only quadrupled refinery capacity, but changed refinery technology to an amazing extent.

During the 23 years, 1919 through 1941, we drilled 551,676 wells in the United States, of which 136,381 were failures. In 1918, technical men of the industry estimated the crude oil of the United States, both "proved" and "to be discovered," at only 7 billion barrels and the automobile industry feared that an oil shortage would hamper its growth. Since that time, our private oil industry has produced 23 billion barrels of oil and still has proved reserves of 20 billion barrels, while we continue to discover new fields.

The great network of highways and roads covering the United States was built by Federal and state governments largely out of funds derived from special taxes levied on automobiles and the comsumption of oil products. In the case of gasoline alone, the states were collecting taxes at the rate of $948,038,000 yearly in 1941. Along these roads and highways the oil industry has established the greatest distribution system in the world. During normal peacetime in America, a so-called "nation on wheels," the motorist is rarely, if ever, beyond reach of a service station where he is assured of fine products and exceptionally efficient service.

A business dealing with so vital a product, organized so efficiently, and enjoying so rapid and constant an increase in consumption, might perhaps be expected to earn a great rate of profit and pay dividends at high percentages on investment. On the contrary, the industry's profits, large in total dollars, have been small in relation to the investment, because the investment in dollars has grown so great. It has been able to pay dividends at only modest rates. In the past 20 years they have averaged only 4 per cent on net depreciated investment.

The great progress of the American oil industry has been accomplished without government participation, but with some government encouragement. The record, with few exceptions, is a tribute to the sound relationship which has usually prevailed between the industry and government. . . .

Outside the United States the open-door policy of our Department of State, although not completely successful in all countries, has helped American companies to compete in the development of various oil areas. Without threat of force and without the use of force, our nationals have been able to hold their own with foreign enterprises, whether private or governmental partnerships, even in those regions of the world designated as some other nation's sphere of influence. Recently an impression seems to have gained ground that our nationals have not done so well as others in securing foreign oil reserves. The truth is the contrary.

In reviewing this amazingly successful history of the American oil industry, we ought first to examine the policies of the past when we think of possible change in policy. The results have been good. It is a natural presumption, therefore, that past policies have been sound. Recently, however, you may have heard much about the need for a drastic change in oil policy, which would greatly increase government control. We hear that our oil reserves are dwindling at an alarming rate; that we must look to other countries for sufficient oil for our peacetime economy and our national defense; that as a consequence the Federal government must own and operate a corporation chartered to engage abroad in all forms of oil activity—production, transportation, refining, and marketing.

We have heard intimations that at home the government should limit the production rate of our oil fields and make room for large imports, so that a production reserve will be on hand for emergency use; that proved and developed oil fields might be condemned and locked up under government ownership as a national defense measure; that government, not private industry, should try to develop oil on the public lands; that billions of barrels of crude oil should be stored by government above or below ground; or that there should be equally costly storage of a huge volume of oil products.

The American private oil industry at home and abroad would be gradually throttled if such ideas were put into effect. Any system of underground hoarding for emergency use would have to provide for a daily production rate of at least a million barrels for emergency purposes (one-fourth of our present production). It would have the effect of locking up proved and developed reserves of about 7 billion barrels, but with all the necessary completed wells and field installations ready to produce immediately when called upon if the reserve were to be of real value in the emergency. Any such restrictions by government would require large numbers of Federal employees who would exercise rigid control over the operation of nearly half a million oil wells. Still more would be required to maintain in workable condition the wells and installations in proved oil fields taken over and locked up by the government, and to drill up the partially developed fields as they are expropriated.

Storage above ground would be equally costly and impractical. For example, if the above-ground storage were adequate to provide an emergency supply of 1 million barrels a day for only 3 years, the total volume would amount to over a billion barrels.[1] If stored as crude oil, the cost over a 20-year period would amount to about 4 billion dollars; if stored as products, to over 6½ billion dollars. This estimate does not take into account the difficulties of transportation in assembling storage facilities, or the disturbance of normal business operations caused by removing such a volume of commerce from the regular stream, or the extra refinery capacity required to provide the products for storage.

Aside from these cost factors, locking up a reserve supply would weaken or destroy incentive for discoveries or wildcat efforts by small and large producers alike. When we bear in mind that only one wildcat well out of every five is a producer, we may ask who will be willing to face a loss of 80 per cent of his venture for the sake of a dubious 20 per cent success, when he faces, on the one hand, possible government expropriation of his property at a low price before he can prove the real value of his discovery by additional drilling, and, on the other, the danger that the government might release a flood of oil into the market at any time, thereby upsetting all the values which induced the explorer to run his great risk?

The way to provide for defense reserves of oil at home is not to set aside for the Army and Navy certain areas or fields to be

[1] Abrams, F. W. See this volume, p. 149.

drilled up and maintained in idleness between wars at great public expense. Our national defense reserve always will comprise all the oil of the entire nation and owned by all the citizens. The freer we are to find and develop oil, the greater these national defense reserves will be. A great emergency production will always be available for war by producing fields for a time at a rate higher than best engineering practice would dictate, plus restrictions on wartime civilian use. Locked-up reserves would mean decreasing reserves for the reasons previously given.

To this home reserve we can add the fields located close by in friendly nations of northern South America, where oil discoveries are certain to increase, and also the fields in the rest of the world to which we have access by overseas transportation under the protection of our military forces. In the Maracaibo basin of Venezuela alone there are proved reserves of at least 5 billion barrels of crude oil, which will be drawn on relatively slowly and which by their nature can be largely adapted to fuel for our Navy.

Today our well-established position in the foreign field is threatened by the recently organized government agency, the Petroleum Reserves Corporation, which under its charter has power to put the government into any kind of oil activity abroad. The entrance of this government into other nations' territory, as owner and operator of oil fields and/or transportation systems in whole or in partnership, will create tension in countries thus invaded and in all other producing or potentially producing countries. It would raise again the cry of Yankee imperialism, which we have taken such pains to disavow, and would gain us nothing that could not be secured without such a policy.

In actual practice all this well-meant planning would only ensure the coming of the very disaster that the planners seek to avoid. Both the planning and the fear of oil shortages which prompt it have a familiar ring to the older men of the industry. As far back as 1908 the chief of the U.S. Geological Survey expressed great concern over the coming oil shortage. Saying that practically all good geological prospects had been tested, he wanted the government to prevent further entry on to public lands. Predictions of oil shortages made headlines after the First World War, and the proposals that seem to be going the rounds today are similar unfortunately.

In 1920 a bill was introduced into the Senate to form a United

States Oil Corporation which would operate abroad with capital supplied by the oil industry and a directorate of nine appointed by the President of the United States. Gasoline at a dollar a gallon was predicted as an almost immediate prospect. The then Secretary of the Navy even wanted to nationalize the whole oil industry. With the benefit of hindsight we see clearly how fortunate we were to avoid such dreadful mistakes. These plans would have halted the industry's progress and might easily have reduced greatly our chances of winning the present war.

No necessity or urgency compels such dangerous and revolutionary changes in our government's policy toward oil. Our total oil resources—not only in crude petroleum but in all forms—in the United States alone regardless of any other oil area are sufficient to meet our needs for an indefinite period. These oil resources are as follows:

1. That part of the discovered crude oil which is recoverable by today's practices is called proved reserves. They represent the smallest part of our total oil resources but are just as great today after 2 years of enormous war demands as on the day of Pearl Harbor. They are figured at 20 billion barrels under severe rules of measurement and bases of calculation. From this figure has been derived the often-quoted but quite erroneous statement that we have only 14 years' supply of oil.

2. Crude oil also remains to be discovered through the years by constant exploration and wildcatting if private industry is not hindered by ill-devised plans that destroy incentive. All the crude oil produced in our country to date plus the proved reserves would occupy only about 2 cubic miles of space, whereas at least 2,100,000 cubic miles of sedimentary strata exist in which to discover oil.

3. We must also take into account the crude oil not included in the first two classes of reserves, but which will be added thereto by improvement in production methods, both primary and secondary. These improvements may easily increase by 50 per cent our estimate of the first two categories.

4. Natural gas exists in proved volume great enough to produce by present conversion techniques as much gasoline as the average refinery is likely to yield from the proved reserves. Although more than half of our proved gas is contracted to move for fuel, it is certain that great additional volumes of gas will be found.

5. Shales containing material convertible into oil exist in vast quantities. Estimates based on using only the richest and most easily mined shales indicate that they should provide 50 billion barrels of gasoline, or enough at the probable postwar rate of consumption for about 65 years. Cost of gasoline produced from shale is probably no higher than gasoline from coal.

6. Coal deposits in North America are calculated in the trillions of tons. Estimates show this coal could supply 6,000 billion barrels of gasoline, which at probable postwar consumption would provide enough gasoline for 8,000 years without infringing on other uses for coal. Even today coal can be mined, converted to oil and then to gasoline, and sell at a price to the dealer, excluding tax, no higher than the price of 1918–1922, excluding tax. The technology of this conversion has naturally received little attention in the United States. When our able research talent really begins to work on it, the cost will be greatly reduced. The prices of 1918–1922 would seem high to our people today, because our private oil industry has continually reduced the cost of gasoline.

Finally, we should not overlook the fact that our greatest, though intangible, oil resource lies in the ability, energy, and brains of operating, engineering, and research talent working coordinately in the American private oil industry. A combination of courage, energy, and technology created the oil industry here and abroad. If it is permitted to survive, it will constantly re-create itself and make all sources of oil available to the country in sufficient volume and at reasonable cost. Without the benefit of American daring and technological ability, our crude-oil resources would have lagged in volume and almost disappeared long ago.

Crude oil cannot be obtained merely by building a factory and installing machinery to make it. It does not occur in solid beds close to the surface where it may be simply dug out of the ground. It does not run in surface channels, needing only to be harnessed to a pump and a refinery. Nor can it be produced by planting seeds or saplings and letting nature mature the crop. Only by technological brains, great courage, and persistence is crude oil brought to light out of nature's hidden stores a mile or 2 or 3 beneath a ground surface which looks unpromising.

The role of private industry in the development of oil resources is that of a creator. Unless the search for oil goes on without halt or hindrance in spite of uncertainties and difficulties, the resources will cease to exist for mankind. If this forceful American enterprise is preserved, we will have enough oil at home to carry us through generations to come—undoubtedly until the advancing technology of the machine no longer requires a large volume of oil. Oil will continue to be a vital product only so long as it continues to give the best and most convenient service at low cost. When it fails in these respects, it will gradually be superseded. But until that time, our oil resources will prove adequate unless the initiative to find and to develop them is destroyed.

These resources mentioned above are domestic. They represent the natural desire of a great nation to have its own supply. But we do not need to insist upon self-sufficiency. Our production of crude oil may fall behind our country's enormous consumption. The costs of finding oil, which according to the Petroleum Administration for War have quadrupled in the past 10 years or so, may continue high; a higher price therefore may be necessary. A few years may be required before the cost of making oil from shale and coal is reduced to the cost of producing it from crude petroleum. If we are unwilling to pay a slightly higher price to discover oil in our own country or to get our surplus needs from shale or coal, we can still import from other countries. There is no immediate shortage of crude oil in the world as a whole. The known fields are vast, and those yet to be found are sure to be very productive. In these fields our nationals hold a strong position.

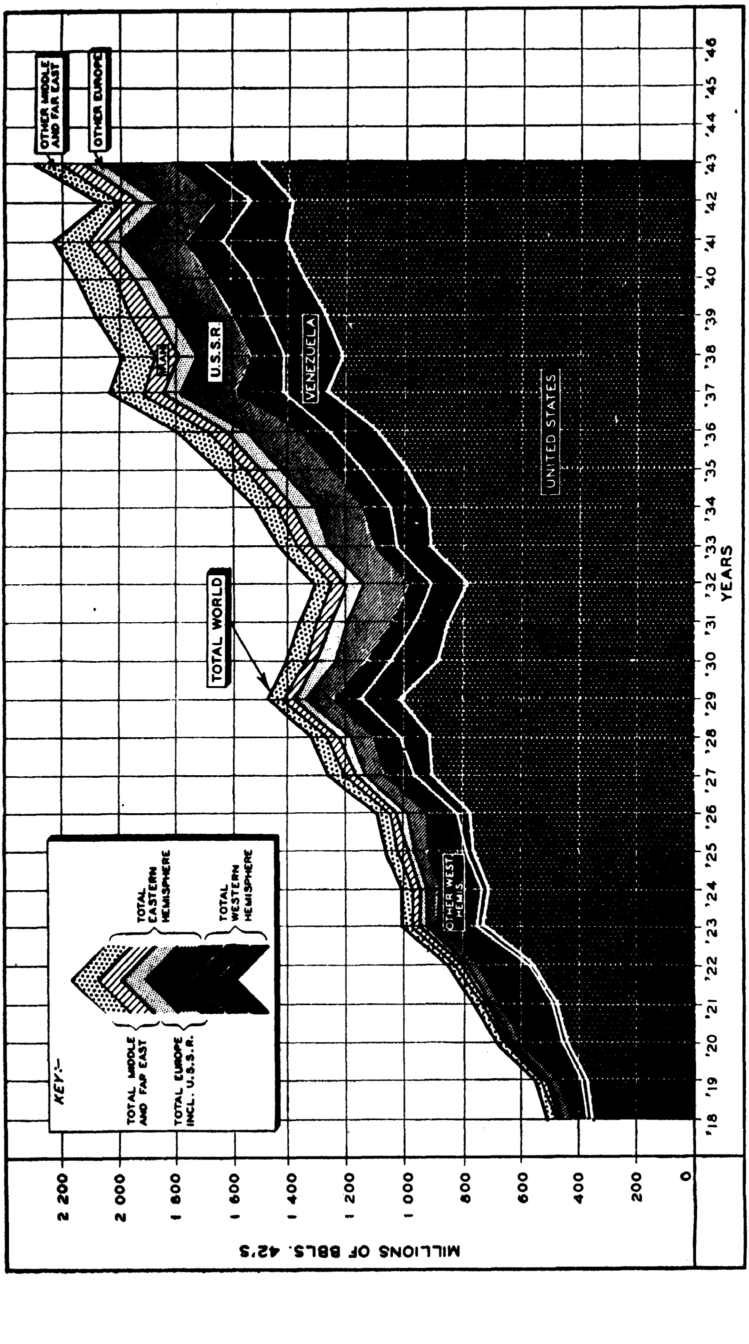

Fig. 1.—World crude-oil production.

CHAPTER II

AMERICAN OIL COMPANIES IN FOREIGN PETROLEUM OPERATIONS

By EUGENE HOLMAN

President, Standard Oil Company (New Jersey)

That the United States domestic oil industry has been preeminent in the world petroleum picture is generally known. Less widely known is the fact that American oilmen have also played a leading part in developing foreign oil supplies. They have not only participated in large measure in the discovery of foreign oil reserves, now greater than our own, but they have also helped to produce foreign oil, transport it, refine it abroad, and market the finished products.

In view of the increasing discussion of postwar foreign trade and the growing attention which is being paid to the formulation of world trade policies (including oil policy), the time seems propitious to review the part Americans have already played in the discovery and development of foreign oil reserves. What follows is an outline of the crowded story of American oilmen abroad. It concerns primarily the geologist and the producing man, but also included is a brief review of refining, marketing, and transport activities, with some observations on the economic and social influences which have resulted. The full story has never been told in its entirety and perhaps never will be, for much of it has been lost or forgotten with time.

The early American oilmen lost no time in starting operations abroad. They began shipping oil to foreign markets within two years after the completion in 1859 of Col. E. L. Drake's 69-ft. oil well near Titusville, Pa. The latter event is generally accepted as marking the birth of the modern oil industry. The oilmen's interest in foreign countries has never lagged since then, and over the years Americans have marketed petroleum products in every corner of the world. Americans have searched for and discovered

TABLE 1.—WORLD CRUDE-OIL PRODUCTION, BY COUNTRIES AND YEARS, 1857 TO 1943[1] (Barrels of 42 U.S. gal. daily)

Year	Rumania	United States	Italy	Canada	Russia	Poland	Japan and Taiwan	Germany	India	Burma[3]	Dutch East Indies	Peru	Mexico	Argentina	Trinidad	Egypt	British Borneo	Iran (Persia)
1857–1860	13	344																
1861	47	5,791																
1862	63	8,375		33														
1863	77	7,154		227	112													
1864	90	5,781		246	178													
1865	107	6,844	5	301	184													
1866	115	9,858	3	479	227													
1867	140	9,169	3	521	329													
1868	153	9,963		546	240													
1869	162	11,548		603	553													
1870	230	14,414		685	559													
1871	247	14,260		740	452													
1872	249	17,194		842	505													
1873	285	27,107		1,000	1,301													
1874	282	29,937	3	463	1,597	411												
1875	296	24,075	3	603	1,910	433	14											
1876	303	24,955	8	852	3,609	448	19											
1877	296	36,576	8	855	4,934	466	27											
1878	299	42,184	11	855	6,578	482	49											
1879	301	54,560	8	1,575	7,564	589	63											
1880	314	71,820	5	956	8,199	626	71	25										
1881	334	75,784	3	753	9,866	786	47	79										
1882	373	83,151	5	755	12,433	904	41	159										
1883	381	64,246	5	685	16,444	1,000	55	74										
1884	577	66,168	8	683	29,522	1,115	77	126										
1885	529	59,888	5	685	38,151	1,274	82	112										
1886	460	76,891	5	1,600	49,332	838	104	203										
1887	499	77,488	3	1,441	50,323	942	79	203										
1888	598	75,443	3	1,899	62,975	1,276	101	232										
1889	816	96,339	3	1,932	67,422	1,411	145	186	258									
1890	1,049	125,547	8	2,178	78,605	1,805	142	296	323									
1891	1,337	148,746	22	2,069	94,721	1,729	145	299	521									
1892	1,620	138,019	49	2,131	97,746	1,765	189	276	661									
1893	1,466	132,688	52	2,186	110,841	1,899	290	274	819		1,644							
1894	1,392	135,188	58	2,271	99,658	2,600	474	337	896		1,885							
1895	1,578	144,909	71	1,989	126,411	3,981	466	332	1,019		3,332							
1896	1,484	166,557	49	1,986	129,019	6,678	648	396	1,175		3,899	128						
1897	1,564	165,687	38	1,945	149,038	6,099	718	455	1,496		6,992	195						
1898	2,126	151,680	41	2,077	168,795	6,510	874	504	1,485		8,121	195						
1899	3,907	156,357	44	2,214	180,699	6,340	1,477	526	2,578		4,921	244						
1900	4,463	174,305	33	2,501	207,616	6,430	2,386	981	2,956		6,173	751						

1901	4,597	190,108	44	2,074	233,337	8,907	3,060	860	3,921		10,997	753	27					
1902	5,644	243,196	52	1,455	220,658	11,348	2,729	970	4,430		6,658	786	110					
1903	7,570	275,236	49	1,334	207,099	14,342	3,312	1,222	6,877		15,808	762	208					
1904	9,833	319,894	71	1,511	214,582	16,249	3,331	1,740	9,249		17,781	792	344					
1905	12,112	369,088	121	1,737	150,575	15,797	3,690	1,537	11,334		21,507	1,022	688					
1906	17,474	346,558	148	1,559	161,362	14,981	4,285	1,586	11,003		22,414	1,455	1,375					
1907	22,241	455,056	164	2,162	169,455	23,167	4,707	2,074	11,901		27,350	2,058	2,753					
1908	22,546	487,778	139	1,443	168,910	34,459	5,112	2,757	13,790		28,096	2,582	10,746	33				
1909	25,553	501,839	115	1,153	180,740	40,912	5,170	2,792	18,293		30,252	3,866	7,436	49	156			
1910	26,641	574,128	140	866	192,704	34,721	5,011	2,827	16,816		30,222	3,447	9,956	55	392			
1911	30,433	603,963	205	797	181,326	28,819	4,759	2,786	17,674		33,351	4,014	34,392	36	781	58		
1912	35,453	609,111	148	664	185,844	23,320	4,533	2,817	19,445		31,788	4,787	45,241	128	1,194	585		
1913	37,136	680,673	129	625	183,159	21,419	5,315	2,348	21,726		31,797	5,674	70,401	359	1,381	269	386	5,088
1914	35,141	728,117	110	589	178,824	17,633	7,222	2,140	20,301		32,459	5,033	71,878	756	1,765	2,063	871	7,973
1915	32,959	770,148	121	589	189,482	14,663	8,022	1,926	22,471		34,004	7,066	90,166	1,406	2,055	581	1,074	9,907
1916	24,440	821,768	139	541	195,430	17,997	8,096	1,792	23,199		35,741	7,085	102,213	2,368	2,538	1,104	1,719	12,232
1917	10,195	918,674	112	586	172,750	17,063	7,838	1,759	22,134		37,343	7,060	151,671	3,337	4,390	2,584	1,485	19,581
1918	23,918	975,145	96	836	72,012	16,526	6,688	740	22,433		36,360	6,923	175,899	3,706	5,704	5,301	1,381	23,624
1919	18,508	1,036,622	96	660	88,233	16,701	6,132	726	23,934		43,984	7,200	253,288	3,646	5,044	4,156	1,633	27,778
1920	20,736	1,210,189	96	536	75,842	15,320	6,041	672	22,883		47,877	7,697	445,462	4,511	5,961	2,847	2,787	33,415
1921	23,391	1,293,652	88	515	79,364	14,156	5,950	751	23,929		47,992	10,134	549,544	5,634	6,450	3,438	3,866	45,679
1922	27,465	1,527,482	85	490	97,786	14,321	5,519	874	23,367		48,442	14,559	508,455	7,850	6,700	3,255	7,805	60,951
1923	30,487	2,006,595	93	466	107,252	14,800	4,796	948	23,030		57,387	15,614	415,242	9,137	8,359	2,888	10,795	69,123
1924	37,127	1,950,656	107	440	123,921	15,456	4,784	1,109	22,995		58,904	21,344	384,300	12,729	11,085	3,036	11,374	88,451
1925	46,585	2,092,447	167	910	143,359	16,329	4,924	1,482	22,668		62,012	24,507	317,628	16,406	12,019	3,359	11,663	95,994
1926	65,181	2,111,984	112	998	174,958	16,011	4,759	1,789	21,948		61,432	28,843	247,408	21,503	13,620	3,255	13,540	98,197
1927	73,541	2,468,847	129	1,306	208,943	14,389	4,365	1,816	22,005		72,718	27,260	175,739	23,672	14,740	3,471	13,542	108,734
1928	86,180	2,463,044	126	1,715	239,571	14,757	4,844	1,721	23,883		84,450	32,283	137,099	24,782	20,994	4,906	14,270	118,746
1929	98,209	2,759,789	135	3,070	282,194	13,383	5,357	2,104	23,965		104,228	36,723	122,345	25,730	23,786	5,059	14,917	115,466
1930	119,075	2,460,304	185	4,268	370,782	13,290	5,233	3,520	24,347		110,159	34,107	108,231	24,662	24,989	5,229	13,766	125,570
1931	136,900	2,331,729	397	4,338	446,685	12,642	5,165	5,044	23,876		93,913	27,641	90,335	32,089	26,635	5,276	10,511	121,578
1932	149,700	2,145,243	663	2,888	421,544	11,132	4,370	4,732	24,091		100,698	27,049	89,443	35,833	27,639	4,899	10,369	135,164
1933	151,032	2,481,249	568	2,676	419,408	11,042	3,878	4,715	23,927		110,277	36,321	92,822	37,436	26,194	4,301	12,230	148,066
1934	172,353	2,487,849	440	2,767	470,425	10,611	4,173	6,138	25,216		120,817	44,600	104,123	38,428	29,847	3,976	13,219	157,271
1935	170,943	2,730,400	343	2,597	497,554	10,322	6,177	8,241	25,280		120,856	46,753	109,775	39,167	31,934	3,267	14,304	156,523
1936	177,983	3,004,609	283	2,491	532,607	10,211	6,678	8,504	26,282		128,288	48,074	111,527	42,227	36,167	3,283	13,259	170,904
1937	145,625	3,504,548	314	6,368	555,951	10,090	6,835	8,697	5,929	21,433	145,843	47,854	127,918	44,811	42,474	3,081	15,466	212,548
1938	134,050	3,327,000	231	17,521	579,596	10,232	6,806	10,587	6,679	20,663	148,025	43,391	104,874	46,784	47,463	4,550	17,756	213,737
1939[2]	127,141	3,465,649	241	20,664	600,718	9,058	6,471	12,823	6,375	21,570	160,554	37,007	117,203	50,999	53,541	12,796	19,383	202,611
1940	116,789	3,697,306	224	23,078	624,000	9,600	6,331	19,433	7,500	21,795	159,821	33,134	119,982	56,314	58,000	17,788	19,619	178,628
1941	109,749	3,841,721	225	26,957	647,000	8,950	6,300	20,000	8,000	20,959	14,918	32,702	117,488	60,315	60,000	23,343	13,731	138,704
1942	105,822	3,799,027	225	27,697	625,000	11,300	6,438	20,000	7,500	3,562	43,973	37,338	95,113	64,942	65,000	22,241	5,000	199,433
1943	100,000	4,118,290	225	26,447	675,000	10,000	6,100	18,000	7,...	2,500	144,000	40,149	95,595	68,063	60,000	24,596	15,000	212,000
1944	63,000	4,584,025	110	26,580	700,000	10,000	6,000	17,000	9,500	2,500	70,000	39,307	103,863	66,205	60,000	25,850	10,000	280,000

[1] Bureau of Mines and private information. [2] Commencing in 1939 figures for many countries in the Eastern Hemisphere reflect assumed approximations.
[3] Included with India up to 1935.

TABLE 1.—WORLD CRUDE-OIL PRODUCTION, BY COUNTRIES AND YEARS, 1857 TO 1943 INCLUSIVE.[1]—(*Continued*)

Year	Venezuela	Ecuador	France	Czechoslovakia	Great Britain	Colombia	Sakhalin	Bolivia	Iraq	Austria	Bahrein	Albania	Hungary	Saudi Arabia	China	Yugoslavia	Other countries	Total foreign	Total world
1857–1860																		13	357
1861																		47	5,838
1862																		96	8,471
1863																		416	7,570
1864																		514	6,295
1865																		597	7,441
1866																		824	10,682
1867																		993	10,162
1868																		939	10,902
1869																		1,318	12,866
1870																		1,474	15,888
1871																		1,439	15,699
1872																		1,596	18,790
1873																		2,586	29,693
1874																		2,756	32,693
1875																		3,259	27,334
1876																		5,239	30,194
1877																		6,586	43,162
1878																		8,274	50,458
1879																		10,100	64,660
1880																		10,196	82,016
1881																		11,868	87,652
1882																		14,668	97,819
1883																		18,644	82,890
1884																		32,108	98,276
1885																		40,838	100,726
1886																		52,542	129,433
1887																		53,490	130,978
1888																		67,084	142,527
1889																		72,173	168,512
1890																		84,406	209,953
1891																		100,843	249,589
1892																		104,437	242,456
1893																		119,471	252,159
1894																		109,571	244,759
1895																		139,179	284,088
1896																		145,462	312,019
1897																		168,540	334,227
1898																		190,728	342,408
1899																		202,950	359,307
1900																		234,290	408,595

1901																	55	268,632	458,740
1902																	71	254,911	498,107
1903																	99	258,679	533,915
1904																	109	275,592	595,486
1905																	82	220,202	589,290
1906																	82	237,724	584,282
1907																	82	268,114	723,170
1908																	82	291,695	779,473
1909																	55	316,542	818,381
1910																	55	323,853	897,981
1911																	55	339,486	943,455
1912																	55	356 002	965,113
1913																	55	387,267	1,067,940
1914																	58	384,816	1,112,933
1915																	37	416,529	1,186,677
1916																	90	436,724	1,258,492
1917	618	156															104	460,766	1,379,440
1918	1,006	164	995														87	404,399	1,379,544
1919	708	164	915	132	5												69	503,712	1,540,334
1920	1,437	164	973	189	8												64	695,248	1,905,437
1921	4,104	164	1,066	258	8	182	6										62	826,731	2,120,383
1922	6,569	164	1,359	329	3	887	19										84	837,338	2,364,820
1923	13,032	238	1,353	203	3	1,164	25										90	786,525	2,793,120
1924	25,014	273	1,358	208	5	1,215	219										95	825,579	2,776,235
1925	55,915	459	1,258	433	8	2,758	486										96	841,425	2,933,872
1926	101,178	1,042	1,310	411	5	17,654	600	60									71	895,888	3,007,872
1927	173,087	1,339	1,381	307	5	40,912	1,305	71	926								58	985,761	3,454,608
1928	288,966	2,967	1,399	257	3	53,695	2,276	33	1,948								62	1,161,933	3,624,977
1929	376,809	3,701	1,537	258	3	54,947	3,288	151	2,186								89	1,319,640	4,079,429
1930	375,308	4,269	1,410	426	3	54,670	6,073	152	2,002								90	1,431,816	3,892,120
1931	325,696	4,812	1,419	411	3	48,815	6,938	69	2,000								90	1,433,269	3,764,998
1932	322,705	4,358	1,404	344	3	43,844	8,230	121	2,000								130	1,433,403	3,578,646
1933	329,978	4,536	1,512	359		35,217	9,341	307	2,501	37	86						163	1,468,990	3,950,239
1934	373,592	4,555	1,535	527		46,410	8,976	435	21,896	67	784							1,663,181	4,151,030
1935	407,915	4,806	1,574	404		47,218	7,672	449	76,359	110	3,465							1,794,008	4,524,408
1936	425,992	5,330	1,456	397		50,502	8,832	286	83,089	110	12,691	1,000						1,908,453	4,913,062
1937	511,934	6,013	1,367	337		54,944	9,300	203	88,000	572	21,267	1,603	55					2,096,832	5,601,380
1938	521,841	6,264	1,364	397		58,925	9,315	250	88,877	1,089	22,734	2,315	908	1,370				2,128,654	5,455,654
1939[2]	562,829	6,461	1,370	326	88	64,835	10,601	589	82,079	2,580	20,791	3,027	3,069	10,778				2,228,578	5,694,227
1940	508,562	6,532	1,037	500	358	69,136	11,270	647	51,498	6 508	19,388	4,000	5,339	14,000			...	2,170,811	5,868,117
1941	625,017	4,385	1,350	525	632	66,816	12,000	644	31,632	12,000	18,600	3,507	8,944	11,800			75	2,234,268	6,075,989
1942	405,436	6,418	1,350	575	1,656	28,732	11,000	844	51,570	16,000	17,100	4,775	13,500	12,400	1,000	1,000	28	1,913,968	5,712,995
1943	491,505	6,518	1,500	600	2,298	36,316	11,000	1,082	74,430	24,000	18,000	2,500	15,500	13,000	2,700	1,500	142	2,207,266	6,325,556
1944	702,278	8,107	1,400	550	1,912	60,904	10,000	833	86,899	32,500	17,000	.	16,500	21,268	1,500	2,000	175	2,453,741	7,037,766

[1] Bureau of Mines and private information.
[2] Commencing in 1939 figures for many countries in the Eastern Hemisphere reflect assumed approximations.

large oil reserves in most of the world's oil regions, except where barred by nationalistic laws or policies. The best measure of their success perhaps is the fact that they hold today one-third of proved foreign reserves. Further, the technical skill and advice of American technicians have been instrumental in finding and developing much of the remaining two-thirds of foreign reserves held by other nationalities.

Let us review briefly the history of developments abroad according to the major divisions of the industry. We can best look at production first, since it is the focal point of the national interest in our foreign operations and the major factor in the international diplomatic activity centering around the industry.

Crude-oil Production.—The search for oil outside the United States began almost immediately after the Drake well was completed in this country. While the United States experienced far greater development in oil than any other nation, several, notably Russia, Rumania, and Burma, had become prominent sources of petroleum by 1900. Table 1 (pages. 12–15) shows the annual world oil production by countries from the beginning of the industry. It may be noted here that the potential oil-producing area abroad is far greater in extent than that in the continental United States, the latter possessing 10 per cent to 15 per cent of the world's land area favorable to oil accumulation. See also Fig. 1, page 10.

The earliest known effort by Americans to develop oil resources abroad occurred in 1883 when a small American operator secured prospecting acreage in Mexico. Two shallow wells were drilled practically over the site of what later became the huge Potrero del Llano pool, but he failed to strike oil. No further efforts are known to have been made until the turn of the century.

Shortly after the 1900's began the first American-owned production abroad—in Mexico. It was followed shortly thereafter by the appearance of an American operator in Rumania. These two areas remained the only sites of American producing activity up to the First World War. By 1914 a total of 18 foreign countries were producing oil, with American participation amounting to approximately 13 per cent. The following table shows world production, its division between United States and foreign areas, and the volume of the American share therein during this period and the war years:

IN MILLION BARRELS DAILY

Year	Total world	Total United States	Per cent of world	Foreign					
				Total foreign	Russia	Total foreign except Russia	American-owned foreign	Per cent of total foreign	Per cent of total foreign except Russia
1900	0.41	0.17	43	0.24	0.21	0.03			
1910	0 90	0.57	64	0.33	0.19	0.14	0.01	2	6
1912	0 97	0.61	63	0.36	0.19	0.17	0.03	8	18
1914	1.11	0 73	65	0.38	0.18	0.20	0.05	13	24
1918	1.38	0 98	71	0.40	0.07	0.33	0.13	32	39
1920	1.91	1 21	64	0 70	0 08	0.62	0.33	48	53
1922	2 36	1 53	65	0.83	0.10	0.73	0.42	50	57

American participation in foreign production thus rose rapidly during the war years, reaching an all-time peak in 1922 of about 50 per cent of total foreign production.

Developments during the First World War set the stage for the second phase of American interest in foreign oil. During this period American oilmen have established themselves strongly in most of the important areas with the exception of Russia. The war had made great demands on the petroleum resources of the United States, which resulted in a 60 per cent increase in domestic production between 1912 and 1918. The demand for petroleum products reached new high levels in the immediate postwar period and fears of an oil shortage were voiced in the United States.

In the early twenties the United States government strongly urged that American oil interests expand abroad and develop adequate reserves to supplement what appeared at that time to be the dwindling supply at home. A sign of the times may perhaps be seen in the fact that in 1926 the Federal Oil Conservation Board, appointed by President Coolidge to study the petroleum picture, estimated officially that proved reserves in the United States were only 4½ billion barrels—equivalent to only 6 years' supply.

With the strong diplomatic backing of their government, American operators embarked on exploratory efforts in many parts of the world. American geologists during the early and middle twenties were active on every continent of the globe. Even today much of the available knowledge of oil prospects in many inaccessible and undeveloped regions stems from these far-flung ventures. American drilling equipment was soon being dispatched to most of these outposts and many new producing areas in which American capital participated were discovered during the first post-war decade. At least 40 American concerns are known to have been active in foreign production and exploration during this period.

Large oil reserves were developed abroad by Americans in the course of this intensive search. But along with success overseas came the discovery of many large fields in the United States. The downward trend in the annual supply index was halted. Public interest in the activity abroad and also the strength of government support declined. Many operators, particularly the smaller ones, were lured back from the foreign field to the United States by the changed picture at home and the realization that most foreign operations require extended, difficult negotiations and large, long-range expenditures before commercial production can be established.

The trend of American-owned oil production abroad since the First World War is reflected by the following table of comparative production for selected years between 1923 and 1943.

IN MILLION BARRELS DAILY

Year	Total world	Total United States	Per cent of world	Foreign					
				Total foreign	Russia	Total foreign except Russia	American-owned foreign	Per cent of total foreign	Per cent of total foreign except Russia
1923	2.79	2.01	72	0.78	0.11	0.67	0 31	40	46
1926	3.01	2.11	70	0.90	0.17	0.73	0.28	31	38
1929	4.08	2 76	68	1.32	0.28	1.04	0.39	30	38
1932	3.58	2.15	60	1.43	0.42	1.01	0.33	23	33
1935	4 52	2.73	60	1.79	0.50	1.29	0.46	26	36
1938	5.46	3.33	61	2.13	0.58	1.55	0.51	24	33
1941	6.08	3.84	63	2.24	0.65	1.59	0.61	27	39
1943	6.33	4.12	65	2.21	0.68	1.53	0.44	20	30
1944	7.04	4.59	65	2.45	0.71	1.74	0.65	27	37

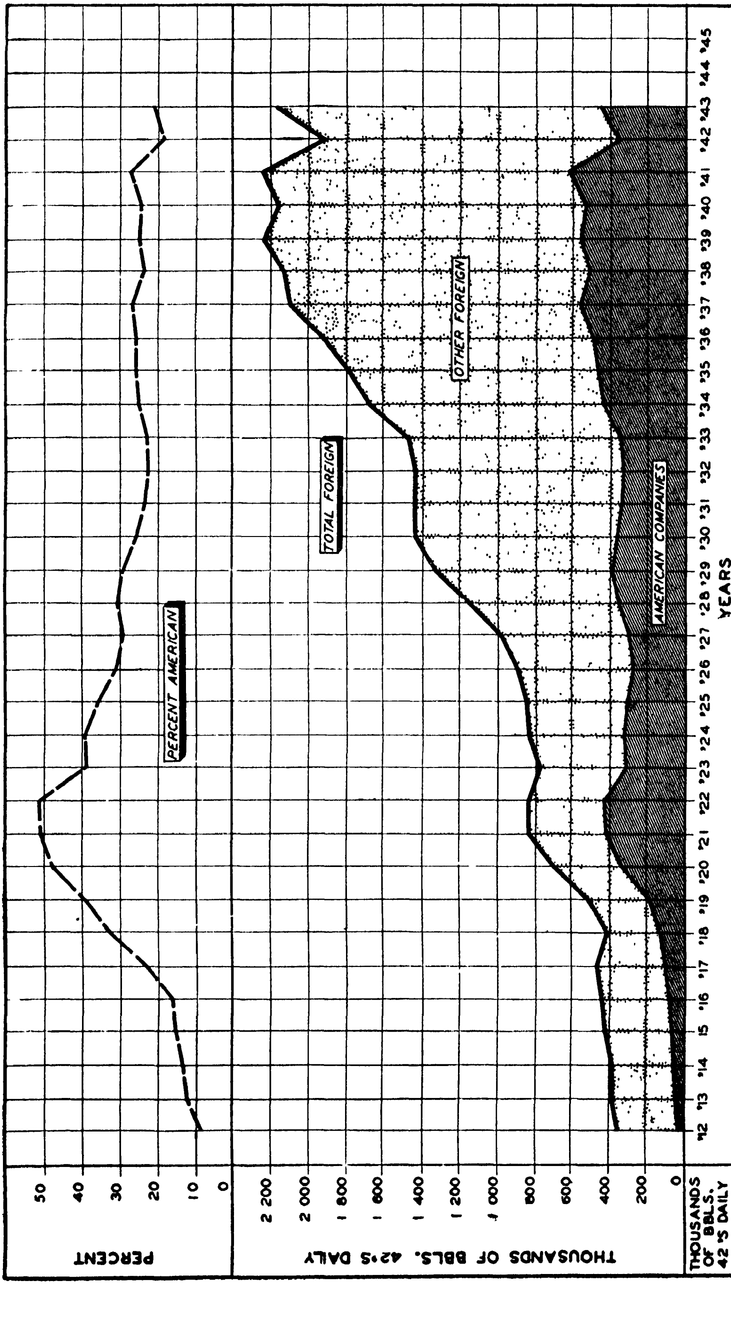

FIG. 2.—American participation in estimated foreign crude-oil production.

Although the volume of American-owned foreign production increased steadily over the interwar period, reflecting the results of previous exploratory efforts, the percentage participation declined from the levels of the immediate postwar years. One reason for this decline lay in the postwar revival of Russian production. Thus, while production in the United States approximately doubled from 1923 to 1943, foreign production increased by 180 per cent, chiefly because of an increase in Soviet output from 107,000 bbl. daily in 1923 to 675,000 bbl. daily in 1943. Even excluding Soviet-controlled production in which non-Russians could not participate, the United States-owned share of all other foreign production declined from 46 per cent in 1923 to 39 per cent in 1941. These figures reflect another factor—the relatively small interest American companies abroad secured in areas such as Iran, Iraq, and Trinidad, which underwent great expansion in oil production following the First World War. Other nationals than Americans obtained preferential standing in concession and development rights.

Principal developments connected with American participation in the more important foreign producing areas—Fig. 1 (page 19) and Table 2 (page 21)—are reviewed in more detail as follows:

Mexico.—An independent American operator entered Mexico in 1883, but oil production did not actually come until 1900 when another American operator purchased a hacienda in northern Mexico and in the following year found oil at a shallow depth in the Ebano field. Between 1901 and 1908 several successful wells were completed in various areas and production reached 10,000 bbl. daily in 1908. But not until 1908, when the famous Dos Bocas well came in, caught fire, and burned almost 2 months was attention from the outside world focused on Mexico. The year 1910 was also eventful because of the completion of another famous well, Potrero del Llano No. 4, which flowed wild for 60 days at an estimated rate of over 100,000 bbl. daily and opened what proved to be the Golden Lane between the Panuco and Tuxpan Rivers. By 1911 Mexican production had reached 34,000 bbl. daily, of which more than half was American-owned, and proved reserves were estimated between 600 and 700 million barrels.

The collapse of the Russian oil industry in the First World War, together with the increased use of oil-burning ships for

Table 2.—Foreign Crude-oil Production—Major Nationalities[1]
(Barrels of 42 U.S. gal. daily)

	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923
American companies	29,908	46,772	49,480	63,068	69,551	104,464	129,944	195,596	330.347	415,214	421,858	311,415
British and Dutch companies	103,825	126,635	148,020	151,829	152,966	173,522	163,178	179,994	246,497	278,181	263,285	312,902
Russian government	...	...	...	...	...	...	...	88,233	75,842	79,364	97,786	107,252
All others.	222,268	213,859	187,315	201,632	204,207	182,780	111,277	39,889	42,562	53,972	54,409	54,956
Total foreign companies...	356,001	387,266	384,815	416,529	436,724	460,766	404,399	503,712	695,248	826,731	837,338	786,525

	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933
American companies	328,657	304,936	276,446	293,033	354,119	392,103	368,285	332,550	328,326	340,127
British and Dutch companies	306,649	316,662	352,939	391,645	470,582	541,211	573,625	522,542	550,177	567,448
Russian government	123,921	143,359	174,958	208,943	239,571	282,194	372,587	449,147	425,290	424,216
All others	66,352	76,468	91,545	92,140	97,661	104,132	117,319	129,030	129,610	137,199
Total foreign companies	825,579	841,425	895,888	985,761	1,161,933	1,319,640	1,431,816	1,433,269	1,433,403	1,468,990

	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944
American companies	417,079	461,977	484,273	562,869	506,978	554,899	527,879	610,298	357,965	438,407	653,253
British and Dutch companies	632,914	665,512	707,553	810,807	810,051	795,393	710,555	661,904	560,311	596,579	707,313
Russian government	475,494	502,732	538,189	562,022	585,969	609,656	638,675	659,465	633,600	683,600	709,750
All others	137,694	163,787	178,438	161,134	225,656	268,630	293,702	302,601	362,092	488,680	383,425
Total foreign companies	1,663,181	1,794,008	1,908,453	2,096,832	2,128,654	2,228,578	2,170,811	2,234,268	1,913,968	2,207,266	2,453,741

[1] Partly estimated.

commercial and military purposes, created a tremendous demand during the war for heavier grades of crude oil, such as those produced in Mexico. The country therefore underwent its greatest expansion during and immediately following the First World War.

The development of Mexican production, between the period 1912–1922, is shown in the following table:

IN BARRELS DAILY

Year	Production	American-owned production	Per cent American-owned
1912	45,200	25,900	57.3
1913	70,400	40,300	57.2
1914	71,900	41,200	57.3
1915	90,200	51,600	57.2
1916	102,300	58,600	57.3
1917	151,700	99,500	65.6
1918	175,900	124,800	70.9
1919	253,300	187,900	74.2
1920	445,500	320,800	72.0
1921	549,500	401,900	73.1
1922	508,500	404,200	79.5

During the period of greatest development more than 25 American concerns were active in producing Mexican oil. At the height of this activity the country became the world's greatest petroleum exporter.

A substantial part of Mexican output was imported by the United States to offset deficiencies in domestic supplies. In the three years from 1920 to 1922 total imports by the United States were greater than its exports—the only time in the history of the American industry prior to the Second World War that this country was a net importer.

The producing fields in the Golden Lane started showing water in 1920, but new areas were discovered which not only helped retard the decline but even expanded output to an alltime peak of 550,000 bbl. daily in 1921. The discovery of new areas did not continue at a rate sufficient to offset the decline of the older fields, and during the next five years Mexico's output was reduced by over 50 per cent. In the ensuing years output declined still further, never again attaining the early levels.

This decline in new discoveries and total output began coincidentally with the beginning of many long-continuing difficulties between Mexican labor and politics on one hand and the oil operators on the other. Relations between the oil companies and the Mexican government had been on a mutually satisfactory basis up to the time when they became strained over confiscatory implications of Article 27 in the new 1917 Constitution, with the threat of its retroactive application. Despite the fact that many efforts were made to settle disputed questions, conditions became steadily worse, culminating in the Expropriation Decree of March 18, 1939, which confirmed operators' fears of the retroactive application. Throughout this period the country never experienced the intensive exploratory effort of the early days and Mexico's position as a world source of oil has steadily deteriorated since.

Up to the end of 1943 Mexican fields had produced 2,125 million barrels, with a proved reserve of over 680 million barrels, all of which were located in fields discovered by the expelled private owners. The government has so far been unable to develop any new reserves.

Venezuela.—Prior to 1912 petroleum developments in Venezuela were confined to the exploitation of seepage oil in southwestern Venezuela by a local company which also carried on small refining operations, the products of which were sold for local consumption. In 1907 several large blanket concessions for asphalt were granted to Venezuelans. In 1910 an American company, which also owned a concession on a large asphalt lake in Eastern Venezuela, obtained concessions for oil rights in the vicinity of Lake Maracaibo and in eastern Venezuela. In 1913 this operator completed the country's first oil well, located in eastern Venezuela, and although the discovery was not developed, it ushered in the intensive exploration of Venezuela's oil resources which has made it second only to Russia in the foreign oil picture.

British-Netherlands' interests became very active in the country between 1913 and 1920, and for a time held more extensive concessions than Americans, whose interest did not take the form of active search until the early twenties. By 1920, 29 wells had been drilled in Venezuela, resulting in 4 discoveries with an estimated reserve of around 400 million barrels. Production amounted to about 1,000 bbl. daily. In 1920 the Venezuelan government passed a petroleum law which was widely regarded as providing a mutually equitable base for oil development. By this time it was evident that Venezuela's oil resources were vast, and the government's encouragement of foreign capital gave a great stimulus to exploration. Some 35 American companies, many of them still active in Mexico, started to acquire petroleum exploratory concessions and carried out exploratory work to such good effect that by 1925 the estimated proved reserves of the country had increased to around 900 million barrels.

After 1925 American-owned production in Venezuela rose rapidly in both amount and percentage of the total to over 50 per cent in 1928, and increased still further during the thirties, until it accounted for nearly two-thirds of the total in 1943.

The following table shows the course of production in Venezuela and the American-owned share, from 1921 to the present:

IN BARRELS DAILY

Year	Industry production	American-owned production	Per cent American-owned
1921	4,100		
1922	6,600	36	0.5
1923	13,000	200	1.5
1924	25,000	1,200	4.8
1925	55,900	17,500	31.5
1926	101,200	37,400	37.0
1927	175,100	83,400	47.6
1929	376,800	206,300	54.8
1932	322,700	171,600	53.2
1936	426,000	256,300	60.2
1939	562,800	335,100	59 5
1940	508,600	312,200	61.4
1941	625,000	403,500	64.6
1942	405,500	247,000	60.9
1943	491,500	317,500	64.6
1944	702,300	496,400	70.7

Up to the end of 1944 Venezuela had produced 3,300 million barrels of oil, and proved crude-oil reserves at the end of 1943 have been estimated at close to 5,900 million barrels, of which Americans have rights to nearly 74 per cent.

Of particular interest in the Venezuelan petroleum picture are the unique over-water oil operations in Lake Maracaibo, where an

American company has developed means of drilling and producing in water over 100 ft. in depth, an unmatched engineering feat and one that opened vast oil reserves which would otherwise have remained untapped.

Colombia.—Exploration for petroleum began along the northern coastal plain of Colombia in 1908. Records mention that a Colombian company financed by American and Colombian capital found a small amount of oil, but no commercial production was obtained. In 1909 this company opened a refinery at Cartagena with a capacity of 400 bbl. daily and operated it on crude oil imported from the United States.

The first commercial discovery of oil was made by an independent American operator in 1918 in the jungles of the upper Magdalena River Valley, some 300 miles from the coast. In 1920 one of the major American companies purchased the property through an affiliate and undertook its development. A refinery was erected in 1922 adjacent to the fields to supply local markets, and in 1926 a 335-mile pipe line to the seacoast (a tremendous engineering achievement) was completed, and Colombian crude oil began to reach the world market.

In 1917 another American company had become interested in a large concession in eastern Colombia bordering on Venezuela. Because of legal entanglements exploration did not start until early in 1930, and the first producing well was completed only in 1933. Development proceeded slowly until a pipe line was completed in 1938 over a nearby mile-high branch of the Andes to the coast.

Since completion of the first pipe line in 1926, Colombia's production has ranged between 40,000 and 69,000 bbl. daily, fluctuating with export market and shipping conditions. All production to 1943 had been under American control, but favorable results of recent work by a British-Netherlands company indicate that it will develop commercial production, thus ending the 100 per cent American phase of Colombia's oil history. At the end of 1943, 310,900,000 bbl. of oil had been produced in Colombia and reserves were estimated at over 200 million barrels, of which about 90 per cent were American-owned.

Colombia's oil laws have long contained various restrictive provisions which have hindered intensive exploratory work, but during the past quarter of a century many American companies, both large and small, have held acreage in Colombia and drilled exploratory wells, while several companies of other nationalities have also been interested at one time or another. The country has not however had the same intensive development apparent in Venezuela, probably because of the less favorable terms of the law.

Peru.—In Peru a small oil production under British control dated from 1896, but American interests acquired the properties in 1915 and materially increased production, maintaining it at a level of from 20,000 to 40,000 bbl. daily. There has been some other small production by British interests, but American control has risen to some 80 per cent of the total for the last 20 years; at the end of 1943 American-owned reserves represented 81 per cent of the country's total.

All commercial production to date has been located in the extreme north of the country along the seacoast, but an American operator made the first discovery of oil in the relatively inaccessible trans-Andean section of Peru several years ago, and this region will undoubtedly be developed as the demand arises. As in Colombia, Peru's oil laws have been regarded by operators as containing hindrances and restrictions which have served to retard intensive exploratory efforts.

Rumania.—Rumania began producing oil long before the turn of the present century (see Table 1), and in fact had a very small oil industry based on shallow, hand-dug wells 2 years before the drilling of the Drake well in the United States. Production developed slowly however, until after 1900. It was mentioned earlier that an American company first entered Rumania in 1903. By 1914 the American share was 8,300 bbl. daily or 24 per cent of the total for the country. The American share declined after the war, however, and by 1939 had dropped to 11.4 per cent. The principal American share has always been held by the company which entered Rumania in 1903; other Americans have been interested in Rumanian oil only on a very limited scale.

Over most of Rumania's oil history, government policy has restricted operators to leasing small tracts, a situation generally unfavorable to broad exploration programs involving large expenditures on preliminary work. Largely as a result, much of the country's potential oil area remained untested at the outbreak of the Second World War despite the long history of the industry.

Netherlands East Indies.—The first oil production in the East Indies was developed by Netherlands interests in 1893, and for many years thereafter all operations were confined to nationals, who had preference on state land. Americans discovered a small amount of oil in 1914 on land secured from private owners, but such output did not exceed 3,500 bbl. daily, or 5 per cent of the Netherlands East Indies total up to 1927. In 1928, however, after a number of years of strenuous intervention by the United States State Department for recognition of the open-door policy, government lands were granted to Americans on an equal basis with Netherlands companies. Discoveries were made shortly thereafter by Americans on the new concessions, and active development followed with the result that by 1939 Americans' share in the industry amounted to 27 per cent of production and 35 per cent of reserves.

Near and Middle East.—The story of petroleum in the Near East stretches back beyond the dawn of history when seepage oils and tar were utilized for a multitude of purposes, but little or no modern drilling had been done up to the First World War. With the breakup of the Turkish Empire, British, Dutch, and French interests took up rights to explore in various of the newly set up mandates and protectorates.

During 1919 American companies became interested in the possibilities of Mesopotamia, formerly part of the Turkish Empire and now known as the Kingdom of Iraq, but had no success in relaxing the British-French hold on the area. Two years later the American State Department started negotiations with the British and other governments for the adoption of an open-door policy in respect to the Mesopotamian oil properties. The State Department, however, required assurance that if an opportunity were presented, American companies would be prepared to dispatch an adequate geologic investigating party to make preliminary examinations of this supposed oil territory. Seven American companies indicated a desire to participate, and in November, 1921, addressed a joint letter to the Secretary of State stating that they were prepared to send the necessary experts for a reconnaissance survey of Iraq. About one year later, in 1922, representatives of the American group sailed for Europe to represent the seven companies in negotiations with the Turkish Petroleum Company.

Because the small participation offered to the American group appeared entirely unacceptable, the American representatives terminated the discussions and returned to the United States. Only after 6 years of protracted negotiations was an agreement formulated in the middle of 1928 which satisfactorily conformed to the State Department's open-door policy, and the American companies became partners with British, Netherlands, and French interests to develop the resources of Iraq. American participation was fixed at 23¾ per cent and was divided among the five remaining American companies. Subsequently three of the original American partners withdrew, selling their interests to two of the original American participants in the Turkish Petroleum Company agreement.

Drilling operations began in April, 1927, and the first well was completed on the Kirkuk structure in October. The well came in out of control and flowed at an estimated rate of over 100,000 bbl. daily. Subsequent drilling proved the existence of a field of great proportions, and a pipe line was constructed by American engineers to the Mediterranean, 620 miles distant, with exports commencing in the fall of 1934.

Up to the beginning of the Second World War, Iraq's production had been averaging about 88,000 bbl. daily.

In the middle thirties other American companies secured concessions in the Persian Gulf area through the active diplomatic support of the United States State Department. By 1939 very large discoveries had been made in Bahrein Island, Saudi Arabia, and Kuwait. A refinery was built on Bahrein and shipments to world markets were already being made by tanker as the Second World War began. Americans hold concessions on 100 per cent of the Saudi Arabian and Bahrein reserves, which are rated at several billion barrels, and on 50 per cent of those on Kuwait, where reserves are also great. All the known fields are close to the shore of the Gulf.

Early in 1944 the United States government through the Petroleum Reserves Corporation announced its proposal to build a government-owned pipe line to the Mediterranean to serve both the Kuwait and Arabian fields. No final action had been taken at this writing.

American companies have never owned production in Iran (Persia), the other great oil source of the Middle East, where oil operations to date have remained exclusively in the hands of a British concern. This British company for many years held a blanket concession on all but the far interior of the country, effectively preventing American entry, but this situation has since been changed by limitations on the old concession and the country now is open to new concessionaries.

Other Areas.—Aside from the major oil areas discussed above, American companies have also produced oil in many other countries. In fact the only foreign producing areas in which American companies have not been represented are India, Burma, Japan, Sakhalin, Iran, British Borneo, and Russia, and their absence from these is largely due to restrictions by the local governments.

The table below gives pertinent statistical data on the producing countries not reviewed above, but in which American oil companies have participated. With the exception of Trinidad, all are of minor importance, although the activities are of course significant in the local economies of most of the areas.

Country	First oil discovery	First American production	Latest reported American production, barrels daily	Per cent of total
Bolivia	1926[1]	1926	185	100 0[2]
Poland	1874	1920	275	2.7
Italy	1865	1927	140	62.8
Canada	1862	1922	7,675	29.0
Germany	1880	1933	2,700	13.5
Austria	1933	1938	500	4.2
Hungary	1937[1]	1937	10,611	99.3
England	1918	1939	4	0.2
Argentina	1907	1926	3,349	4.9
Trinidad	1908	1928	89	0.1

[1] Americans made the first oil discoveries in these countries.
[2] Property expropriated.

Proved Crude-oil Reserves.—The development of foreign oil reserves by Americans parallels the developments of production reviewed above. The estimated proved oil reserves abroad at the end of each year since 1927 are shown in Table 3 (p. 31) and Fig. 3 (page 32). Data for previous years are not available. These figures are summarized below, with the reserves owned by

Americans, but until recently controlled by the enemy, credited to American ownership.

ESTIMATED PROVED CRUDE-OIL RESERVES, JAN. 1, 1944
(In thousand barrels)

Region	Industry	American	Per cent American
North America, except United States	832,386	119,671	14 4
Caribbean area	6,314,100	4,535,288	71 8
Other South America	441,982	106,912	24 2
Total Western Hemisphere except United States	7,588,468	4,761,871	62.8
Europe except Russia	508,963	138,049	27.1
Near and Middle East	16,500,000	4,998,264	30.3
Other Eastern Hemisphere	1,172,493	335,284	28.6
Total Eastern Hemisphere except Russia	18,181,456	5,471,597	30 1
Total foreign except Russia	25,769,924	10,233 468	39.7
Russia	5,661,598	0	0
Total foreign	31,431,522	10,233,468	32.6

Refining.—The data available on American-owned refining operations abroad are very scanty for years prior to 1927, only general trends being ascertainable.

The first record of an American refining enterprise abroad indicates that in 1880 an independent American operator began running crude oil through a refinery he had built in Galicia, then part of Austria-Hungary, with equipment imported from the United States. From that date up to the start of the First World War American participation remained minor, although American-owned refineries are known to have been constructed prior to 1913 in Canada, Cuba, Mexico, Argentina, Japan, Rumania, Austria, Russia, France, and Germany. The total capacity of all these plants was probably between 35,000 and 40,000 bbl. daily. American refining equipment, however, was in demand in most of the foreign areas.

The real American interest in foreign refining came with a wave of exploration and discovery of new crude supplies after the First World War. In the period between 1918 and 1939 substantial expenditures were made in Argentina, Venezuela, Peru, Netherlands West Indies, Colombia, Mexico (enlargement of pre-war facilities), France, Germany, Poland, Rumania (also expansion), Italy, Netherlands East Indies, and to a minor extent in several smaller countries. While most of these plants were built to process local crudes, American companies were obligated in some areas lacking an indigenous supply to construct refineries running on imported crudes because of local government decrees which would otherwise have forced the companies out of their marketing business.

TABLE 3.—ESTIMATED PROVED CRUDE-OIL RESERVES IN FOREIGN COUNTRIES[1]
(In thousand barrels)

	Total foreign	American companies	Per cent American of total foreign	Total foreign except Russia	Per cent American of total foreign except Russia
Jan. 1, 1928	12,597,189	2,080,216	16.51	9,175,179	22.7
1929	13,036,445	2,592,961	19 89	9,702,118	26.7
1930	12,664,932	2,519,227	19.89	9,433,606	26.7
1931	12,190,353	2,423,225	19.88	9,094,362	26.6
1932	11,709,744	2,505,456	21.40	8,776,793	28.5
1933	11,284,668	2,497,868	22.14	8,506,002	29.4
1934	11,003,560	2,447,836	22.52	8,177,978	30.3
1935	11,203,574	3,054,363	27.26	8,796,160	34.7
1936	11,428,860	3,180,649	27 83	9,692,972	32.8
1937	11,727,218	3,290,692	28.06	9,968,757	33.0
1938	14,278,582	4,329,367	30.32	12,375,308	35.0
1939	21,822,424	4,820,785	22 09	19,698,999	24 5
1940	21,801,986	4,727,819	21.69	19,684,160	24.0
1941	22,440,983	5,637,909	25.12	20,299,757	27 8
1942	24,058,823	6,572,646	27.32	21,553,752	30.5
1943	23,920,743	6,690,608	27.97	21,528,797	31.1
1944	31,431,522	10,233,468	32.56	25,769,924	39 7

[1] Source: Jan. 1, 1928 to Jan. 1, 1943—private sources. Jan. 1, 1944, Russia—PAW, January, 1944. Jan. 1, 1944, Iran, Iraq, Kuwait, Bahrein, Arabia, and Qatar—De Golyer, March, 1944.

The first complete record of foreign refinery runs (from a private source) is for 1927. In that year it was estimated that foreign refineries ran 750,000 bbl. daily, of which American-owned plants accounted for 142,800 bbl. daily, or approximately 19 per

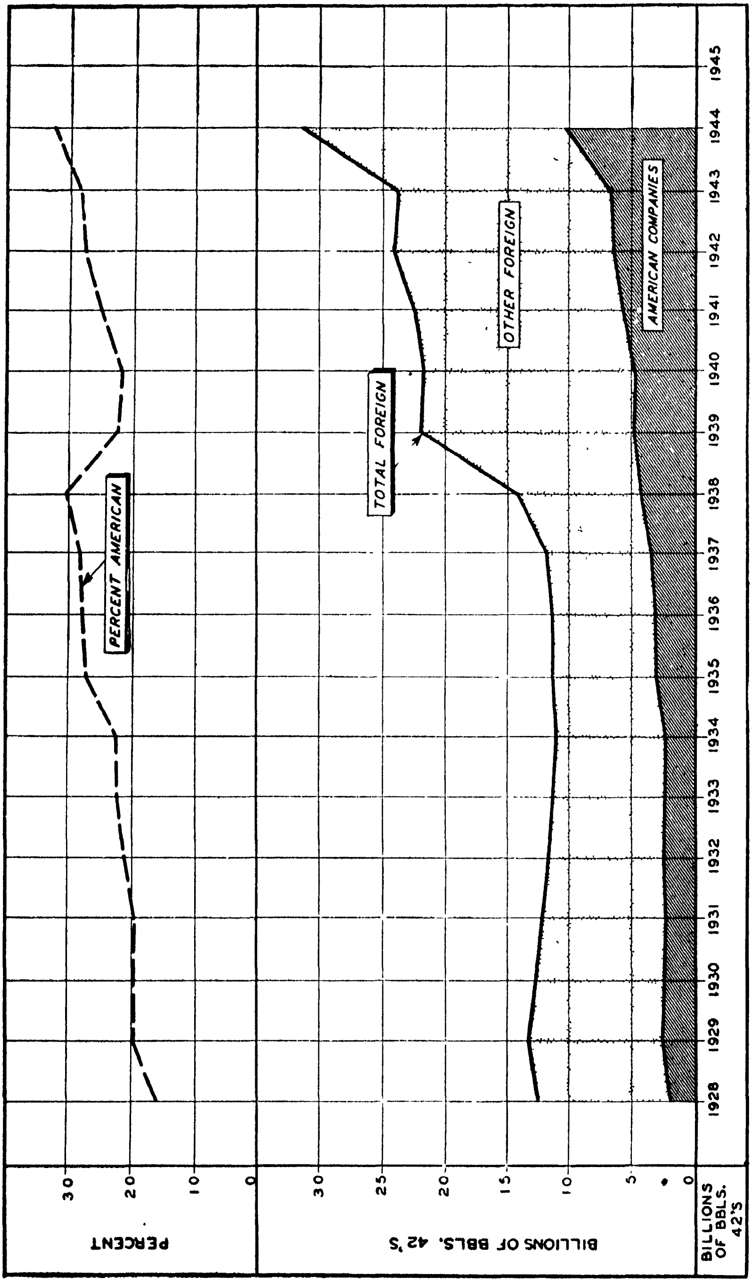

FIG. 3.—Estimated proved crude-oil reserves in foreign countries, showing quantity and percentage American-owned.

cent. Excluding Russia, American participation amounted to 23 per cent. By 1939 the American share in foreign refinery runs had increased to 23 per cent, and 31 per cent of the total excluding Russia.

The following comparison of foreign refinery runs and American participation shows the growth which has taken place between the years 1927 and 1939 (see also Fig. 4).

ESTIMATED CRUDE RUNS TO STILLS[1]
(Barrels of 42 U.S. gal., daily)

Year	Foreign	Foreign except Russia	American companies	Foreign	American per cent of foreign except Russia
1927	757,100	613,300	142,800	18.9	23.3
1928	871,500	682,500	141,300	16.2	20.7
1929	1,064,500	840,000	219,600	20.6	26.1
1930	1,253,700	933,200	254,000	20.5	27.2
1931	1,314,900	916,700	268,200	18.9	27.1
1932	1,335,200	931,400	242,500	18.2	26.0
1933	1,369,700	1,022,800	286,400	20.6	28 0
1934	1,580,300	1,173,600	359,400	22.7	30.6
1935	1,726,900	1,304,700	405,800	23 5	31.1
1936	1,892,900	1,400,000	446,700	23.6	31 9
1937	2,078,500	1,563,200	307,400	24 4	32 5
1938	2,165,300	1,627,900	504,300	23 3	30.9
1939	2,242,500	1,669,000	524,800	23.4	31 4

[1] From private sources.

Marketing.—Only broad trends on the American marketing position abroad are known, as detailed data on sales are not available.

We have already seen that it was in marketing that American oilmen first entered the foreign field. Records show that soon after the discovery of oil at the Drake well, a small shipment of American oil casks was made to Belgium. In 1861 a small sailing vessel was chartered to carry a 100 per cent oil cargo, also in casks, to London.

Exports from the United States continued to grow, but up to the eighties were made largely to third parties in foreign countries. With the development of foreign oil production, however, intense competition developed in the foreign market, and despite general preference for United States products for quality reasons, American exporters, dependent on third-party purchasers, were faced with loss of foreign markets. The result was formation of foreign marketing units by American companies in the eighties and entry into direct marketing in all foreign consuming centers outside Russia—and even there American specialty products have been sold. Records of early times reflect active cooperation by American consuls and ministers to assure these American ven-

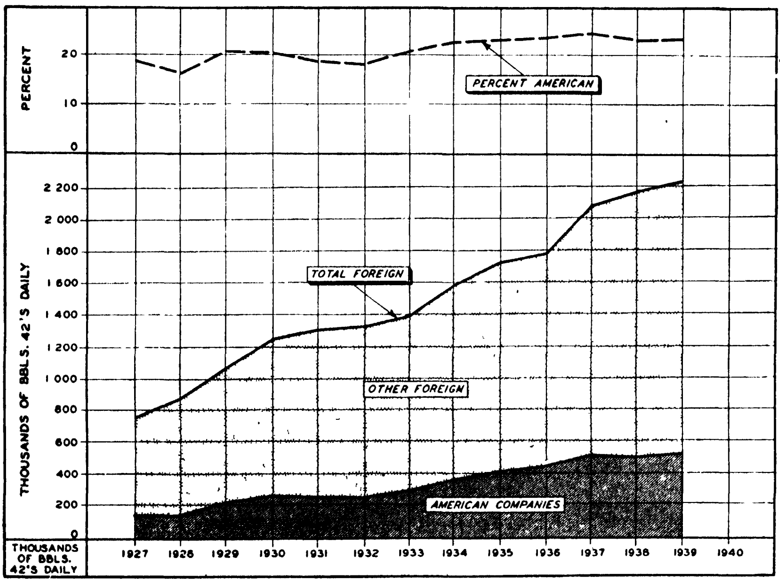

Fig. 4.—Estimated foreign refinery runs of crude oil, showing quantity and percentage in American-owned.

tures an equal competitive opportunity in the various countries concerned (see Fig. 5 and Table 4).

Perhaps typical of the scope and far-flung nature of foreign marketing by United States interests around the turn of the century is the fact that the American supplier was so closely identified with oil in China that the Chinese expression for kerosene was taken from their name for the principal American marketer there.

United States oil exports in 1900, just prior to the first entry of Americans into foreign production, amounted to about 20 per cent of estimated total foreign consumption. Since part of this

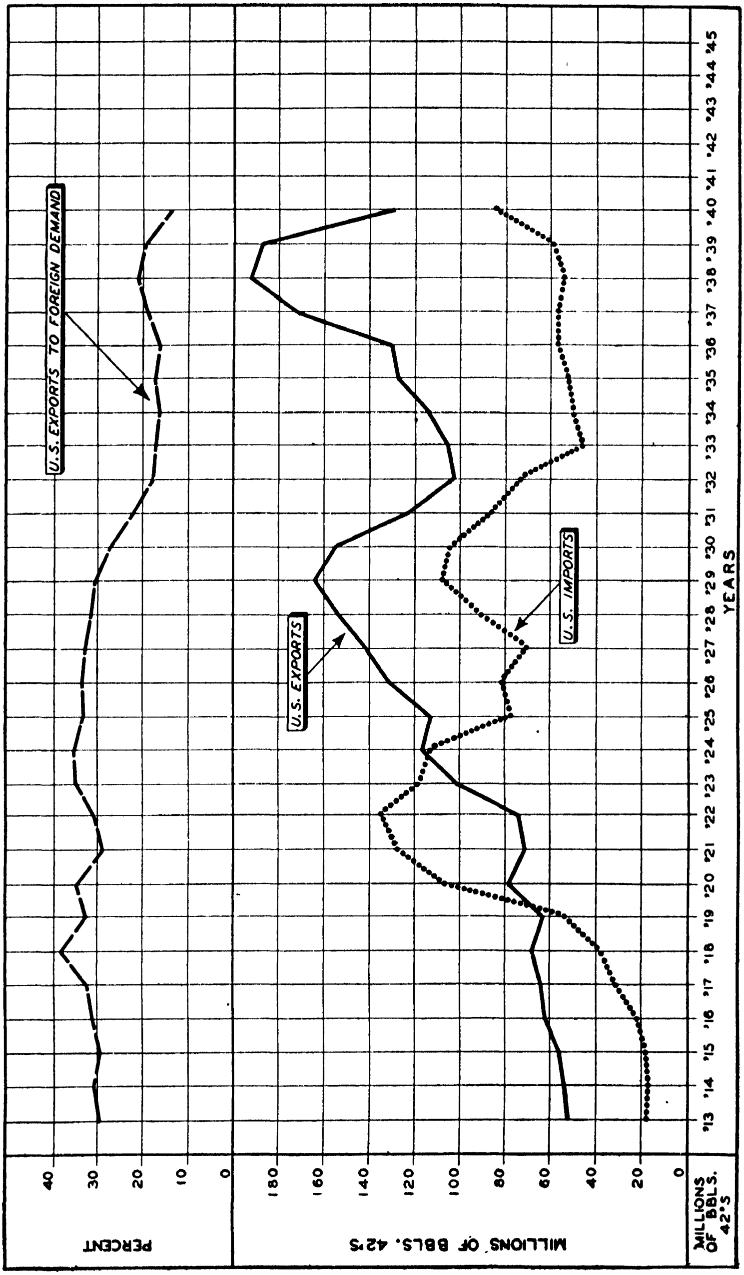

FIG. 5.—United States imports and exports of crude oil and products.

total undoubtedly went to third parties and American companies abroad also purchased some oil from foreign sources, the figure is not a dependable index to the American share in foreign markets for that year; but it does suggest that it was substantial.

With the development of production abroad by United States companies (the major share of which has been marketed abroad),

TABLE 4.—EXPORTS AND IMPORTS OF CRUDE AND PRODUCTS BY THE UNITED STATES
(In thousand barrels of 42 U.S. gal.)

Year	United States exports	United States imports	Per cent United States exports to foreign demand
1913	52,251	18,231	29.8
1914	54,359	17,247	30.6
1915	56,449	18,192	29.7
1916	62,459	21,244	31.1
1917	64,503	31,563	32.1
1918	68,012	38,963	38.5
1919	63,848	54,198	32 9
1920	79,576	108,822	35.2
1921	71,652	128,792	29 1
1922	74,344	135,973	30 2
1923	101,981	99,653	35 1
1924	117,144	94,581	35 6
1925	113,834	78,200	33 3
1926	131,950	81,320	33.6
1927	141,649	71,736	33.1
1928	154,957	91,557	31.8
1929	163,120	108,710	30.3
1930	156,499	105,618	27.3
1931	124,394	86,087	22.1
1932	103,275	74,494	18.1
1933	106,727	45,394	17.5
1934	114,507	50,494	16.9
1935	128,987	52,635	17.8
1936	131,994	57,104	16.6
1937	172,834	57,157	19.6
1938	193,728	54,308	21.1
1939	188,959	59,060	19.8
1940	130,466	83,751	14.4
1941	108,830	97,142	
1942	116,907	35,966	
1943[1]	207,201	30,757	
1944[1]	319,820	62,626	

[1] Estimated.

the American companies were able to supplement United States exports. An index to the marketing position of these companies just prior to the present conflict is provided by a private estimate, believed to be reliable, that in the year 1938 American-owned oil entering foreign markets amounted to 44 per cent of total foreign requirements, excluding Russia. While United States exports to third parties are included as well as some sales of American-produced foreign oil to others, the figure serves to show the relative importance of American-controlled oil abroad.

Transportation.—The picture on petroleum transportation divides naturally into two segments: the pipe line, unique to the industry and essentially a plant facility; and all other means of transport, with the tank ship, of course, the paramount factor in this group.

The first petroleum pipe line was built in Pennsylvania in 1865, some 6 years after the Drake well, and from that beginning the network of pipe lines for which the United States is so famed grew rapidly. There has never been a comparable growth in any foreign area. Because of the inaccessibility of many important oil reserves, however, several major pipe lines have been built abroad to deliver landlocked oil to the seacoast. While no statistics are available, it is safe to say that American engineers have been responsible for the great majority of the work.

Chief among such lines are the two in Colombia already referred to, and the line from Iraq to the Mediterranean. The two Colombian lines were built through jungle and swamp country presenting tremendous obstacles. One of these was the problem of crossing a mile-high branch of the Andes over largely uncharted country; the nature of others may be judged from the fact that much of the supplies and material had to be brought in by air.

The Iraq line, 620 miles in length, was built by American engineers, it may be noted, despite the fact that the American participation in the area was only one-fourth. The line crosses barren deserts and rugged mountains to the sea, and its completion was hailed as a major engineering achievement.

Americans have also built lesser pipe lines in many oil areas. The largest diameter line in existence prior to the construction of the war-born "Big Inch" line in the United States was an American-owned, 100-mile, 16-in. line in eastern Venezuela.

Turning to the tank ship, the situation differs from other phases of the industry in the fact that these vessels, while an essential part of the petroleum industry, are actually owned and operated in considerable part by shipping interests. As a result, pre-Second World War tanker registration followed the broad maritime picture, with the great shipping nations owning the majority of the world's tankers. Some 44 per cent of the approximately 1,600 ocean-going tank ships afloat at the outbreak of the Second World War were owned outside the petroleum industry, and the majority of tankers were under foreign flags. Some 10 to 15 per cent of these were American-owned, however, which figure, added to American flag tonnage amounting to around 25 per cent of the world total, indicates that about 35 to 40 per cent of total world tanker tonnage was operated by Americans.

Technology.—Many nationalities have contributed to the tremendously diversified modern technology of petroleum, but so great has been the part played by Americans in developing both the early and present know-how in finding, producing, and utilizing oil that it is no exaggeration to say that modern petroleum technology is almost wholly American.

This fact emphasizes how widely American oilmen have spread technical proficiency in oil, carrying experience and skill with them, to the benefit of all the peoples of the countries affected. Petroleum operations throughout the world follow American practice and generally use American standards of equipment and performance. Indicative of this picture is the world-wide preference for American-made oil equipment, the export of which has always been a major factor in our foreign trade. American technical skill in petroleum exploration has long had universal recognition. Entirely aside from the activities of American-owned companies abroad, in all the far corners of the earth American geologists and geophysicists have long worked under contract to foreign companies or governments, and several independent American exploration companies have built up over a period of years a large business in foreign oil explorations for other than American interests.

It has not always been appreciated that in their foreign operations American oilmen generally have maintained technical standards fully abreast of average practice at home. In fact some major advances in technique, particularly in the produc-

TABLE 5.—COMPARISON OF DOLLAR VALUE OF UNITED STATES EXPORTS AND UNITED STATES IMPORTS OF CRUDE PETROLEUM AND PETROLEUM PRODUCTS (IN THOUSAND DOLLARS); ALSO, PER CENT OF PETROLEUM IMPORTS AND EXPORTS TO TOTAL UNITED STATES IMPORTS AND EXPORTS[1]

	Value of total United States exports	Value of total petroleum exports	Per cent petroleum to total	Value of total United States imports	Value of total petroleum imports	Per cent petroleum to total
1913	2,448,288	160,584	6 6	1,813,008	12,997	0.7
1914	2,071,056	149,040	7 2	1,893,926	11,501	0 6
1915	3,493,236	159,792	4 6	1,674,170	10,564	0.6
1916	5,422,644	221,136	4.1	2,197,884	13,887	0 6
1917	6,169,620	275,148	4 5	2,659,355	20,605	0 8
1918	6,047,880	371,184	6 1	2,945,655	25,670	0.9
1919	7,749,816	377,124	4 9	3,904,365	31,441	0.8
1920	8,080,476	592,872	7.3	5,278,481	65,903	1.3
1921	4,378,932	401,232	9 2	2,509,148	78,844	3.1
1922	3,765,096	345,504	9.2	3,112,747	88,485	2 8
1923	4,090,716	366,792	9.0	3,792,066	78,713	2.1
1924	4,497,648	443,784	9 9	3,609,963	101,357	2.8
1925	4,818,720	474,024	9 8	4,226,589	107,694	2.6
1926	4,711,716	555,432	11 8	4,430,888	124,556	2.8
1927	4,758,864	486,768	10 2	4,184,742	113,434	2.7
1928	5,030,100	526,740	10 5	4,091,444	132,842	3.3
1929	5,157,084	562,116	10.9	4,399,361	143,557	3 3
1930	3,781,176	495,264	13 1	3,060,908	145,116	4 7
1931	2,377,980	271,284	11.4	2,090,635	92,741	4 4
1932	1,576,152	208,992	13.3	1,325,093	60,630	4 6
1933	1,647,216	200,688	12 2	1,449,559	25,693	1 8
1934	2,100,132	228,312	10 9	1,636,003	36,521	2 2
1935	2,243,076	251,124	11 2	2,038,905	37,346	1 8
1936	2,418,972	264,540	10 9	2,423,977	40,570	1 7
1937	3,298,932	378,132	11 5	3,009,852	44,586	1.5
1938	3,057,170	390,216	12 8	1,949,624	39,461	2 0
1939	3,123,343	385,068	12 3	2,276,099	43,541	1.9
1940	3,934,182	310,140	7.9	2,540,656	70,110	2.8
1941	5,019,877	284,653	5.7	3,221,954	82,455	2.6
1942	7,959,539	.		2,745,000		
1943	12,590,538	...	..	3,372,000		
1944	14,142,117		..	3,900,000		

[1] Sources: *Survey of Current Business, Foreign Commerce and Navigation, Statistical Abstract of United States.*

tion field, have been intensively applied in American-owned foreign fields before they became prevalent in the states. A prominent instance is the practice of pressure maintenance in oil fields by return of gas, now receiving wide attention in this country. This technique was conceived at home, and the general principles were outlined in the early twenties but did not find wide use until recent years. The opportunity to apply them first in fields abroad was taken by the engineers of one of the largest American operators abroad. As a result the oldest and perhaps still the best examples of this practice are found in American-owned fields in Sumatra and Peru.

Many other instances of up-to-date technique in American oil operations abroad could be cited in all phases of the industry from exploration to marketing. The foreign countries in which Americans operate share to the full in the continuing benefits of advances in petroleum technology for which the industry at home is so noted.

Economics.—The American petroleum industry, both domestic and foreign, since its birth has been one of the most important factors in the economics of our foreign trade. Petroleum exports accounted for 9 to 13 per cent of the total value of all merchandise exports by the United States from 1921 to the Second World War (see Table 5 and Fig. 6). During this period the value of petroleum exports varied from 200 million dollars in 1932 to over 550 million dollars in 1926. Generally petroleum and petroleum products have been the second most important factor in our exports for a great many years, preceded only by King Cotton in the earlier period and in recent years by machinery of all classes. The favorable balance of merchandise trade which the United States has enjoyed during these two decades has varied widely, but in several years of this period—specifically 1923, 1926, 1935, 1936, and 1937—the value of petroleum exports equalled or exceeded the net balance due this country from merchandise shipments.

The income from direct American investments[1] abroad has also been of foreign trade significance (see Table 6). Accord-

[1] Direct investments are made up principally of plants and facilities, excluding the value of oil in the ground, which is of course of great value although difficult to fix as investment, while total long-term investments include direct investments plus portfolio investments, and are principally in foreign-government securities.

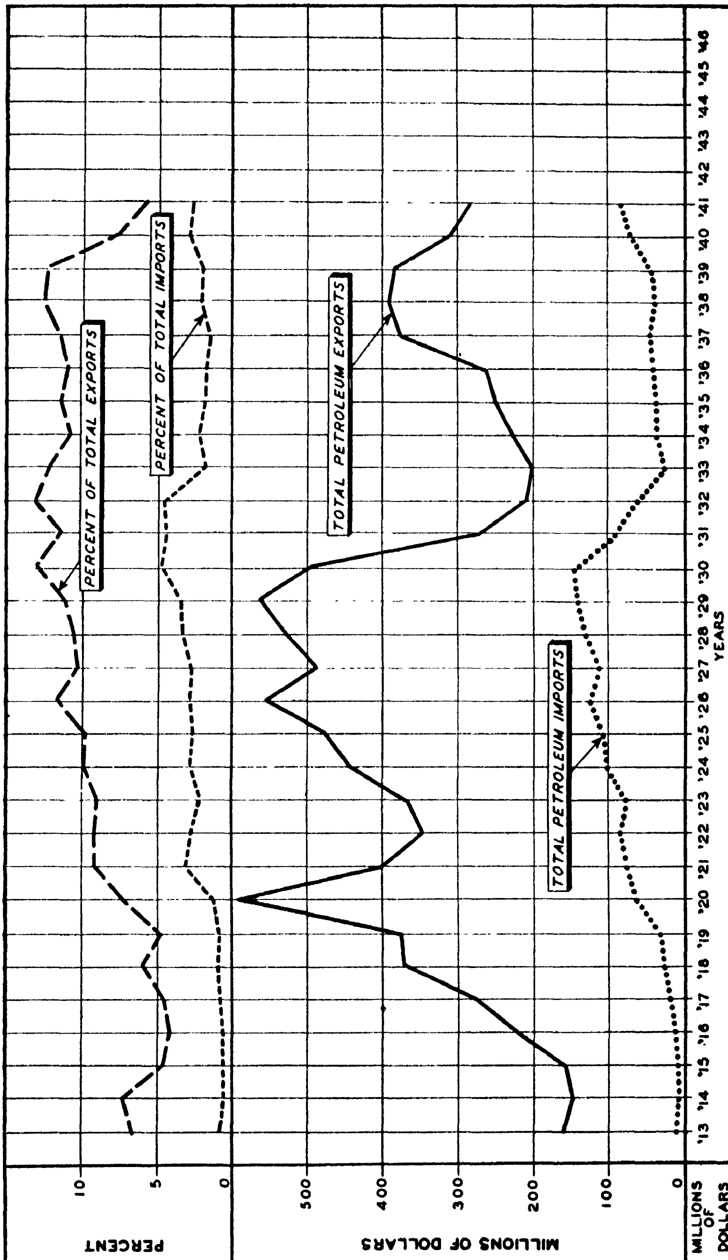

FIG. 6.—Comparison of dollar value of United States imports and exports of crude oil and products with percentage to total.

TABLE 6.—AMERICAN DIRECT INVESTMENTS IN FOREIGN COUNTRIES[1]
(In thousand dollars)

Countries	1929				1936				1940			
	Total direct investments	Petroleum			Total direct investments	Petroleum			Total direct investments	Petroleum		
		Amount	Per cent total petroleum	Per cent total direct investments		Amount	Per cent total petroleum	Per cent total direct investments		Amount	Per cent total petroleum	Per cent total direct investments
Canada and Newfoundland	1,960,320	55,047	4.9	2.8	1,951,641	108,138	10.0	5.5	2,102,694	119,606	9.4	5.7
West Indies:												
Cuba	918,957	9,030	0.8	1.0	666,254	6,078	0.6	0.9	559,797	10,195	0.8	1.8
Other West Indies	134,794	25,562	2.3	18.9	86,877	22,715	2.1	26 1	114,136	54,760	4.3	48.0
Total West Indies	1,053,751	34,592	3.1	3.3	753,131	28,793	2.7	3.8	673,933	64,955	5.1	9.6
Mexico and Central America:												
Mexico	682,536	205,868	18.5	30.2	479,465	69,039	6.4	14.4	357,927	41,970	3.3	11.7
Other Central America	234,557	3,608	0.3	1 5	148,416	1,670	0.2	1.1	188,094	8,095	0.6	4.3
Total Mexico and Central America	917,093	209,476	18.8	22.8	627,881	70,709	6.6	11.3	546,021	50,065	3.9	9.2
South America:												
Argentina	331,819	29,811	2.7	9.0	*	*		.	*	*		
Brazil	193,606	23,010	2.1	11 9	194,345	32,678	3.0	16 8	24,109	30,717	2.4	12.8
Colombia	123,994	55,835	5.0	45.0	107,549	58,577	5.5	54.5	111,616	75,090	5.9	67.3
Uruguay	27,904	3,260	0.3	11.7	*	*	. .		10,918	2,429	0.2	22.2
Venezuela	232,538	226,171	20.2	97.3	186,266	174,430	16.3	93 6	262,376	249,679	19.5	95.2
Other South America	638,034	34,403	3.0	5.4	977,829	87,374	8.1	8.9	926,463	99,149	7.8	10.7
Total South America	1,547,895	372,490	33.3	24.1	1,465,989	353,059	32.9	24 1	1,551,482	457,064	35.8	29.5
Europe:												
Belgium	64,246	18,963	1.7	29.5	34,890	14,374	1.3	41.2	17,004	5,181	0.4	30.5
Denmark	15,824	6,006	0 5	38 0	13,778	5,474	0.5	39 7	19,691	9,626	0.7	48.9
France	145,009	25,108	2.2	17 3	145,683	40,463	3.8	27.8	117,199	42,682	3.3	36.4
Germany[2]	216,514	35,270	3.2	16.3	227,817	49,993	4.7	21.9	349,399	57,391	4.5	16.4
Italy	113,216	25,903	2.3	22 9	*	*	. . .		75,493	37,7[illegible]9	3.0	50.0
Netherlands	43,224	12,144	1.1	28.1	18,836	6,824	0.6	36.2	18,167	4,124	0.3	22.7
Portugal	11,546	7,910	0 7	68.5	*	*		.	7,050	3,779	0.3	53.6
Spain	72,230	8,482	0.8	11.7	80,532	1,373	0.1	1.7	73,396	1,890	0.1	2.6
Sweden	*	*	.	. . .	25,493	8,272	0.8	32.4	26,361	7,181	0.6	27.2

Switzerland	16,804	6,634	0.6	39.5	*	*		.	23,852	2,546	0.2	10.7
United Kingdom	485,235	20,960	1.9	4.3	474,130	60,572	5.6	12.8	540,694	71,257	5.6	13.2
Other Europe[3]	168,905	63,591	5.7	37.6	223,793	87,599	8.2	39.1	152,059	62,105	4.9	40.8
Total Europe[3]	1,352,753	230,971	20.7	17.1	1,244,952	274,944	25 6	22.1	1,420,365	305,521	23.9	21.5
Asia:												
Arabia, Bahrein and Iran	*	*		..	17,780	17,453	1 6	98.2	57,234	56,266	4.4	98.3
British Malaya, French Indo-China, and Siam	27,103	2,201	0.2	8.1	*	*		..	*	*		
China	113,754	42,839	3 8	37.7	*	*	.	..	*	*		
India	*	*			*	*	..		48,775	19,478	1.5	39.9
Cyprus, Iraq, Palestine, and Syria[4]	7,050	1,875	0.2	26.6	29,605	20,911	2.0	70.6	*	*		
Japan	60,700	8,007	0.7	13.3	*	*	...	...	*	*		
Philippine Islands	79,935	10,381	0.9	13.0	*	*		...	*	*		
Other Asia[5]	105,998	48,628	4 4	45 9	369,608	108,599	10 1	29.4	315,936	101,138	7.9	32.0
Total Asia	394,540	114,001	10.2	28.9	416,993	146,963	13.7	35.2	421,945	176,882	13.8	41.9
Africa:												
British South Africa[6]	76,846	19,199	1.7	25 0	55,127	20,994	2.0	38.1	72,901	24,427	1 9	35.5
Egypt and Anglo-Egyptian Sudan	*	*	.	. .	*	*	...	..	22,753	9,395	0.7	41.3
Portuguese Africa	*	*	..		10,451	10,451	1.0	100.0	*	*		
French Africa	*	*	.		*	*			9,789	8,937	0.7	91.3
Other Africa	25,383	12,293	1 1	48 4	27,116	8,072	0 7	29.8	25,630	7,176	0.6	28.0
Total Africa	102,229	31,492	2 8	30 8	92,694	39,517	3.7	42 6	131,073	49,935	3.9	38.1
Oceania, Australia, and New Zealand	149,154	68,856	6.2	46 2	111,027	42,986	4.0	38.7	120,232	49,365	3.9	41.1
International	.	.	.		26,190	8,962	0.8	34.3	32,597	3,780	0.3	11.6
Total world	7,477,735	1,116,925	100.0	14 9	6,690,498	1,074,071	100.0	16.1	7,000,342	1,277,173	100.0	18.2

* Included in "Other."

[1] Source: *U.S. Dept. Commerce Trade Inf. Bull.* 731, American Direct Investments in 1929; American Direct Investments in Foreign Countries, 1936; American Direct Investments in Foreign Countries, 1940.

[2] Including Austria in 1940.

[3] Including Turkey in 1929.

[4] Including Iraq in 1929.

[5] Including Turkey in 1936 and 1940.

[6] Including other British Africa in 1929.

ing to estimates by the United States Department of Commerce on net worth of American investments abroad (based on the equities shown by the books of foreign corporations and reported by American companies on questionnaires returned to the Department), direct investments in 1929 constituted 52 per cent of total American long-term investments abroad and 60 per cent in 1940.

No breakdown of this foreign direct investment as shared by the producing, refining, and marketing branches of the industry is available, but there are fairly complete data on the geographical distribution. In Table 6 this geographical breakdown is shown by major areas for 1929, 1936, and 1940.

American direct investments in the foreign petroleum industry were valued at more than 1¼ billion dollars at the end of 1940—an amount equal to almost one-fifth of total United States foreign direct investments in that year. More than one-third of the industry total was represented by investments in South America, with Venezuela, where the value of American investments in petroleum was estimated at 250 million dollars, accounting for a major portion of the area's total, and Colombia with 75 million dollars in second position.

Investments in the petroleum industry in Europe, amounting to almost one-fourth the total American investment in the area, were principally in the United Kingdom (71 million dollars), Germany (57 million dollars), France (43 million dollars), and Italy (38 million dollars). Investments in Asia (chiefly in the Middle East, the Netherlands Indies, and China) and in Canada accounted for most of the remainder of the United States petroleum investments abroad.

The total income from all foreign investments in 1940 was 577 million dollars, of which the income from direct investments amounted to 450 million dollars. The latter figure represents a return of 6.4 per cent on the total capital employed in that type of investment. From petroleum alone the income received was 105 million dollars, or 8.2 per cent of the value of the investment. This figure, it may be noted, effectively disposes of the often-heard fallacy that foreign oil operations are fabulously profitable. The return is no greater than from well-situated properties at home, and it reflects the tremendous physical and operating difficulties often faced in the development of foreign production.

Let us now briefly review the influence of the oil industry on the economy of some of the Latin-American countries in which American oilmen have operated.

The case of Venezuela is an outstanding example of the very favorable economic results to a country and to private business of an open-door oil policy backed by equitable and stable laws. Total foreign investments in the petroleum industry of Venezuela were estimated in 1940 at about 400 million dollars,[1] of which American capital accounted for 250 million dollars, or 62½ per cent. In that year Venezuela ranked third among the countries of the world in the production of petroleum, only slightly behind Russia, and was first in exports. Between 1935 and 1941 petroleum and its products accounted for 80 to 90 per cent of the value of total exports from Venezuela.[2] Without these petroleum exports it would have been impossible for Venezuela to finance the volume of imports she has received in recent years. The sale of foreign exchange in Venezuela by the oil companies to cover wages, taxes, and other production costs in that country is generally sufficient to cover entirely the import balance in nonpetroleum trade, plus the amounts owed abroad for freight, insurance, and other service items, and to leave in addition a substantial net credit balance before gold and capital movements take place. This favorable position stems from the intensive development enjoyed by the country rather than from exceptional resources; other nations with far greater area for oil exploration have experienced but slight oil development, due to less equitable policies and laws.

Approximately half the proceeds from the sale of drafts in Venezuela by the petroleum companies is applied to the payment of taxes levied upon the industry, including surface and royalty taxes on petroleum concessions and oil produced therefrom, duties on material imports by the oil companies, stamp taxes, etc. It is estimated that between 1935 and 1942 about one-third of the government's total revenue was contributed by

[1] Report to the Minister of Finance, submitted by the American Advisory Economic Mission (Fox Mission), February, 1940.

[2] Using official estimates of the real value of petroleum exports.

the petroleum industry, and for the fiscal year 1943–1944 the percentage is expected to be nearer 40 per cent. In addition to those direct tax payments the petroleum companies have of course made many indirect contributions to the economy: accelerated industrialization, expanded employment, construction of roads, schools, hospitals, port works, etc.—all have materially aided the development and general welfare of the country and its people.

In other Latin-American countries petroleum has also contributed substantially to economic development, particularly in Peru, Colombia, and Mexico. In Peru, where approximately 80 per cent of petroleum output is produced by an American company, petroleum and its products constituted about 30 per cent of the value of the country's total merchandise exports in the period from 1935 to 1941.

Although petroleum has provided a somewhat smaller percentage of the total merchandise exports of Colombia, the narrow margin by which her total exports normally exceed her imports emphasizes the importance of the petroleum trade. Eliminating petroleum exports, Colombia would have found it necessary to curtail the volume of her imports in each year of the 1935-1941 period.

In the early part of the 1920's, when petroleum operations in Mexico were at their height, the export value of oil and its products accounted for about 40 per cent of the country's total exports and nearly equaled the sizeable favorable balance of trade which Mexico had at that time. In 1923 Mexico's exports of petroleum and petroleum products were valued at 113 million dollars, or 41 per cent of total exports of 276 million dollars and the favorable trade balance amounted to 123 million dollars. In 1937 and 1938, however, the value of petroleum exports declined to 15 per cent of total exports and in 1939 to only 8 per cent. In these years Mexico's total exports exceeded imports by a narrow margin. The percentage of government income derived from taxes on the petroleum industry has varied directly with changes in the volume of production, rising from 7 per cent in 1917 to a peak of 28 per cent in 1922 and subsequently declining to an average of slightly less than 7 per cent in the decade from 1927 to 1936. The disturbed internal situation in this country since the middle twenties and its adverse effect on oil developments, culminating in expropriation of foreign oil properties, has been pointed out earlier; its economic effects are obvious from the foregoing.

Social Effects.—Except for a very few instances the major oil deposits abroad have been developed in sparsely populated, often all but inaccessible regions—many of them tropical. As reconnaissance work is completed, roads are needed, and vast areas of the countryside must be cleared for the material to be used in the oil development. Care for the health of employees, both national and foreign, is a hallmark of American oil ventures in these areas, and medical work is of paramount importance as operations expand.

The program for the control of endemic diseases such as malaria, dysentery, hookworm, etc., commences with the spudding operation of a well. In the establishment of a camp, sanitation and cleanliness are the foundations upon which medical programs have been constructed. The contributions which American petroleum companies have made to the steady improvement in health conditions in areas where they have been operating have received very favorable comment from many of the local health authorities in foreign countries.

The record in Venezuela is interesting and informative on this score. When the oil companies entered Venezuela some two decades ago, the population, because of the agricultural nature of the country, was untrained in the mechanical trades and hence not well equipped to participate in the early stages of development. The companies embarked on educational and training programs, and the Venezuelan employees showed marked aptitude for mechanical training. As the vocational education developed, nationals were employed to an increasing extent, and today practically every well is handled efficiently by Venezuelan drilling crews; Venezuelans are also taking major responsibility in the conduct of the refining and transportation phases of the industry. Training in supervisory work and in clerical and stenographic fields has also been carried on widely.

Outstanding students in the technical schools of the country have been given scholarships to continue their studies in United States schools, and many of the important departments of the petroleum industry are now headed by Venezuelans.

The picture in Colombia, Peru, Argentina, Aruba, the Netherlands East Indies, and other areas is generally similar to that described for Venezuela, varying only in scope as determined by the nature of the areas and degree of development.

Many American companies abroad have organized various plans among local employees for systematic saving and employee-sponsored credit unions, through which employees can obtain financial aid at a reasonable rate of interest.

Along with specialized social and educational work looms the broad background of widespread employment and opportunity for economic advancement brought by oil developments American oil companies abroad are noted for favorable wage levels, and the over-all influence of their operations improved standards of living simply through the increase in national wealth accruing from their activities.

Influence of United States Government Policy.—A traditional basis of the United States' foreign policy has been support for the open door in commerce, essentially a matter of securing the same opportunity for American business abroad as enjoyed by nationals of other countries—in effect, endeavoring to obtain only the same equality of commercial opportunity in other countries as afforded to foreigners in the United States.

In the field of petroleum the pursuit of this policy encounters problems not found in dealing with most commodities. Subsoil mineral rights in most foreign countries belong to the state; all negotiations by Americans seeking to develop these resources therefore must be carried on with government rather than private interests. Temporary political expediency, diplomatic pressure from other interested governments, and on occasion the tendency to yield blanket or exclusive concessions to one's own nationals—all may react (and frequently have) against equitable opportunity for Americans.

Such problems were not acute prior to the First World War, for petroleum had not yet attained its present importance. Most foreign activity by American oilmen had been concentrated in marketing, and as we remarked earlier, American diplomatic and consular representatives abroad had generally been very active and helpful in assuring fair treatment for American business.

The coming of the First World War made petroleum a major factor in the world's economy, with tremendous commercial and military potentialities; any tendencies toward discrimination in international petroleum trade that may have existed before were accentuated. The literature of the early and middle twenties carries abundant evidence that the major powers, particularly the British and Netherlands governments, were concerned over petroleum. They tended to give strong preference to their own nationals in petroleum exploration within their empires, and obtained spheres of influence in other sovereign countries.

The interest of the United States government in these trends was sharpened by an oil-shortage scare at home after the First World War. Over a period of a decade after the war the government repeatedly urged American oilmen to develop reserves abroad, offering strong diplomatic support wherever inequitable barriers were imposed. Warnings of impending United States oil shortages were sounded by the Secretary of the Interior even during the Wilson administration. The 1920 Democratic platform was very positive in its urgings to American citizens to acquire and develop oil properties abroad. Plank 9 stated:

> The Democratic Party recognizes the importance of the acquisition by Americans of additional sources of supply of petroleum and other minerals and declares that such acquisition both at home and abroad should be fostered and encouraged.

Both the Harding and Coolidge administrations publicly recognized the urgent necessity for Americans to develop petroleum resources abroad, and fostered an open-door policy in foreign oil areas. The Federal Oil Conservation Board, formed during the Coolidge administration, after careful research and analysis of the situation made the following recommendation in September, 1926:

> The fields of Mexico and South America are of large yield and much promising geologic oil structure is yet undrilled. That our companies should acquire and explore such fields is of first importance, not only as a source of future supply but supplies under control of our own citizens. Our experience with the exploitation of our consumers by foreign controlled sources of rubber, nitrate, potash, and other raw materials should be of sufficient warning as to what we may expect if we become dependent upon foreign nations for our oil supplies. Moreover, an increased

number of oil sources tend to stabilize price and minimize the effect of fluctuating production.

The response of American companies to the wishes of the government was substantial from 1918 to 1928, and large oil reserves abroad were developed in American hands. Notable government aid was given during this period in the cases of Iraq and the Netherlands East Indies; without such assistance it is doubtful that Americans could have entered these areas on any appreciable scale. The successful outcome of these early efforts is a marked tribute to the sound relationship which has usually prevailed between American industry and our government. Without threat of force but solely by justifiable diplomatic support our nationals were enabled to hold their own and better with foreign enterprise.

Whenever and wherever our government's support has been less active, Americans have been correspondingly less successful in circumventing existing barriers. Many such obstacles still exist. In British Borneo, India, and Burma, all rich or potentially rich oil provinces, Americans are rather effectively barred from large-scale participation in oil developments by restrictions on the leasing of Crown or state lands, which generally have been restricted to British nationals. Only by leasing limited available areas of private land or by minority participation in British-owned companies are Americans at present able to share in oil developments in these areas.

Certain Latin-American countries also have erected positive legal barriers to substantial entry of foreign capital into oil development. Brazil and Chile are noteworthy in this respect, and American companies have repeatedly made unsuccessful efforts to secure modification of these legal obstacles and to undertake exploration and production operations. Both countries, particularly Brazil, have large areas favorable for oil exploration, but despite sporadic efforts by the local governments and local interests no significant deposits of oil have yet been found.

In Argentina American companies have been engaged in production since the middle twenties, but since 1934 she gradually placed more and more restrictions on these companies to favor a government-owned oil venture. At present most of her prospective oil land is reserved to this government company, thus effectively limiting the prospects of American and other private companies.

The expropriation of American and other foreign oil concessions by Mexico through retroactive application of laws promulgated subsequent to the granting of the concessions has been reviewed earlier. Bolivia similarly has taken over American-leased oil properties. The pros and cons involved in the disputed issues need not be reviewed here, but perhaps it may be said that the wave of energetic expansion of American companies abroad had completed a cycle and reached a low with the first actual expulsion of established American interests from a foreign-producing area. Many observers have expressed the opinion that despite the disturbed internal situation in Mexico and what may have been diminution of the United States governments' interest in foreign oil in the thirties because of the ample supply developed at home, a more mutually satisfactory conclusion could have been attained, with resultant advantages to the economy of Mexico and the private oil operators concerned.

During their 85 years of direct and indirect participation in foreign petroleum business, American oilmen have sought only an equitable basis for operation, with reasonable assurance of local governmental integrity and adherence to agreements. The record shows clearly that they have sought neither monopoly nor special advantages. Without seeking subsidy or government aid other than diplomatic support in dealings with foreign governments, they have made a proud record.

Conclusion.—With only 10 to 15 per cent of the world's potential oil land, the United States has produced over 60 per cent of the world's total oil supply to date. No one has seriously questioned the fact that this impressive picture is founded on the opportunity provided in this country for free competitive play of individual initiative and enterprise. It should not be surprising then that American oilmen overseas have looked for no more than similar freedom to win oil from the earth and make it more available to the countries concerned and for the future welfare of the United States.

It has often been remarked that American oilmen seem to have developed a nose for oil—that both at home and abroad they are more successful than any other peoples in the search for oil. Whatever the validity of this idea, it is interesting to note that those countries which have welcomed American oilmen and most nearly provided the atmosphere of free enterprise seem to have received the highest realization on their potential oil resources. Far in front in this respect is Venezuela, where an open-door policy and encouragement of private oil operators have been notable. The present proved reserves of Venezuela represent approximately 75 bbl. per acre of her potential oil land. In contrast Argentina with its near-monopoly government oil company has less than 1 bbl. of reserve per acre of favorable area. Even Russia, with an oil-development history almost as long as that of the United States and with territory far more favorable than any other nation, today has a reserve of only 3 bbl. per acre.

The future of oil in the world is today a prime subject of thought and international discussion. Our own government is seeking to formulate a national oil policy, perhaps more particularly a foreign oil policy, that will safeguard our national interest and provide a base of continuity and stability on which American oilmen may depend in planning their operations abroad. Americans have been a key factor in the development of the world's oil resources. As a result the world has greatly benefited by American ingenuity and aggressiveness. It is unthinkable that Americans should not continue to contribute to foreign oil production with its attendant benefits to all civilization.

CHAPTER III

CONSERVATION OF OUR OIL AND GAS RESOURCES

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The Current Situation and Some Existing Problems.—The urgent need for petroleum and its products in order to prosecute a war and at the same time meet essential civilian needs has focused attention upon the oil industry and the problem of conserving our oil and gas resources. Fortunately, through research, the employment of scientific methods in discovering, producing, and refining petroleum and its products, and finally, through the gradual development and application of conservation methods and practices, the oil industry has been able to accumulate reserves and provide daily producing capacity sufficient to meet the most exacting demands. When we consider that the oil industry has been able to develop and supply 100-octane aviation gasoline in undreamed-of quantities, has furnished synthetic toluene sufficient in amount to meet all demands, has started from scratch and erected plants, developed new and untried processes to supply the urgent need for synthetic rubber, and at the same time has been able to meet all military and essential civilian needs for lubricants, motor gasoline, and fuel oils, it can truthfully be said that no other industry has so completely met the demands made upon it as has the oil industry.

Like all other business enterprises the oil industry is living in a dynamic age. As it solves one set of problems others emerge. This is to be expected. The industry now faces several important problems. But it is felt that inherent within the system of free enterprise in which the industry flourishes and does its best work are the forces which will enable it to find a solution for all existing problems and to press on to newer and firmer ground. Some of the problems faced by the industry are: to continue and enlarge its oil-finding operations to the end that adequate reserves may be maintained; to continue its progress in developing and operating oil and gas fields; to press for needed legislation and administrative procedures in oil states which do not have adequate conservation laws; in furtherance of the industry's conservation program to stand steadfastly for the principle that private initiative and business enterprise should find, produce, transport, refine, and market oil and gas and their products, and that, at most, governmental authority should be asserted only to the extent necessary to protect legitimate public interests and private rights; and to seek from the Federal government only such support as may be necessary to enable the states properly to administer their conservation laws to safeguard our domestic petroleum industry against undue and harmful encroachments of foreign oil, and to vouchsafe American oilmen such diplomatic support as may be reasonably necessary to enable them to find and produce oil on equal terms with others in foreign lands.

Brief History of Conservation.—The history of conservation of oil and gas is checkered. To begin with, little or no accurate knowledge existed concerning oil and gas reservoirs, the behavior of oil and gas in reservoirs, the existence and utilization of reservoir energy, and consequently the need for conservation or the principles upon which it is based.

Conservation has passed through a long and painful process of trial and error during which there has been a steady march from a state of gross ignorance to one of known and established engineering principles applied currently in the discovery, development, and operation of oil and gas pools.

The necessity for conserving oil and gas and for protecting correlative rights has induced most oil-producing states to pass conservation statutes. In enacting such legislation these states have restricted the operation of the so-called "rule of capture." In such states it has become merely a rule of convenience under which each operator is recognized as the owner of the oil and gas he produces from his own wells.

Inasmuch as oil and gas in a pool will drain to low-pressure areas created by penetrating the reservoir with a well, the rule of capture under unrestricted conditions has heretofore forced operators into intensive offset-drilling campaigns and obliged them to produce their wells to maximum capacity. Wholly ignored is the fact that an oil or gas pool is a single mechanism, and under ideal conditions should be developed and operated without reference to surface property lines. In the early days wells were completed as rapidly as possible, and were produced wide-open so long as a means of disposing of the oil could be found. Gas for the most part was popped into the air or flared. Gas caps were dissipated, oil was drawn into the dry gas sands, water was permitted to channel or cone through the oil sections, and as a consequence only a fraction of the recoverable oil was produced. Oil fields which were discovered soon were exhausted, and the industry suffered alternate periods of feast and famine.

In course of time geologists, engineers, and practical oil operators began more fully to understand the physical conditions under which oil and gas are accumulated in the earth, and the physical laws which govern their production. It began to dawn on oilmen in particular and also upon the public that oil and gas were limited natural resources, and that many production practices were wasteful and detrimental to producers and public alike. Men began to believe that the prevention of waste and the protection of one operator against the wanton waste or cupidity of his neighbor were proper subjects for public concern. Before the close of the nineteenth century state legislatures became interested in these problems. As early as 1899 the legislature of Texas enacted a statute requiring that water-bearing strata be cased off, that abandoned wells be plugged, that gas not be permitted to escape into the air, and that gas must not be burned in flambeau lights.[1]

In 1924 the conservation of oil and gas, as we now use the term, had its beginning. We had passed successfully through the First World War, and by great effort the oil industry had been able to supply the petroleum products essential to win the conflict. Following the war the price of crude oil and products was high and the known reserves were small. President Coolidge appointed the Federal Oil Conservation Board to take stock of the oil situation and find ways and means of increasing the available supply and the reserves for future use. While the board was making its own investigation, the American Petroleum Institute appointed in 1925 a committee of eleven

[1] *Acts*, 26th Legislature Regular Sess. 1899, C. 49, p. 1868.

for the purpose of making independent studies and surveys. In September, 1925, the committee published its report, entitled "American Petroleum—Supply and Demand." In summarizing its conclusions it reported that contrary to popular belief undiscovered petroleum reserves were no doubt sufficient to supply the needs of the country for many years to come. It recommended that the right to own and lease oil lands be made secure; that those engaged in the industry be permitted to exercise initiative, have liberty of action, and enjoy free competition; and that the law of supply and demand be allowed to operate to the end that prices might seek their natural level and provide returns commensurate with the risks involved and the capital invested. Acting partly in response to satisfactory prices for crude oil and stimulated further by the depletion allowance then newly adopted by Congress, the industry engaged in extensive wildcat operations. New and prolific oil fields were discovered in western Texas, the Texas Panhandle, Oklahoma, and California in 1926 and 1927. In 1930 the giant East Texas field was discovered.

Whereas in 1924 it looked to many as if the country would suffer an acute and prolonged oil famine, by 1927 conditions were reversed; both the industry and the public were concerned with a generous oversupply of immediately available crude oil. Under impetus of the rule of capture it seemed that the industry would drown itself in an ocean of oil and that no one was able to remedy the situation. In view of this situation many thoughtful people both within and outside the industry began to give conservation serious consideration. The automobile had come into general use, and society was rapidly becoming more and more dependent upon machines that cried aloud for gasoline, lubricating oils, and other petroleum products. Men with vision knew well that it would be little short of criminal needlessly to dissipate natural resources so vitally essential to our peacetime economy and national safety in event of war. All could see that a means must be found at once to save the industry from its own profligate ability to produce, and to preserve for posterity the blessings that would ensue from ensuring the maximum benefits from the oil and gas resources uncovered. Lawyers, oil executives, geologists, petroleum engineers, bankers, legislators, and government executives began to recognize that this was a problem in which all were interested, and that its proper solution required thought, effort, and forbearance.

In looking into the legal bases for sound conservation, lawyers found that well-established legal principles could be resorted to for the purpose of stabilizing an otherwise chaotic condition. They referred to the Ohio Oil Company case[1] and found that a state is fully authorized to pass and enforce conservation legislation in order to prevent waste and protect the correlative rights of operators and royalty holders. The several states thus are fully authorized to exercise the police power in the public interest to prevent waste and protect private rights.

Soon the legislatures of a number of states had enacted a considerable body of conservation legislation. Following the prolific discoveries in the Cushing and Healdton fields, the legislature of Oklahoma enacted in 1915 an oil and gas conservation statute which included the first provision authorizing the conservation agency to limit the production to current market demand. Other states have since followed suit, and Kansas, Texas, New Mexico, and Louisiana now have market-demand provisions in their statutes; and in Arkansas it is possible to arrive at substantially the same result.

In 1917 the constitution of Texas was amended in such manner as to authorize the legislature to enact conservation legislation. In the same year the legislature enacted a statute defining waste of oil and gas. Two years later it passed a comprehensive conservation act which defined and prohibited waste of oil and gas and conferred broad regulatory power upon the Texas Railroad Commission. Pursuant to this legislative grant the commission promptly adopted numerous rules and regulations relating to the spacing, drilling, cementing, casing, completion, and operation of oil and gas wells, and to pipe-line common carriers and other matters. A spacing regulation known as Rule 37 has been upheld by the highest courts of Texas after many years of turbulent litigation.[2] There are numerous other cases upholding this rule.

In 1929 the legislature of Texas amended its definition of waste to exclude economic waste. Shortly after the East Texas field was discovered. The Railroad Commission sought

[1] *Ohio Oil Co. v. Indiana,* 177 U.S. 190.

[2] *Brown v. Humble Oil & Refining Co.,* 126 Tex. 296, 83 SW (2nd) 935.

to limit production to current reasonable market demand in order to prevent waste and nonratable takings. Then followed much litigation in the Federal courts during which successive orders of the commission were stricken down on the grounds that it had no authority to limit production to current market demand. This was in 1931. The state courts, however, in the Danciger case[1] of 1932, upheld the authority of the commission to limit production to current reasonable market demand in order to prevent waste and noratable takings. Meanwhile in 1931 the legislature of Texas had passed a new and comprehensive conservation statute.

Arkansas, Louisiana, and New Mexico have since enacted what may well be considered model conservation laws. Oklahoma and Kansas likewise have conservation laws which apparently serve the desired purposes, although they appear less complete than the laws of Arkansas, Louisiana, and New Mexico. Other states have statutory provisions designed to define and prevent waste of oil and gas, but have not tackled the problem as successfully and comprehensively as the states mentioned above. Experience has shown that conservation of oil and gas is a problem which can best be solved by the several states, and we can expect that the remaining oil-producing states will follow the pattern so well set by Arkansas, Louisiana, and New Mexico.

The legislatures of the several states have recognized the fact that conservation statutes cannot be self-administered. They have found it necessary to set up administrative agencies to enforce the statutes and to promulgate necessary or convenient rules and regulations designed to carry out the policies of the laws. Accordingly, in each of the states having comprehensive conservation laws an administrative agency has been set up and has been granted broad administrative powers. The administrative agency in Arkansas is the Arkansas Oil and Gas Commission; in Kansas, the State Corporation Commission of Kansas; in Louisiana, the Commissioner of Conservation; in New Mexico, the Oil Conservation Commission; in Oklahoma, the State Corporation Commission; and in Texas, the Railroad Commission. Within their spheres of delegated authority these agencies exercise enormous power and influence over the

[1] *Danciger Oil & Refining Co. v. Railroad Comm.*, 49 SW (2nd) 837.

oil and gas industries, and on the whole are doing a magnificent job in the matter of conserving the oil and gas resources of their respective states.

The need for coordination and cooperation among the several oil-producing states resulted in the creation of the Interstate Compact to conserve oil and gas. This important and unique waste-prevention treaty of the states was made in 1935 through enabling state legislative action and with approval by Congress.

This agency has made notable progress in the advancement of conservation through fact finding, coordination, and educational activities. The compact now has grown to include a membership of 13 states in which more than 80 per cent of the nation's oil is produced. The present member states are Arkansas, Colorado, Kansas, Kentucky, Illinois, Louisiana, Michigan, New Mexico, New York, Ohio, Oklahoma, Pennsylvania, and Texas. The compact is operated by an Interstate Compact Commission consisting of one representative from each state. Many committees have been created by the commission to make studies, reports, and suggestions relating to the legal, administrative, engineering, research, coordination, and educational phases of the conservation problem. Regular meetings of the commission are held at which extensive discussions are heard, findings of fact determined upon, and recommendations made. The compact has acted as a sort of clearinghouse for information and exchange of ideas, has stimulated interest, and has materially assisted in the success of the whole conservation program.

Worthy of mention also is the assistance rendered to the several states in enforcing their conservation policies by the Connally Hot Oil Law,[1] enacted by Congress in 1935. This act has been extended from time to time and now is permanent law.

While state legislatures and to some extent the Congress have wrestled with conservation of oil and gas, the courts also have found it necessary to deal with the problem. In a remarkably clear and prophetic opinion the Supreme Court of the United States, as we indicated above, in the Ohio Oil Company case laid down the principle that a state in the exercise of the police power may enact legislation in the public interest to prevent waste, and in defense of private interests may provide for the protection of correlative rights.

[1] 49 Stat. 33; 15 U.S.C.A. Sec. 715 to 715L.

It is not possible within the scope of this paper to more than call attention to a few other landmark decisions. In 1928 the courts of Texas upheld Rule 37, the spacing regulation. This judgment was confirmed in the famous case of Brown v. Humble in 1935. The Supreme Court of Oklahoma in 1930 sustained the validity of the 1915 conservation statute of Oklahoma in the Julian Oil & Royalty Company case.[1] In 1932 the Supreme Court of the United States in the Champlin case[2] sustained the proration orders of the Corporation Commission of Oklahoma, which limited production to current market demand. In the Patterson case,[3] decided in 1938, the Supreme Court of Oklahoma held that the spacing and pooling provisions of the Oklahoma statutes were constitutional and enforceable. The conservation statute of Louisiana was recently held valid by the Supreme Court of Louisiana and by the Supreme Court of the United States in the Hunter case.[4] In this case the compulsory pooling provision of the statute was under special attack.

State conservation agencies cannot arbitrarily issue valid regulations or orders in excess of their delegated authority. Of vital importance in this connection is the recent far-reaching opinion of the Supreme Court of Texas in the Marrs case,[5] which struck down allocation orders of the Railroad Commission of Texas for the Gulf-McElroy field. These orders were held to be arbitrary and to bear no reasonable relation to prevention of waste or protection of correlative rights.

Conservation legislation and orders, rules, and regulations of state administrative agencies have suffered a drumfire of attack in state and Federal courts. But now it can be said that these statutes rest on firm and legal grounds. In a long line of judicial decisions the courts have sustained them from almost every conceivable angle. Thus, as a result of many years of legislative, administrative, and judicial history we can safely conclude:

1. That the several states are fully authorized to enact adequate conservation statutes and to provide for their administration and enforcement by state agencies in reliance upon the police power.

[1] *C. C. Julian Oil & Royalty Co. v. Corp. Comm.*, 292 Pac. 841.

[2] *Champlin Refining Co. v. Corp. Comm.*, 286 U.S. 210, 76 L. Ed. 1063.

[3] *Patterson v. Stanolind Oil & Gas Co.*, 77 Pac. (2nd) 83.

[4] *Hunter Co. v. McHugh*, 202 La. 97, 11 So. (2nd) 495, 64 S. Ct. 19.

[5] *Marrs v. Railroad Comm.*, 177 SW (2nd) 941.

2. That these statutes and administrative orders thereunder may be enacted not only for the purpose of preventing waste of oil and gas, but may also be employed to protect the correlative rights of producers and royalty holders and in the public interest to limit or restrict production to current reasonable market demand.

3. That regulations of administrative agencies which bear a reasonable relation to the objects set forth in the conservation statutes and lying within the scope of delegated authority will be upheld and enforced by the courts.

4. That these orders may cover a wide variety of subjects: the spacing, drilling, casing, completion, and plugging of wells; gas-oil and water-oil ratios; the conservation and utilization of reservoir energy; limiting the production of oil and gas from the several fields in a state; allocation of the allowable production among the several fields in the state and among the various properties within each field; pooling; cycling of gas; secondary recovery operations, etc.

5. That administrative agencies are not authorized to act in excess of their delegated powers or to act unreasonably, capriciously, or arbitrarily in the promulgation and enforcement of their rules and regulations.

Modern Conservation Practices.—Modern conservation practices really date from the realization that an oil reservoir is a physical unit and may be controlled as a unit. So long as only the well was considered it remained impossible to determine the true interrelation among all the wells producing from a common pool. The essence of modern conservation is so to utilize the natural energy originating in the reservoir and its environs as to secure the maximum amount of economically recoverable oil from each pool. Only by control of a reservoir as a whole is this achievement possible.

Only within recent years have we realized that the underground forces in an oil reservoir and its environs (or forces which can be supplied thereto) can be employed to control the movement of oil within the reservoir. With this realization has come the discovery that there are both effective and ineffective ways of utilizing the underground energy, and that by its proper use and control can be recovered a greater amount of oil from a given pool.

This underground energy resides not in the oil itself but in the water and gas associated with the oil, including free gas, the gas dissolved in the oil, and the universal force of gravity. Thus, the production of gas and water must be controlled through proper completion and repair of wells and through such other measures as may be necessary or adaptable to any particular field.

Since the recovery of the maximum amount of oil from a pool requires that the water or gas displacing the oil from the porous rock be effective throughout the entire reservoir, merely to prevent the dissipation of these materials is not sufficient. Two factors predominate in this control: control of the rate of production from the field as a whole as well as from all parts of it; and the use of an adequate number of properly located wells to produce the desired amount of oil.

Experience has shown that the movement of underground fluids on a large scale is not rapid; the small and tortuous passages through which they must move effectively slow down their movement. Hence most engineers believe that to use effectively all of the natural underground forces and energy available, it is necessary to produce the oil from any field slowly. This procedure is necessary in water-drive fields to maintain the reservoir pressure, and in volumetric-control fields to prevent gas-channeling and permit proper control of gas-oil ratios. Thus restriction of the production rate is the first and most important step in any conservation program. While experience has shown that in many fields a production rate which will correspond to depletion of the underground oil reserve over a period of twenty to thirty years is sufficient restriction, actually each oil pool differs in many respects from all other oil pools. It is necessary to study each individual field and to determine according to the peculiar and unique conditions encountered the restriction needed to secure the maximum economic recovery.

Accordingly, the terms "maximum-efficient rate" and "optimum rate" of production have come into usage. When the rate of production is adequately restricted, conditions are created for any field which are favorable for the use of natural reservoir energy to recover the maximum amount of oil. As the rate of production is increased, these conditions usually grow progressively less favorable, until finally they become so unfavorable as to result in appreciable underground loss of oil. Thus the maximum-efficient rate or optimum rate is the maximum rate of production which is compatible with favorable underground conditions, and beyond which an increased rate of production would rapidly lead to waste.

Control of the total-production rate alone will not suffice to insure efficient recovery of the underground oil. The production must be properly distributed over the reservoir in order to avoid excessive localized withdrawals which might cause waste of the reservoir-energy sources and resultant waste of oil. The problem of production rate control also involves the proper and equitable distribution of the controlled rate. Allocation among the various separate operators or leaseholders in a common pool must be fair and equitable. Insofar as possible each operator must be afforded an opportunity equal with all other operators to produce the equivalent of the recoverable oil underlying his property. Allocation and conservation are thus inseparably associated.

Proper spacing of the producing wells is also a necessary part of any program designed to increase the recovery of oil from a reservoir. An adequate number of wells must be drilled to delimit the reservoir properly and to produce the maximum efficient total production from the field. The wells must be so spaced as properly to control the underground movement of the various reservoir fluids—oil, gas, and water—and to prevent excessive localized withdrawal. Because irregular spacing of wells or unequal development of properties may lead to waste-producing localization of withdrawals, uniform spacing of wells is desirable in most fields. The drilling of more wells than are actually required to develop a reservoir and to produce the maximum efficient rate constitutes excessive drilling. Excessive drilling frequently leads to waste and to inequitable and improper distribution of production. Not only does it frequently cause actual waste of petroleum, but it also is an unnecessary and unprofitable use of capital, a waste of materials, and a nonproductive use of labor.

Some reservoirs are so lacking in original store of energy that even when the rate of production is restricted and equitably distributed the oil recovery is low in magnitude. In other reservoirs with ample energy in the form of available water and gas the nature of the oil accumulation and the structural conditions are such that in spite of proper well completion and repair and a controlled rate of production, prevention of excessive gas and water production is still impossible. Under each of these conditions it is frequently found desirable to increase or replenish the reservoir energy through the injection of water or gas into the oil-producing horizon. Cooperative programs to increase the recovery of oil are conducted in many states and have received the sanction and encouragement of various regulatory agencies.

Excessive production of gas and water in any field may lead to waste. When all ordinary remedial measures are found to be ineffective, it is necessary to restrict the output of the particular wells responsible for excessive production. Water-oil-ratio and gas-oil-ratio limitations therefore are found in various regulatory orders. These measures prevent a few wells from dissipating the store of energy which must be used to produce the oil from the common pool.

Widely recognized is the principle that production should be limited by market demand and the requirements of underground-waste prevention—whichever quantity is the lower. Oil produced in excess of reasonable market demand leads to unnecessary problems of storage and above-ground waste, and in most fields leads to underground waste as well. Likewise, excessive producing rates usually result in waste of reservoir energy and the consequent loss of a considerable portion of the recoverable oil.

Generally for most fields a proper control of flow necessitates an annual production rate representing a small fraction of the total reserves. For the 12 years preceding our entry into the Second World War, our ultimate reserves were so large that the market demand was below the over-all efficient rate of production, and the chief problem was proper allocation among areas and pools. This excess productive capacity has been the chief source of supply for the unprecedented demands of war. An essential factor in sound conservation on a broad scale in peacetime is sufficient reserves to provide a daily productive capacity in excess of daily demand. Such a condition is also our best safeguard for oil in time of war. In the future conservation will be more necessary than ever; state authorities and the industry must not only continue but expand the optimum-flow and maximum-efficiency-rate principles.

Several means will be available by which our reserves can be augmented and the ratio between efficient rates and reserves modified:

1. Intensification of the search for additional reserves by means of an adequate price for crude. We can expect that an adequate price will be realized when the law of supply and demand is permitted to operate freely without artificial control of prices.
2. The improvement and extension of secondary-recovery methods.
3. Properly regulated imports.
4. The gradual supplementing of supply by the conversion of natural gas, oil shale, and coal into gasoline and other products.
5. Increases in maximum-efficient rates through improved techniques such as the augmentation of natural water drive by artificial flooding and the maintenance or creation of an artificial gas cap by injection of gas.

Except in cases of dire emergency there should be no need to abandon the principles of conservation at any time in the predictable future.

With a few exceptions the present United States daily output of approximately 4,500,000 bbl. is being produced at rates that are not causing appreciable waste. The maximum-efficient rates of our important pools have been carefully estimated by the industry, subsequently checked by state and Federal administrative bodies, and the findings thereof generally adopted. These rates have been largely based on scientific analyses of reservoir behavior.

In all probability the extraordinary war demands thus far have been fulfilled without the necessity of serious wasteful production rates. It is true that there has been a curtailment of civilian use. However, if industry in other Allied countries had been as fully prepared as our own industry, and had been able to furnish products in proportion to their oil reserves, our normal civilian demand could have been met in addition to an equitable contribution to the war effort.

Because of the complexity of underground conditions in petroleum reservoirs and the impossibility of actually observing the movement of the fluids through the pores of rock, research in production methods has had to depend upon the development of methods and tools for effective indirect observation. Time has been required for the development of scientific principles, their application in practice, and observation of the results. So long as the development of an oil reservoir was a race by each operator to drill the most wells first, and thereafter to produce the most possible oil through those wells in the shortest possible time, conditions were not favorable to the observation of true reservoir behavior and to the development and application of scientific principles.

With the more orderly development accompanying the restricted rates of production, opportunity was afforded for observation, experimentation, and field evaluation of new ideas and techniques. Soon it became obvious that the waste of gas and water energy and the low oil recovery attending wide-open production were not inevitable consequences of the nature of petroleum accumulations but the result of a particular method of operation. As soon as we appreciated that waste resulted from bad practice and that improved practice might yield increased recovery, the incentive for technological progress was born.

Thus began a period of progress during which scientific talent was applied to the study of the behavior of oil fields. Subsurface-pressure gauges were developed, and the reservoir pressure of oil fields observed at various rates of production. Research was inaugurated in the laboratory to determine the characteristics of oil, gas, and water at the temperatures and pressures found in petroleum reservoirs. The flow of these fluids through porous rock in the laboratory was quantitatively measured. Mathematics was called in to express in usable form the principles developed in the laboratory and in the field. The results of experiments in various laboratories of oil companies and educational institutions were freely exchanged and published in technological journals. Still further research and progress was stimulated as new research people built upon the foundation laid by others.

As the nature of the underground forces that are effective in oil production became more clearly understood through research, improved practices were rapidly adopted by producing companies and fostered by state regulatory agencies. An effective and still active cycle of research came into being that aided improved conservation, which in turn stimulated further research toward even greater efficiency. Today research and conservation work together in active partnership, each supplementing and supporting the other.

Cycling operations in condensate fields and in oil fields with large-sized gas caps are the highest type of conservation measure from the viewpoint of waste prevention and increasing ultimate recovery. Cycling is a primary-recovery method by which condensate is recovered from high-pressure gas, and the residue gas is compressed and returned to the reservoir from which it was originally produced. The return of the residue gas tends to maintain the pressure and thereby prevent condensation with its resultant waste of hydrocarbon liquids in the reservoir. Cycling plants afford a greater degree of recovery than normal production methods.

Due to the nature of the hydrocarbons as they exist in a reservoir, it is nearly always necessary to pool the ownership in a condensate field in order to insure a proper development program, production practice, and equitable distribution of income. The pooling of interests is difficult in fields with many different ownerships. The legal work is tedious, and lack of cooperation is often due to a misunderstanding of the problems. Voluntary pooling has been accomplished in all Texas pools where cycling is carried on. In Louisiana compulsory unitization under state regulations has eased the problem. It is customary to pool the royalty ownership into units or into one pool. The plant may be operated by the pooled lease owners or under a contract between the lease owners and plant owner, who may be a third party in the contract. The first cycling plant was built in Texas in 1938. Texas now has 31 of these plants, and Louisiana has 4. We can expect that this type of production will play a more important part in supplementing our oil reserves.

Accepted Conservation Principles.—Conservation of our oil resources of this material is absolutely essential. Conservation is not hoarding; it is not holding back an exhaustible material for future generations. Rather, it is the prevention of the waste of an urgently needed natural resource. Waste prevention is in the public interest. It is necessary to ensure a continuous and economic supply of a vital ingredient of our national economy. In its broadest sense, waste prevention not only must include prevention of actual physical loss of petroleum, both underground and at the surface, but also must include deterrents to conditions that might lead to the diversion of petroleum to inferior uses.

Fortunately, as a result of observing reservoir behavior and of the research and production practices employed during the period of effective conservation, a clear understanding has emerged of the physical principles and practices necessary to prevent the waste of petroleum. Stated briefly these principles are:

1. One of the most important single factors affecting the ultimate recovery of oil from a reservoir is the rate of production.

2. Uncontrolled, or wide-open production, causes underground waste.

3. Restriction of the production rate is necessary to secure the maximum amount of recoverable oil. The degree of restriction will vary, but for any field a maximum-efficient rate of production exists that is subject to reasonably accurate determination and beyond which underground waste will increase rapidly with further increase in the production rate.

4. Production at rates in excess of market demand leads to waste both above and below ground and creates conditions leading to the diversion of petroleum to inferior uses.

5. Control of the production rate entails the obligation of equitable allocation of the restricted production among the various operators in a field.

6. The natural forces and energy residing in the water and gas associated with underground petroleum may be effectively employed at restricted rates of production to increase the ultimate recovery. Unnecessary waste of this natural energy must be avoided.

7. An adequate number of wells properly located must be drilled in any field. The drilling of more wells than are actually required to produce the field at an efficient rate, without waste of gas and water and without excessive pressure decline near the well bore, constitutes excessive drilling. Excessive drilling is nonproductive use of capital and labor and leads to actual physical waste.

8. Nonratable withdrawals cause waste. Nonuniform withdrawals may be prevented by control of the number and location of wells and by equitable distribution of production.

9. In certain reservoirs deficient in natural energy the reservoir pressure can be maintained and waste prevented by supplying such energy in the form of injected water or gas. Such measures should be encouraged when their need is obvious.

10. An adequate underground reserve is required to permit the demand to be supplied at rates within the ability of the fields to produce efficiently. Conditions favorable to discovery of adequate reserves favor waste prevention.

11. Proper determination of the natural reservoir conditions and of the efficient rate of production for each field is essential to any conservation program. Such determination must depend upon adequate geologic and engineering knowledge. Creation of conditions suitable for securing such knowledge therefore is an integral part of conservation. Frequently such knowledge is secured and exchanged on a cooperative basis.

Suggested Solutions for Some Industry Problems.—With the advance of scientific knowledge and the growing conviction that conservation of oil and gas is essential to the public safety and welfare, and in addition to the impact made on the thinking of those within and without the industry as a result of advanced conservation practices and legislation in several of the most important oil-producing states, substantial progress has been made in conservation. Much more than mere trail blazing has been accomplished. A firm foundation has been laid and in some states the superstructure has been completed. All that need be done is to capitalize on and utilize generally the experience and progress which have been achieved. In completing the conservation picture it is only necessary to apply true and tried principles. The following suggestions are worthy of careful consideration:

1. It is primarily the function of the several states to enact adequate conservation laws and to set up the administrative machinery to carry them into effect.

2. Some states have advanced conservation statutes but have not completed the job. They should round out their conservation statutes. Texas for example should enact a pooling statute providing for the cooperative development and operation of oil, gas, and condensate fields.

3. While a number of states have adequate or even model conservation statutes, all oil- or gas-producing states without

such laws should promptly enact them. Likewise, all states in which exploratory work is being carried on should anticipate discoveries and enact conservation laws to encourage development of their oil and gas resources and prevent waste thereof.

4. All of the oil-producing states should be active members of the Interstate Oil Compact.

5. In all instances accepted conservation principles should be applied.

CHAPTER IV

TECHNOLOGY—THE GREAT MULTIPLIER

Part 1. Exploration Technology

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INTRODUCTION

Oil is found in the porous permeable rocks of the earth's crust where geological conditions are favorable for its accumulation in pools. It occurs in anticlinal and stratigraphic traps. To locate and define areas where such favorable conditions exist is the job of technicians.

During the 40 or 50 years after the first commercial oil well was drilled in the United States, little technical advice was sought in the location of well sites. Oil was discovered either by drilling near seepages or other surface indications and by random drilling. Since then scientific methods of search have been employed, though random drilling still yields occasional discoveries of considerable importance. Had the industry continued to explore for oil without the aid of technology, certainly our known reserves and productive capacity would now be much smaller.

DEVELOPMENT OF TECHNIQUE OF OIL FINDING

Beginning about 1912 geologists started the mapping of outcrops to locate favorable places to drill. The results of this first application of science to oil finding were very encouraging, and within a few years most of the promising surface structures had been drilled to depths as great as possible with existing equipment. Had not the oil industry been alert to take advantage of new developments in metallurgy, the old cable-tool system, with which drilling to depths of 3,000 to 4,000 ft. was a slow and precarious process, would still be in general use. Rotary-drilling methods were first used in 1901 in the Spindletop field near Beaumont, Tex. With the advent of better steels this method was greatly improved, and by the early 1920's was the commonly used method for drilling wells. Improvements in rotary-drilling equipment and materials have made available the vast oil reserves below depths of 5,000 or 6,000 ft. that only a relatively few years ago could not have been reached even if their existence had been suspected. Metallurgical research conducted jointly by the steel and petroleum industries has produced such improved alloyed steels that the limitations on the depth of drilling are economic rather than physical.

When geologists began to appreciate in the early 1920's that many structures were invisible at the surface, the great era of subsurface exploration began. Pit digging and core drilling were used in areas where identifiable key beds were not exposed sufficiently to permit surface mapping of underground structures. More careful logging of wells and improved methods of collecting and analyzing drill cuttings vastly increased the accuracy and quantity of available information, thereby permitting the geologist to extend his knowledge of structural conditions both laterally and vertically. Paleontologists effected a correlation of geological horizons between widely separated wells through a study of microfossils, where otherwise correlations could not be made. In some regions mineralogists have been able to correlate the underground geological strata on the basis of the mineral content of the sediments. Electrical well logging has been of great value to the geologist in correlations and in working out the details of subsurface structure. The great strides made in perfecting coring devices have not only improved production and development technique but also have vastly increased the geologist's knowledge of deeply buried formations. The many improvements along these lines, though not spectacular individually, cumulatively have furnished a wealth of assistance to the geologist and have served as the foundation of subsurface geology, which has grown from about 1920 until today it is one of the most useful methods of exploration.

ERA OF GEOPHYSICAL METHODS

Geophysical methods of exploration were introduced into the American oil industry in the middle 1920's. One of the first of these was the refraction seismic method. German scientists attempted unsuccessfully to use this method to map geological structure in Mexico and along the Mexican fault-line zone in 1923. After several refinements they located the first salt dome on the Gulf coast in 1924, after which a number of others were found in a short time.

American technicians began experimenting with this same method in 1919, and the first field party started work in 1925. A number of improvements had been incorporated in the American technique; it was successful in locating a large number of shallow salt domes in the Gulf coast areas, many of which turned out to be productive. Refraction seismic exploration was not successful in working out small deeply buried structures in such areas as the Mid-Continent. Consequently by the close of the 1920's it began to lose ground. Meanwhile American ingenuity, employing sound ranging principles, contributed entirely new concepts to the seismic techniques, and by 1929 the reflection seismic method was developed. The vertical depth to which structures could be mapped and detailed was extended many thousands of feet. The success of the method was little short of phenomenal. In 1930 only a few crews were in the field; by 1935 the number had increased to about 50 and by the end of 1943 to approximately 250. But for manpower and material shortages a still greater number of parties would be in the field today. Continuous refinements in the equipment permit interpretation of more deeply buried structures, until in many instances the method is now possible to apply successfully to sediments deeper than it is feasible to drill. Reflection seismic exploration, as developed by American technicians, using American-made instruments and American field crews, has been used in practically every oil-producing country of the world.

In 1923, at about the same time refraction seismic exploration was introduced into the United States, another oil-finding principle, the gravity method, was imported from Europe. The first instrument employed was the torsion balance, which measures local variations in the intensity of the earth's gravitational field. A Hungarian invention dating back to the 1890's, it was used with moderate success to unravel geological conditions under the great Hungarian plains. Like the refraction seismograph it proved successful in locating salt domes beneath the flat terrain of the Gulf coast, but achieved little success in hilly or mountainous topography. The topographical limitations of the method and its inherent slowness with resulting high cost of operation prevented its widespread application in the search for oil.

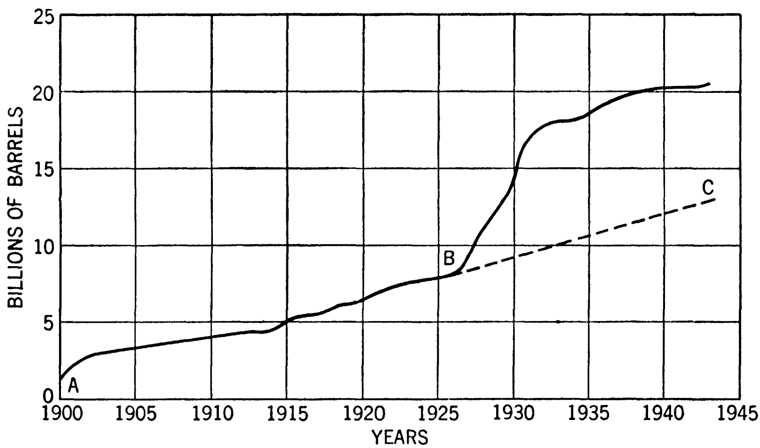
To overcome these operational handicaps, gravity meters were designed in American laboratories with which, for all practical purposes, the same data could be obtained at a greatly increased rate and at commensuratcly lower cost. Moreover, the new instruments were able to operate successfully in more rugged terrain. In 1943 more than 60 gravity-meter crews were in the United States. Particularly successful in finding salt domes if not too deeply buried, they have also contributed much valuable information as reconnaissance tools.

Still another geophysical method introduced in the early 1920's was the magnetic method. The most successful and widely used magnetometer is a sensitive instrument developed in Germany. It has been a useful reconnaissance tool in mapping broad areas, and the information it yields when combined with that from other geophysical and geological methods has contributed to the record ot oil finding in this country.

RESULTS OF EXPLORATION TECHNOLOGY

The discovery and steady improvement of the above-mentioned exploration methods has greatly reduced the hazard in wildcat drilling. From 1937 to 1942 one out of every six wildcat wells that were drilled on technical information discovered an oil pool. However, no significant trend occurred in this figure either up or down during the period. On the other hand a wildcat that was drilled without benefit of technical advice had only 1 chance in 18 of being a producer during the same period. Moreover, the nontechnical wildcat made an increasingly poor record, dropping from 1 well out of 12 in 1938 to 1 out of 25

The effect of these changes on the national reserves is illustrated by the attached curve (Fig. 1) which shows the net amount of added reserves each year after taking consumption into consideration. On the average the reserves increased slowly between the points *A* and *B* on the curve up to the year 1925. If the assumption in 1925 had been that the same rate of increase would continue and that nothing unusual would happen to the discovery rate, then by projecting this curve to the point *C* it might have been anticipated that the reserves in 1942 would be between 12 and 13 billion barrels. Actually, as shown by the



APPROXIMATE RESERVES

Fig. 1.

solid curve this figure was above 20 billion barrels. This increase in the rate of finding reserves was due to exceptionally rapid improvements in geological methods and to the adoption of geophysics, which as previously noted occurred between 1925 and 1930. Random drilling undoubtedly accounted for part of the increase, but for reasons mentioned elsewhere in the report no effort has been made to segregate the discoveries of the various methods. The actual accomplishment was even greater than shown. The annual consumption increased from about ½ billions barrels in 1925 to nearly 1½ billion in 1942, so that a minimum of 5 billion barrels more oil were consumed in this period than might have been expected, even allowing for a steady increase at the 1915–1925 rate. Thus it would not be unreasonable to expect that the combination of further improvements in exploration, together with the introduction of a new method, might add very substantially to our net reserves over the next 20 years.

SEARCH FOR NEW EXPLORATION METHODS

The problem of finding oil in stratigraphic traps is one of the most important problems facing the oil industry today. It will probably have to be solved by the intelligent combined use of all available tools and by new methods and improvements in old methods. The industry spends several million dollars a year in research designed to develop new techniques and improve old ones. Investigations, although somewhat slowed down because many scientists are engaged in war work, are currently being conducted on such problems as:

1. Direct oil finding by electrical or geochemical methods.
2. Further refinements of seismic techniques.
3. Adaptation of various physical instruments such as the electron microscope, the mass spectrograph, and the X ray to the detailed study of well samples and cores.
4. The origin of oil and the transformation of organic material into hydrocarbons.
5. Broad studies of basic geological processes and intensive study of subsurface data accumulated from old wells and from more recent stratigraphic tests.

Enormous advances in radio technique and equipment and in the development of new implements and weapons of war have given rise to hope that new methods will be developed that can be applied to oil finding after the war is over. Radar and associated electronics constitute a vast field which might revolutionize the oil-finding methods of the future even though tremendous obstacles remain to be overcome—such as the earth's very high absorption of short radio waves.

FUTURE PROSPECTING

Prospecting, which involves many highly complicated techniques, is carried on in three dimensions. Laterally, it helps localize new areas displaying characteristics favorable to the accumulation of petroleum; vertically, it involves search for new oil by deeper drilling on known and in many cases already productive structures. In one sense the latter is less hazardous than the former; more definite knowledge about the structure is available from wells already drilled. There are enormous volumes of untested sediments on structure and below the presently drilled depths that in all probability will yield huge quantities of oil. Fortunately, metallurgical improvements that made it possible in the past 20 years to double the maximum drilled depth have advanced to a point where this deeper drilling offers no serious technical difficulties. When skilled man power and material are freely available and particularly if higher crude-oil prices prevail, this deeper drilling, with a consequent large addition to reserves, may be confidently expected.

The urgency for development of increased productive capacity has undoubtedly had a tendency to confine lateral exploration to the less hazardous but already carefully examined areas in proximity to production. This fact undoubtedly accounts in part at least for the continuing decrease in the size of new discoveries. Less than 25 per cent of the present exploratory effort is concentrated in virgin areas. After the war, exploration will be less concentrated, and activity will spread to very large areas where existing techniques have never been applied but where there is some geological reason to expect favorable conditions for oil accumulation. Much Federal land in some of these areas has never been leased. If exploration is to be encouraged, some modifications should be made in the existing Federal land-leasing regulations.

Large reserves of oil can be expected on the flanks of undiscovered salt domes situated close to the Texas and Louisiana coast line; it seems inconceivable that the present coast line represents the southern boundary, beyond which no further domes exist. Indeed, a few domes are already known to be present in the Gulf, but quite close to the shore. Fortunately the depth of the Gulf increases quite gradually, so that it is necessary to go from 10 to 40 miles offshore before a depth of 10 fathoms is reached. That area off the coast where the Gulf is less than 10 fathoms deep must contain a large number of such structures, for an equivalent area on land encloses 30 domes in Texas and 50 in Louisiana. Before these reserves can be made available, not only the legal question of ownership of the underwater land but also the engineering problem of drilling and producing in deep water will have to be solved. The latter probably is no unsurmountable obstacle: considerable progress has been made already in drilling in the open waters of the Gulf.

Whenever a new and successful exploration method has been developed, the tendency has been to use it for a few years almost to the exclusion of all others. Then it takes its place along with older methods, to be used either by itself or in combination with other methods for the best solution of the particular problems involved in the exploration of a given area. In the course of the use of any new method large numbers of anomalies are found, the significance of which cannot be fully appreciated because they do not conform to the anticipated pattern. Generally such anomalies are put on the shelf to await a new instrument or a method of higher resolving power. Occasionally they are drilled before the advent of any new method, and a large oil field is discovered. Toward the end of the refraction era there were many such anomalies. These were immediately subjected to severe scrutiny when the reflection method was introduced, and a number of important new oil fields were discovered. At the present time many more such anomalies exist than at the end of the refraction period because of the relatively greater amount of reflection work. Many of these will undoubtedly turn out to be associated with oil fields. These areas would serve as the immediate happy-hunting grounds of any new method, and the discovery rate of the new method would be abnormally augmented until such areas were exhausted. In the absence of any new method these anomalies will be reworked with gradually improving techniques, until in some cases it will be possible to work out a satisfactory structural picture. Such improvements in technique may also make it possible to map some hitherto unworkable areas. It will be necessary to drill substantial numbers of exploratory or wildcat wells in order to evaluate such anomalous areas and to obtain valuable geological information concerning subsurface conditions. Finally, random drilling can be expected to contribute substantially to our new reserves, just as it has in the past.

A critical examination of all existing geophysical data, together with information obtained from improved electrical and possibly even new logging methods, will augment the geological knowledge of subsurface conditions and thereby assist in the discovery of both stratigraphic and structural traps.

Possibly further developments in geochemistry or soil analysis may be applied successfully to oil finding. Results to date along this line of investigation have not been impressive, but field tests of the method have not been extensive enough to prove that it is of no value.

One of the outstanding characteristics of exploration technology is its dynamic nature. New methods are promptly adopted and given extensive and widespread trial. A common practice is to use several different methods in a given area, check the results of one against another, and weigh the probability of oil-field indications before a well is drilled. As a result of the rapid succession of new methods that have been developed and the interrelation of different methods, it can hardly be said that any exploration method used to date has exhausted its capabilities as an oil-finding tool. This tendency to use several independent exploration methods in the same area has greatly reduced the risk and the expense for new oil fields, but has made impractical allocating the credit for discovery of definite amounts of new oil reserves to a specific method or methods. For example, a careful study and interpretation of all available geological information, including surface work, may indicate the possibility of a regional trend. A gravity survey is made showing that the area is somewhat anomalous but failing to reveal any structural details. A core-drilling program then indicates rather weak structure, so that a seismic survey is finally made. This process not only indicates the trend, but also isolates an area on which to drill. If the test well were productive, it would be very difficult to determine which of the methods should be given credit for the discovery.

CONCLUSION

Undoubtedly the impact of war with all its sudden changes, such as shortages of materials and man power, has had a very considerable effect in reducing additions to reserves in the past few years. We may confidently expect that the end of the war will see a change for the better.

Vast untested areas on land and under shallow water still remain to be explored. Cessation of hostilities will usher in a period when exploration will be conducted in these areas with the expectation that large new oil reserves will be uncovered. Deeper drilling of presently known structures should add substantially to our reserves. Random drilling has made effective contributions to our oil reserves in the past and unquestionably it will in the future.

While no new methods are in sight at the present, there is ample reason to expect that new techniques will be developed which will also uncover additional reserves. Meanwhile the American petroleum industry will continue to use all available instruments and methods in the search for oil. Even tools of doubtful value will be tested. The best approach to the problem of search for stratigraphic traps is through the greater use of slim holes for purely exploratory drilling. The oil industry is fully prepared to extend the use of this tool if no better approach presents itself.

Most of the advances in exploration technology made by any single American company shortly becomes available to all companies. By employing service companies the smallest oil producer may benefit from the techniques available to the largest company. This immediate availability is primarily an American development, and unquestionably it has played an important role in maintaining American methods and techniques in the preeminent position they hold in oil exploration in all parts of the world.

The petroleum industry of the United States, developed under a system of competitive endeavor and free enterprise, can be justly proud of its record in oil exploration and development. Given a chance to exercise its ingenuity and courage, the industry may be relied on in the future to provide the necessary oil products from oil or substitutes to keep the wheels of industry and transportation moving.

Part 2. Production Technology

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At an early date oil operators learned that petroleum deposits were different in character from solid minerals. Whereas the latter remain in place until the owner elects to recover them and regardless of production from other portions of the same deposit, oil is fugacious and will migrate to areas of lower pressure. Thus the first wells in a new field, creating areas of low pressure, frequently drained oil from under neighboring properties. The long-established law of oil and gas known as the rule of capture gives the owner of oil-field land all the oil which he can reduce to his possession, whether or not all such oil originally underlay his particular trace. Upon discovery of a new field, therefore, it behooved every operator to develop his property as rapidly as possible and produce it at maximum capacity so that he might obtain the maximum share of the total oil recoverable from the field. Under such practices operators observed that the first wells obtained the highest recoveries, that unrestricted producing rates yielded higher recoveries, and that more densely drilled tracts obtained more oil per acre than adjoining tracts with wider well spacing. These observations led to the conclusions apparently that rapid development, close well spacing, and maximum producing rates resulted in maximum recovery. Now it is known that these conclusions were unsound and that practices in vogue in the early years of the industry incurred gross economic waste and were detrimental to the maximum recovery of oil from the field as a whole.

The first technological investigations of petroleum production were undertaken by the U.S. Bureau of Mines. Shortly after the First World War petroleum engineers were introduced into the industry, and producing companies began the establishment of research laboratories. These technologists supplemented and greatly expanded the early studies of the Bureau of Mines. As a result of these studies some of the factors which influence the efficiency of oil recovery were recognized, and the first principles of reservoir behavior were formulated. However, not until a series of great new discoveries in the middle twenties culminated in vast overproduction of oil was it necessary to curtail producing rates to avoid surface waste. Engineers were given their first opportunity to apply the theories of scientific operating methods that were designed to increase the ultimate recovery of our oil reserves. The beneficial results of scientific control soon were demonstrated. Since that time rapid strides have been made in petroleum-production technology; we have learned more regarding the science of efficient production since the First World War than in all the time since the Drake well was drilled.

EVOLUTION OF CONSERVATION LAWS

Maximum recovery of oil from an underground reservoir requires that the individual wells and the field as a whole be so operated as to control and effectively utilize the natural energy associated with the oil. This goal can only be achieved when all the owners of production in the field employ efficient producing practices. One operator can, by employing wasteful practices, prevent or completely sabotage the efforts of his neighbors to increase the total oil to be recovered from the field.

His argument that it is more desirable to produce his oil more rapidly, even if he can recover only one-half or one-third the amount otherwise obtainable, might be sound from his particular economic point of view, but certainly it is not in the best public interest. The application of scientific producing practices required a means of enforcing the necessary regulations and control measures.

Under the rule of capture each operator was free to develop and produce his properties as he saw fit. With the restriction of production to market demand in order to prevent surface waste, the initiative of the individual operator was curbed. Therefore it was necessary to protect his property rights and devise a system of control that would give to each operator the same portion of the total recovery of the field as he would have obtained without restrictions. Thus was proration born.

Early state laws concerning oil and gas consisted merely of regulations of such features as well completions, protection of fresh-water sands, and plugging of abandoned wells. With the advent of production restriction the laws of most states were expanded to include control of proration. They were first merely designed to distribute the market demand equitably to the several operators in each field so as to prevent surface waste. With the development of technological knowledge it was soon recognized that restriction of production accomplished a far more important result, namely, more efficient utilization of the reservoir energy to achieve a substantial increase in the ultimate recovery. The proration laws were expanded to include subsurface waste and thereby became conservation laws in the full sense of the term.

The state laws of oil conservation with a few glaring exceptions are adequate to safeguard properly the interests of the nation in preventing wasteful practices, and at the same time safeguard the interests of the individual producer so that each has an equal opportunity to recover his equitable share of the oil contained in the reservoir. The conservation laws have also been effective in furthering the applications of scientific principles to oil production as technical knowledge has expanded.

REVIEW OF TECHNOLOGICAL ADVANCES

Technology is the great multiplier of our petroleum resources. Entirely aside from improvements in exploration technology which have contributed substantially toward increased discoveries of petroleum, the advances in the technology of drilling, completing, and producing oil wells and the technology of reservoir operation have made available today many billions of barrels of oil which it would not have been possible to recover through practices in vogue at the close of the First World War. Technological advances in drilling and producing operations over the past quarter century may be subdivided into two general categories, the first embracing those which are of a mechanical nature and the second relating to more efficient reservoir operation. These advances have not been brought about by any particular group in the petroleum industry, but are the result of an industry-wide effort to improve operating efficiency and reduce operating costs. The advantages stemming from these advances are available to the entire industry. The technological advances are reviewed briefly in the following discussion.

MECHANICAL DEVELOPMENTS

Drilling.—Twenty-five years ago the deepest well drilled was around 7,000 ft., and 5,000-ft. wells were uncommon. Today a well 5,000 ft. in depth is considered relatively shallow, and many fields are producing from below 10,000 ft., or almost 2 miles below the earth's surface. The deepest well to date is over 15,000 ft. in depth, and there should be no great difficulty in exploiting fields at this depth wherever they may be found.

Detailed data by fields are not available to permit an accurate estimate of the oil reserves at various depths, but sufficient data are available to make satisfactory approximations. Review of these data indicates that the ultimate recovery of reservoirs already discovered and 5,000 ft. or greater in depth will be in excess of 11 billion barrels, or almost a quarter of the total ultimate recovery from fields discovered up to this time. The present remaining reserves from reservoirs 5,000 ft. or greater in depth are estimated to be in the neighborhood of 7.4 billion barrels, or approximately 37 per cent of the 20 billion barrels of reserve remaining in known fields. The present proved reserves of fields over 10,000 ft. in depth are estimated to be in excess of 1 billion barrels, or 5 per cent of the remaining proved reserves.

The drilling of continually deeper wells has been possible through

1. General improvements in the design, strength, and power of drilling machinery.
2. Metallurgical progress in the manufacture of alloy steels and advance in fabrication of drill pipe, casing, tubing, and pumping equipment.
3. Scientific control of drilling fluids resulting in greater drilling speeds, minimum formation carving, drilling through the formations previously impossible to penetrate with ordinary drilling muds, and security from blowouts.
4. Improvements in cements and cementing practices, and development of techniques satisfactory under high subsurface pressures and temperatures.
5. Development of subsurface well-surveying instruments and directional-drilling techniques. Also, the application of directional drilling has made reserves available under the deep coastal areas by drilling from shore locations.
6. Development of suitable equipment for drilling from barges and special foundations in lakes, bays, and shallow-water areas of the Gulf coast. These techniques have added thousands of square miles of prospective oil area and have added substantially to crude-oil reserves.

Subsurface Information.—In the earlier drilling operations, information on subsurface strata was secured only from earth cuttings brought to the derrick floor in bailers or in the drilling-mud stream. These cuttings were used to evaluate the various formations penetrated by the drill and to locate their relative vertical position in the well. As the need for better information became apparent, coring devices and other methods of evaluating the formations penetrated were invented.

Progress in this direction is indicated by the following developments:

1. Inventions and improvements in side-wall, pressure, and wire-lined core barrels, which obtain samples of formations penetrated by the drill stem, have improved earth-testing technique and oil prospecting.

2. Introduction of electrical well-logging equipment has greatly assisted in the correlation and evaluation of subsurface strata, and consequently has improved completion practices. The early techniques were applicable only before casing was set, but recent developments make logging possible through the casing, and thus provide a means of evaluating formations behind the pipe in old wells.

3. Formation drill-stem tools and techniques make it possible to test subsurface strata without setting casing. Prospective horizons can now be tested to determine whether they are water- or oil-bearing with only a few hours interruption of drilling. This practice assists in thorough evaluation of the penetrated formations.

4. Core-analysis equipment and techniques have been perfected so that core samples of formations can now be tested immediately upon their recovery at the surface and possible reserves recognized in the process of drilling. Complete truck-mounted laboratories provide this service at the well to any wildcatter in order to make available information as to porosity, permeability, and fluid content of the core samples of the strata.

5. Examination of the drilling fluid under ultraviolet light and other special tests assist in determining the fluid content of formations penetrated by the bit.

Completion of Oil Wells.—With the advances in deep drilling, better equipment and new methods have been developed that made possible exploitation of reserves from productive strata otherwise uncommercial or difficult to reduce to possession. Some of these developments are as follows:

1. Selective well completions by gun perforation of steel casing. Guns are lowered on cables and bullets are fired at points opposite

the prospective oil strata. Thin oil-bearing strata otherwise noncommercial are being exploited now by this method. Similarly cased-off oil zones discovered by new well-logging techniques are opened to production by gun perforation.

2. High-pressure deep wells require slow and controlled methods of completion and production, and special high-pressure well-head equipment. Casingheads with special features and capable of withstanding pressures up to 10,000 lb. per sq. in. were developed and are available for handling of high-pressure oil and distillate fields. Development and use of special surface and subsurface chokes have prevented waste of reservoir energy and thus increased recoverable oil reserves.

3. Introduction of squeeze- and stage-cementing techniques assisted greatly in completion of deep wells. Squeeze cementing is also used extensively to shut off salt water for protecting oil-bearing zones from harmful underground-water pollution.

4. Selective water shut-off by plastics is a recent development of great possibilities, the application of which is expected to improve exploitation efficiency of oil reservoirs operated by water-drive energy.

5. Introduction of acid treating of limestone-producing strata has added substantial reserves of crude oil. Acid treating of oil wells not only increased recoverable reserves from semicommercial pools but in many instances made noncommercial pools attractive for development and exploitation.

Production Practice.—Parallel to advances in drilling and well-completion methods, new developments have taken place in production practices to take care of new problems in production of crude oil from deeper wells. Here it was necessary to devise economical means of lifting fluids from great depths and to improve equipment capable of handling great loads under severe conditions of corrosive salt water and gas. The most noticeable advances in this direction are indicated by developments listed below.

1. Development of high-capacity electric and hydraulic pumping equipment capable of lifting up to 3,000 bbl. daily from shallow wells, or from deep wells in conjunction with gas-lift methods.

2. Application of electric and hydraulic pumps for deep-well pumping.

3. Improvements in pumping units and sucker rods that extended sucker-rod pumping to wells of 8,000 ft. in depth.

4. Improvements in gas-lift practice.

5. Successful use of screens, gravel packing, improvements in subsurface pumps, and other numerous innovations have added greatly, when viewed collectively, to the art of oil production and reservoir exploitation.

ADVANCES IN EFFICIENCY OF RESERVOIR OPERATION

The advances in understanding of the principles of reservoir behavior and the factors affecting recovery have contributed more to our present reserves of petroleum than any other single development. At the end of the last war it was common practice to develop fields with dense well spacing and produce the wells as rapidly as possible. While it was recognized that only a small portion of the recoverable oil was being obtained by these methods, it was the common belief that such was merely the nature of oil reservoirs and that there was nothing the operator could do to improve the recovery efficiency. It is now generally accepted by petroleum-production technologists that control of producing rates and conservation of reservoir energy have a very important influence on the recovery efficiency, and that the practices of early years not only resulted in gross economic waste but also caused large losses in ultimate recovery of oil.

A brief review of present concepts of the principles of reservoir behavior follows. Just as practices in vogue 25 years ago are now considered inefficient in the light of present knowledge, so also will continuing study add to our knowledge and further improve our efficiency of oil recovery.

Reservoir Fluids.—Fundamentally, natural oil reservoirs consist of porous and permeable rock, the pores of which contain oil and gas. In all reservoirs the contained fluids are under pressure, and the characteristics of the oil and gas in the reservoir are greatly different from those at the surface. Reservoir oil is usually saturated with gas at the original reservoir pressure and any gas in excess of that which can be dissolved at the prevailing temperature and pressure exists as a free gas cap in the highest portion of the reservoir.

The gas dissolved in reservoir oil plays an important part in the oil-recovery mechanism, both in its effect on the oil characteristics and in actual expulsion of oil from the reservoir rock. The dissolved gas increases the A.P.I. gravity of the oil and reduces the viscosity and surface tension. The reduction in viscosity facilitates the flow of oil to the well bore, and the reduction in surface tension results in less adhesion of oil to the sand grains leaning toward a higher recovery of the reservoir oil. It is therefore important to maintain reservoir pressure so as to retain the gas in solution if these beneficial effects are to be realized.

The knowledge of the fluid content of oil reservoirs has progressed through several stages. At one time the idea was prevalent that oil as recovered at the surface occupied the entire pore volume of the reservoir rock, but it was later realized that the oil in the reservoir contained gas, and that the release of gas from solution caused a shrinkage of the original reservoir-oil volume. It has also been found in recent years that oil and gas do not comprise the entire fluid content of even oil-saturated reservoir rocks, water usually being present in substantial amount. The initial interstitial water, commonly called connate water, is now believed to occupy the smaller pores of the sand due to the action of capillary forces. The connate-water saturation encountered in practice varies considerably with the character of the sand and the fluids but generally ranges from 10 to 40 per cent and in some cases may be considerably higher. The connate water in most instances is not produced with the oil, and is therefore not apparent except where cores are carefully obtained and analyzed. Early estimates indicated recoveries from oil reservoirs to be in the neighborhood of 15 to 25 per cent. In view of our present knowledge of the shrinkage of reservoir oil upon liberation of dissolved gas and the presence of connate water in the oil sand, it is now realized that the percentage of oil recovered from the reservoir rock is in most cases substantially higher.

The oil-bearing portion of a formation usually constitutes only a small portion of the total stratum. The portion of the stratum extending downdip and away from the productive portion is usually porous and is commonly filled with water. In thick sections, free water may also underlie the oil zone. This water moves into the oil zone as fluids are withdrawn therefrom, and this phenomenon contributes greatly to the recovery of oil.

As may be seen from the foregoing, many oil reservoirs contain three fluids, free gas, oil and dissolved gas, and free water. As a result of gravitational segregation over geologic time, free gas, if present, will be found occupying the highest portion of the sand and will be underlain by the oil zone, which in turn is underlain by water. While this layer arrangement holds as a broad picture, there is seldom a sharp line of demarcation between oil and gas and between oil and water because of capillary forces that cause a region of gradual change in saturation from one of the fluids to the other. This is particularly true with respect to the oil-water interface.

Flow of Fluids in Sand.—The flow of reservoir fluids through porous media is a mechanism in which pressure, relative permeability to oil, gas, or water, and relative saturation of the three fluids is gradually changing. When simultaneous flow of more than one fluid is involved, such as happens when gas or water are flowing with the oil, a complicated system is set up in which oil flow no longer follows the simple mechanism governing its flow when alone. Permeability to each fluid after flow is established is dependent upon the relative saturation of the pore space. As a result of research investigations it has been found that the saturation-permeability phenomenon and the influence of capillary action fix a certain minimum oil saturation in a sand, below which it is not possible to have flow or to recover oil by displacement. The oil remaining in the sand when displacement is no longer possible is termed the residual-oil saturation, and the amount of oil which can be recovered before this point is reached is termed the recoverable oil. The residual-oil saturation varies with the characteristics of the oil and of the sand, but for conditions normally encountered, the minimum oil saturation practically obtainable in the flooded portion of the sand usually ranges from 10 to 20 per cent of the pore space. Thus, after taking into account the connate-water content of the sand, the maximum recoverable oil represents 60 to 80 per cent of the original oil in place, depending upon sand and fluid characteristics.

Recovery Mechanisms.—Since oil in itself has no inherent energy, it can be appreciated that recovery of oil from reservoir rocks is a process involving the displacement of the oil by either gas or water. It is now generally recognized that nature has provided three major mechanisms by which oil may be recovered from underground reservoirs:

1. Through simple expansion of gas released from solution in the oil, no free gas cup or water source being present.
2. Through displacement of the oil from the sand by downward expansion of a free gas cap.
3. Through upward displacement of the oil by the influx of water from below the oil sand.

These processes, generally referred to respectively as dissolved-gas drive, gas-cap drive, and water drive, are discussed briefly below:

1. The dissolved-gas drive is the least desirable type of reservoir since the recovery of oil depends solely on the relatively limited quantity of dissolved gas available for expulsion of oil from the sand. Both the rate of oil flow and ultimate yield are dependent primarily on the degree of exhaustion of the gas. The ultimate yield from this type of reservoir amounts to only 20 to 40 per cent of the original oil in place. However, by proper operating practices it may be possible to bring into play one of the more efficient recovery mechanisms.

2. The gas-cap drive is capable of yielding a substantially higher recovery than dissolved-gas drive. The displacement action of a downwardly expanding gas cap maintains pressure on the oil sand and retards evolution of gas from solution. The recovery expectancy may be as much as twice that obtained under dissolved-gas drive, with a potential yield under favorable conditions approaching the limit of minimum residual-oil saturation, thus obtaining substantially 100 per cent of the recoverable oil. Where an original gas cap does not exist, it is often feasible to create one by injection of gas at the crest of the structure; this practice may also be followed to supplement an original gas cap.

3. The water-drive mechanism is inherently the most effective natural means of displacing the oil and its dissolved gas. The advancing water flushes the oil from the sand and tends to maintain pressure in the reservoir by offsetting the fluid withdrawals. Under favorable conditions the oil content of the sand is reduced to the minimum residual-oil saturation, thus obtaining 100 per cent of the recoverable oil. The efficiency of this mechanism is apparent, since the sands are usually water-wet under original conditions and the flushing action of water can be very thorough.

large, continuous, and permeable water leg extending regionally as a blanket sand over a large area or outcropping at not too great a distance. The presence of major sedimentary changes and regional faulting, if they destroy the effective continuity of the water leg, will generally preclude the effectiveness of the water drive as a major oil-recovery mechanism.

It has been found that usually the movement of water is slow, therefore requiring a severe measure of restriction of oil-withdrawal rates. Many fields of the United States are currently utilizing water drive to a high degree by limiting oil withdrawals to about 3 to 5 per cent per year of the ultimate yield.

The great East Texas field is a good example of this type of reservoir. By limiting net fluid withdrawals to rate of water movement into the structure, the reservoir pressure has been maintained over a period of years. Through this control not only will the ultimate recovery be substantially increased, but the cost of recovery is materially less, the effect of which is lower-cost gasoline in the consumers' tank.

Wide recognition of the effectiveness of water drive has prompted operators to explore the possibilities of artificially stimulating this mechanism by injecting water around the flanks of the oil reservoir at an early date before original pressures have been reduced. This practice is a new development but results are so encouraging it may be adopted wherever physical conditions permit.

In practice probably no one of these three drives will apply exclusively for the complete life of the field, but the degree to which one or another is utilized will have direct bearing on field behavior and ultimate oil yield. Both reservoir characteristics and operating control greatly influence the degree to which a particular drive is operative and hence influence the recovery expectancy. The problem in its simplest terms is to maintain the natural pressure in a reservoir so that the maximum amount of oil will be produced through natural forces. Control of these natural forces not only enables a much greater total recovery of oil but adds materially to the flowing life of the wells, thus reducing the cost of production.

Optimum Producing Rate.—It is believed that in most fields utilizing water-drive or gas-displacement mechanisms, the slower the rate of production the greater is the possible ultimate yield of oil. Reduction in rate below a certain level, however, will result in only insignificant increase in recovery, and it is customary to refer to this level as the efficient rate. At rates of production above the efficient rate, ultimate recovery may drop off rapidly with increase in rate. The rate of production beyond which loss in recovery becomes appreciable is commonly referred to as the maximum-efficient rate or optimum rate.

CONTRIBUTION OF TECHNOLOGY TO INCREASED RECOVERY

From the foregoing discussion it will be obvious that technological advances have contributed substantially to our petroleum resources. Estimates in terms of barrels are of course difficult to arrive at and, because of the many factors involved, such estimates are at the best only good approximations. On the basis of available data, however, it would appear that the addition to our resources which can be credited to mechanical developments (deeper drilling, electric logging, acidizing, gun perforating, etc.) amounts to some 12 billion barrels.

It has been conclusively demonstrated by actual field data that uncontrolled producing rates fail to recover as much oil as could be obtained by efficient reservoir operation. The loss varies widely and is dependent upon the characteristics of the individual reservoir and its contained fluids. As water is a more efficient displacing agent than gas, it may be expected that water-drive fields will obtain higher recovery than gas-drive fields, even though both are produced efficiently. From field experience it appears that water-drive reservoirs may be expected to recover under inefficient practices as much as 90 per cent of the recoverable oil if conditions are extremely favorable, and perhaps only 60 per cent of the recoverable oil under less favorable conditions. On the average it may be assumed that an inefficiently operated water-drive field will recover only 80 per cent of the oil that could be obtained by efficient producing practices. In gas-drive fields the loss in recovery due to inefficiency varies over a much wider range and under the most adverse conditions recoveries may be only 30 per cent of the maximum obtainable and under the most favorable conditions may be as high as 80 or 90 per cent of the maximum possible recovery. Considering the proportion of the nation's reserves represented by water-drive fields as compared with gas-drive fields, it appears reasonable to assume that inefficient producing methods for the average field will yield only 75 per cent of the oil recoverable by efficient methods so that the loss due to inefficiency represents 25 per cent.

The oil fields discovered since the First World War represent a reserve of approximately 37 billion barrels. Most of these fields were discovered after the middle twenties at which time proration was adopted and the efficiency of the operation of oil fields was substantially increased. It might be assumed, therefore, that in large measure the fields discovered since the First World War have been operated efficiently, and if it is assumed that 25 per cent of the reserves represented by these discoveries would have been rendered unrecoverable by inefficient practices in vogue prior to that time, simple calculations will show that the addition to the reserves representing the fields discovered since 1919 amounts to about 9.3 billion barrels. Some of these reserves have already been produced, but applying this same percentage to the remaining reserves of 20 billion barrels indicates 5 billion barrels to be the direct contribution of this phase of technologic advancement to our present reserves.

It will be obvious that the foregoing estimates of contributions to our petroleum resources are not additive, since the percentage increase in recovery resulting from efficient practices is applicable in some cases to the same fields that have resulted from our ability to drill to greater depths and to improvements in completion techniques and other mechanical developments. Taking into consideration these overlaps, it would appear that perhaps 17 billion barrels of the ultimate recovery of 48 billion barrels from present known fields can be credited to improved technology, which represents 35 per cent of the total ultimate recovery from present fields. On the basis of the present reserves it would appear that some 11 billion barrels might be credited to improved technology which represents approximately 55 per cent of the remaining reserves in our present fields.

WELL SPACING

The question of well spacing is an important consideration in planning the development of a newly discovered field. The subject of well spacing and its possible effect on ultimate recovery has been studied and discussed over a period of many years. While it has been a highly controversial question, sufficient field data are now available to permit drawing of certain conclusions with respect to this matter.

It is generally agreed by most engineers that under modern production practices well density, or the distance between wells over the range of spacings normally employed, has little effect on the theoretical maximum recovery of oil. Proper well location and operation are, however, highly important. Well spacing, or the number of wells, obviously has a bearing on the time required for depletion of the field, and is therefore an economic factor of great importance. The cost of producing the oil bears a direct relation to the number of wells through which the oil is recovered, and thus well spacing is one of several factors which determine the economic life of a field.

The time factor must be taken into account in deciding the well-spacing program, and sufficient wells must be drilled so that the amount of production withdrawn from each well is not excessive and will not result in the coning of water into the well or excessive channeling of gas. On the other hand, drilling of too large a number of wells must be avoided, since in such cases the economic pressure to produce individual wells at rates which yield desirable return on the investment may cause excessive or inefficient rates for the field as a whole. No over-all rule can be established for well spacing, as each field represents a different problem and the optimum spacing for a particular field must be determined on the basis of the characteristics of that field. In general the industry has been going in the direction of wider well spacing, and this trend was greatly accentuated during the war years because of the shortage of materials and man power. The basic Federal limitation today is 1 well to 40 acres. Obviously, a given well-spacing program can not be applied uniformly to all fields, and it is possible that in some of the fields in which 40-acre spacing has been employed as a result of Federal limitations, closer spacing would economically have been justified. On the other hand, it is certain that many fields developed on this spacing pattern will not be drilled more closely after this limitation has been removed, and that field data will demonstrate that this wider spacing has not resulted in any loss in recovery.

The industry's trend toward wider well spacing is not without benefit to the public. Wider spacing, coupled with efficient operating practices, has made possible the same ultimate recovery with considerably fewer wells and thus a much lower investment on the part of the producer, which is reflected in lower producing costs. Thus, findings of the technologists on the effect of well density on recovery is of definite benefit to the consumer.

CONDENSATE FIELDS

Deeper drilling in recent years has resulted in the discovery of a new type of petroleum accumulation known as distillate or condensate fields. This type of accumulation exists in the gaseous form under the conditions of temperature and pressure prevailing in the reservoir, but, in contrast with conventional gas fields, a portion of the gas condenses as liquid upon reduction of pressure. For maximum recovery from this type of accumulation it is therefore necessary to maintain reservoir pressure above the point at which condensation takes place; failure to do this renders a substantial part of the liquid components unrecoverable.

The phenomenon of condensation upon reduction of pressure is known as retrograde condensation and has been the subject of considerable research. Knowledge of this peculiar behavior of the reservoir fluids has resulted in the development of a new producing technique known as gas cycling. In this method of operation the reservoir fluid is produced in the gaseous phase, the liquid constituents are recovered at the surface, and the dry gas is compressed, returned to the producing formation, and serves to maintain the reservoir pressure, thus preventing condensation in the formation. The result of this practice is substantially to increase the ultimate recovery of petroleum from reservoirs of this type. More than 1 billion cubic feet of gas per day are now being treated in this manner, most of which is returned to the producing formation. Currently, over 1 million gallons of liquid petroleum products daily are obtained from this source, and the total petroleum reserves in reservoirs of this type discovered to date are approximately 500 billion barrels.

SECONDARY RECOVERY

Producing practices employed in the early years of the industry, before scientific enlightenment, resulted in depletion of the reservoir energy before depletion of the oil, thus leaving a high percentage of the oil in the ground without natural propulsive energy. Modern research has demonstrated that much of this remaining oil can be recovered by supplying extraneous energy to drive the oil to the bottom of the well bore from where it can be pumped to the surface. Water, air, and gas have been injected into old reservoirs for this purpose and have thus stimulated recovery; this operation is known as secondary recovery. Secondary recovery is applicable primarily to fields produced by dissolved-gas drive or by inefficient gas-cap drive. Initiation of secondary-recovery practices need not await the decline of the producing rate to the economic limit, and in most cases is initiated prior to that time.

Secondary-recovery practices have been adopted in a large number of fields in the United States, and have already resulted in the recovery of millions of barrels of additional oil. Water flooding has been used most extensively in the Bradford area of Pennsylvania, where large quantities of additional oil have been recovered from fields which had reached their economic limit perhaps 20 years ago. Water flooding has also been used quite extensively in New York and in several of the other oil-producing states. Gas is probably the most commonly used injection medium in secondary-recovery operations and has been used in practically all of the producing states. Air is used only in cases where gas is not readily available, and the operation is not suitable for water flooding.

In most instances secondary-recovery operations are more costly than primary operations, and the method has therefore been used to date only in the most promising cases. Future technological improvements in secondary-recovery methods and a higher price for oil will no doubt cause its application on a much wider scale than at present. Those best informed on this subject have estimated that at least 1 billion barrels and possibly as much as 5 billion barrels might be obtained by secondary recovery. The portion of these additional potential reserves which are recovered will depend somewhat upon the price of oil, but at least several billion barrels will be recovered when needed badly enough to pay for it. These estimates of oil recoverable by future secondary-recovery operations are not included in the estimate of 20 billion barrels of oil recoverable from present proved fields.

MINING OF OIL SANDS

The mining of oil sands has been limited in this country to one or two pilot operations which have been unsuccessful from the commercial point of view. Mining operations have been successfully carried on for a number of years in a few places in Europe. No doubt semimining methods consisting of a shaft to the oil horizon, with many small lateral bores into the oil sand for drainage of oil into the shaft, will precede direct mining of oil sands. Here again, price is the determining factor, and many billions of barrels of oil can thus be recovered when conditions warrant.

CONCLUSIONS

In the 25 years since the end of the First World War, the petroleum industry has made tremendous progress in the technology of gaining access to, and obtaining maximum recovery of, oil from underground reservoirs. As has been indicated, these advances in the science of petroleum production have added 17 billion barrels of oil to the recovery ultimately expected from present proved fields, or 35 per cent of the 48 billion barrels of oil discovered to date. Some of this oil has already been produced, and of the 20 billion barrels remaining in present fields it is estimated that 11 billion, or 55 per cent, is attributable to improved technology. Looking at it another way, the United States many years ago would have been unable to meet even its domestic requirements had it not been for the reserves made available by technological advances in drilling and producing.

In addition to the present estimate of 20 billion barrels from proved fields, other billions of barrels of oil, devoid of the energy necessary to bring it into the well bore, remain in the reservoirs of fields that have been depleted of their natural energy.

State conservation laws have been extremely helpful in furthering the application of improved producing practices, and the continuation of such laws is essential; those states which do not have such laws at present should adopt and effectively enforce them. However, the fullest attainment of technological advances requires more than compulsion by law; there must be an incentive on the part of industry and the individuals who compose it constantly to improve the efficiency of their operation. The dissemination of information and technical knowledge through the forum of industry societies should be continued, and a sound national oil policy should encourage the exchange of such information through the forum of the Interstate Oil Compact Commission. This state and Federal mechanism, if properly implemented by government and industry, can render great service to the industry and to the nation.

The recovery of oil from the deep-seated strata of the earth's surface is a highly scientific and complex problem. Great progress has been made in our knowledge of the behavior of these accumulations in the past quarter century, and in our knowledge of the factors which control the recovery of oil from the subsurface storehouses. There is every reason to believe that technological knowledge, if permitted to advance, will enable the recovery and utilization of a continuously greater proportion of these deposits in the future.

The technological advances which have been made in the United States can be directly attributable to the American way of life. Creativeness can not be forced or regimented but must be nurtured in the sunshine of free enterprise. A sound national oil policy requires that the atmosphere conducive to greatest technological development be preserved, as this is the great multiplier of our national resources.

Part 3. Refining Technology[1]

By Robert E. Wilson

Chairman of the Board, Standard Oil Company (Indiana)

Questions which have been raised in recent months as to the adequacy of our national oil reserves are naturally attracting much attention from our industry, from our customers the public, and from governmental authorities. Many things do need to be done, and promptly, to aid the industry in meeting the peak wartime demands, but before we become pessimistic as to the postwar outlook, let us take a broad view of both our natural and our technological resources, which are each so vital to the future of our country.

[1] Originally printed under the title, Technology as a Multiplier of Our Natural Resources, *Chem. and Eng. News*, American Chemical Society, May 25, 1944, vol. 22, p. 784.

The most convincing demonstration of our industry's faith in the future of petroleum is that since the outbreak of war the petroleum industry has invested about 525 million dollars of its own money in new refinery equipment to meet war needs. However, thoughtful men will want to know some of the logic and reasoning behind that demonstration of faith, and that is the purpose of the following discussion.

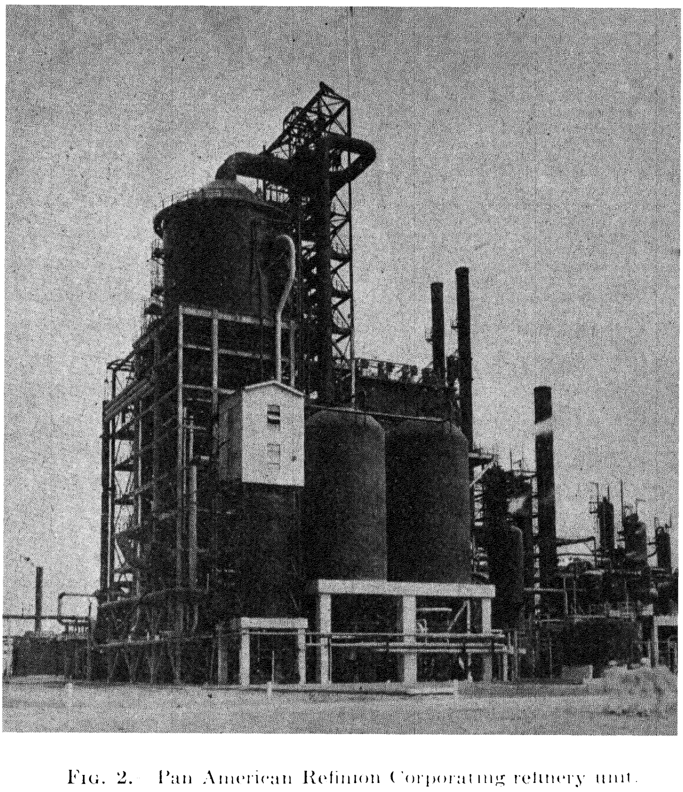

FIG. 2. Pan American Refining Corporation refinery unit.

This is by no means the first time that this country has been concerned about the future of its crude oil reserves. In fact the feast or famine characteristics of the petroleum industry before the general adoption of conservation practices in crude production caused it to be regarded for many years as highly speculative. To obtain a proper perspective, however, let us go back just 25 years to the end of the First World War.

At that time the industry was at the close of a period which had strained its resources. With the stimulus of war demands for crude oil and finished products, and prices at the refinery about double those prevailing today, the industry had sharply increased its production, expanded its refining capacity, and accelerated its search for new fields. Solid trainloads of gasoline had moved regularly from Wyoming to the Gulf coast for shipment to Europe, and a little later others moved from El Paso to California. The shortage of tankers was acute.

There was increasing concern then as now as to the adequacy of our oil reserves. In those days geologists did not follow the present practice of limiting their estimates to proved reserves, but were ambitious enough to endeavor to predict the total recoverable reserves underlying the whole country. In 1918 the current estimate of the total remaining recoverable reserves, made by the U.S. Geological Survey and concurred in by most other authorities, was less than 7 billion barrels, of which probably less than half constituted proved reserves in the modern sense. New discoveries at that time were small, and surface geology appeared to be approaching exhaustion as a method of finding new fields. Only by the importation of over 10 per cent of our crude supplies, mainly from Mexico, was the industry able to meet the heavy demands of the last year of the war. The common prediction was that crude production from the United States would reach a maximum in 1920 or 1921 at a figure around 400 million barrels per year and then gradually decline.

About that same time a top-ranking professor of chemical engineering in one of our leading universities published a book on shale oil in which he predicted that within 10 years oil shale would become our main reliance for oil. Several major oil companies bought up large oil-shale reserves. Walter Teagle, president of the Standard Oil Company (New Jersey), stated in 1920, "Domestic crude is not sufficient even for current home needs, and it is absolutely imperative that American petroleum producers proceed actively and intelligently to develop oil resources in foreign lands."

During these times our customers were increasingly concerned about the future quality and quantity of various products. While the average yield of gasoline from crude had been increased during the war from around 18 per cent to around 25 per cent, partly on account of the Burton thermal cracking process and partly because of raising the end-point of gasoline, the Burton process was approaching its apparent limit. The increasing end-point of gasoline was the cause of widespread complaint by automotive engineers and users because of hard starting, crank-case oil dilution, and excessive knocking even in the low-compression cars of that day. C. F. Kettering of General Motors told the American Petroleum Institute in 1920, "The only cloud on the internal combustion engine horizon today is the fuel supply, and there can be no doubt that the business public is apprehensive on that point." Economists advised against making investments which would be dependent upon the continuation of gasoline as cheap as 25 cents per gallon—and that was before the day of gasoline taxes! The elder LaFollette was soon to make his published forecast of $1 per gallon for gasoline. Others feared that the increasing diversion of kerosene into gasoline would force the farmers back to whale oil as their principal source of light. Still others predicted serious shortages of lubricating oil, as it was not then known how to make good lubricants from shale oil. No one even guessed that processes would soon be developed for converting either coal or natural gas into gasoline. There was considerable agitation for the nationalization of our industry and sharp limitation of consumption.

With this drab outlook, so reminiscent of many recent gloomy statements, let us see what has happened to that total recoverable reserve, which was estimated to be about 6.5 billion barrels. Since 1918 cumulative production has totaled 23.5 billion barrels. And yet we had at the end of this 25-year period really proved reserves in excess of 20 billion barrels of crude oil. The miracle of feeding the multitude with 5 loaves and 2 fishes, with 12 baskets left over, seems to have a modern counterpart! Small wonder that geologists have ceased trying to estimate any limit on the amount of oil which may yet be discovered.

During the same period our proved reserves of natural gas increased approximately sevenfold. In 1934 this country produced more than 4 times as much crude oil, more than 7 times as much gasoline, 13 times as much natural gasoline, and 5 times as much natural gas as in 1918.

Lord Curzon and others gave the petroleum industry a large share of credit for winning the previous war. However, our daily output of gasoline for military use in the Second World War ran about 18 times as great, and that of aviation gasoline about 80 times as great, as in the last year of the First World War, and the improvement in quality was equally amazing. In 1943, our nation supplied nearly 80 per cent of the war oil requirements of the United Nations, with crude production 7 per cent higher than in any previous year; and yet our proved underground reserves at the end of the year were only 0.1 per cent lower than at the beginning!

With such a record of achievement why should we today revert to a pessimism similar to that of 25 years ago, or revive proposals which would hamstring an industry and a system of free enterprise which has accomplished such results? Let us rather analyze what has happened since 1918 to bring about these results.

The dynamic factor which made these achievements possible has been improved technology resulting from research, and its application to every branch of the industry. This technology has not merely added to, but has in effect multiplied many-fold our available petroleum resources.

It is impossible in the space of this chapter to cover any large number of the many discoveries and inventions which have brought about the results referred to, but it does seem worthwhile to mention the major developments in each field that were largely unpredictable in 1918, but which were the inevitable result of intelligent research plus the spirit of enterprise that has always dominated the petroleum industry.

OUTSTANDING DEVELOPMENTS IN OIL-FINDING AND PRODUCING TECHNIQUES

Undoubtedly the greatest single factor in improving our oil-finding technique has been the development of geophysical methods of locating underground structures favorable for the trapping of oil. The gravity meter and the magnetometer, which respectively measure tiny variations in the gravitational or magnetic fields in a given area, have played a substantial part in finding and opening up new fields, but the largest contribution has been made by seismic methods which, by setting up earth waves and measuring their refraction or reflection, have accounted for nearly three quarters of the discoveries of new oil fields during the past decade, over most of which there were no surface indications of oil-pool structure. This was a tool not even dreamed of by the industry in 1918, though it is interesting to note that it came partly as the outgrowth of some scientific work on range finding to locate large guns carried out during the previous war.

Electrical logging has been another outstanding development of recent years. These devices, by measuring certain electrical properties of each stratum in newly drilled wells, make possible the determination of the position and probable content of even

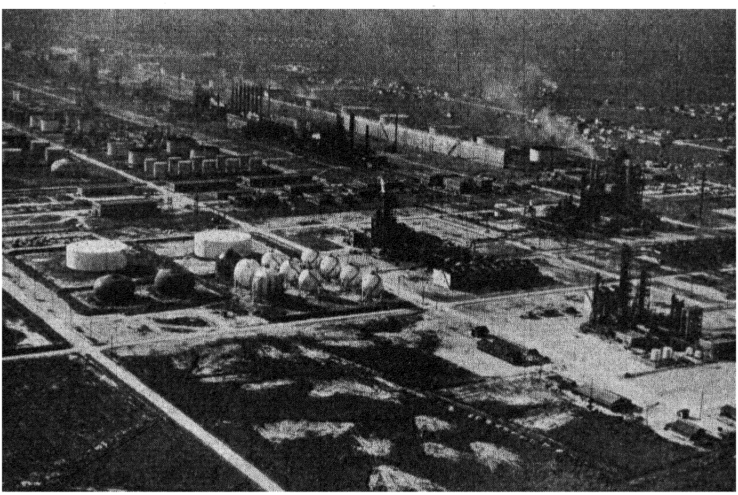

FIG. 3.—Texas City refinery of Pan American Refining Corporation.

thin sands. This tool minimizes faulty completions, permits far better correlation between wells to determine the nature and trends of the structure, and saves much time-consuming coring, which is especially important in drilling the very deep wells characteristic of today.

This deep drilling has been another important technical development made possible by a wide variety of improvements in steel, drilling-bit designs, mud circulation, and the improvement of rotary drilling. In 1918 the deepest well, considered to be about the practical limit, was 7,579 ft. Today the deepest well is just about twice this depth, and most of the important discoveries of the past few years have been made at depths below the 1918 limit of the drill.

Certainly it is not necessary to say more to demonstrate the fact that improved technique has served as a tremendous multiplier in the discovery and development of new oil reserves. Probably of equal importance, however, has been the development of improved producing technique, and particularly the practical elimination of wide-open methods of production. Typical fields operating according to production methods of 1918 normally recovered less than one-third of the oil in the sand. Today the industry and the state control authorities recognize the prime importance of limiting the flow of an oil field throughout its life to a figure which will avoid premature water intrusion or dissipating gaseous energy, and thus ensure maximum ultimate recovery of the oil in the sand. In some cases this involves an artificial water or gas drive to flush out the oil as completely as possible. Such procedures result in typical ultimate recoveries of approximately 75 per cent of the oil in the sand, again multiplying our recoverable oil resources. Similar methods are employed for the secondary recovery of large quantities of oil left in older depleted fields, though such methods are more costly and less effective than following proper production practices from the time a field is first discovered.

Considerable question has been raised with regard to the propriety of repeatedly revising upward the estimates of proved reserves in old fields, and such additions are sometimes discounted as mere pencil discoveries. However, many of these additions reflect the discovery of new horizons or extensions, and others reflect the proved result of better producing methods or secondary-recovery methods. Such figures therefore represent very real additions to the proved reserves on which we can definitely rely.

To summarize, it may safely be concluded that if we had to continue to rely on the 1918 techniques for discovery and the 1918 general practice in drilling and production, either our industry would be moribund or we would have been forced long ago to high-cost substitutes. In either case, neither the oil, automobile, or rubber industries could have enjoyed the tremendous growth which they have, and ours would not be a nation on wheels.

NEW TECHNOLOGY IN REFINING

Of equal importance from the standpoint of getting the most out of our natural resources have been the amazing developments in refinery technology since 1918. In this field there was an important forerunner visible in 1918 in the Burton thermal cracking process, which contributed substantially to the unprecedented yield of 25.3 per cent of gasoline from crude. More important than this was the fact that the development of the cracking process first awakened the refining branch of the industry to the realization that it was fundamentally a chemical industry, and that its future did not consist in merely taking just what came out of the ground and separating it for the markets. Large cracking royalties, whether received or paid, constituted the greatest stimulus to research any industry has ever known. In 1918 there were fewer than 200 technical men engaged in research in the petroleum industry. Compare this with today's figure of 8,000 to 10,000 and you see both the principal cause and one of the effects of the contributions of technology to our industry during the last quarter century.

Tremendous improvements in the art of cracking, beyond anything which could have been envisioned in 1918, steadily increased the yield of gasoline to around 45 per cent in 1941.

The outstanding development of recent years in this field is, of course, catalytic cracking, the giant towers of which dominate the landscape in most of our refining areas. The new art of catalytic cracking will probably exert as large an influence on the quantity and quality of future gasoline as did the original Burton thermal cracking process. If the catalytic units already built or building in the United States are to be used in such a way as to make a maximum yield of high-quality automobile gasoline without shutting down other cracking units, the average yield of gasoline from crude will be increased to about 57 per cent. As a matter of fact the only remaining limitation to the yield of gasoline obtainable from a barrel of crude by processes already fully developed is the public demand for other products whose economic value is close to that of gasoline—namely, kerosene, lubricants, and household fuels. Even without any change in individual product prices, this possibility should put a higher postwar value on every barrel of crude in the United States, because it will no longer be necessary to produce a large by-product of heavy fuel which would have to compete with coal. However, those uses of heavy fuel which can stand a moderate premium above the cost of coal will undoubtedly continue to be supplied either by the older type of refineries or by the importations of heavy foreign crudes for fuel.

Catalytic cracking is, however, only one of many processes which have made important contributions to the yield and quality of modern motor fuel. Polymerization processes now make pos-

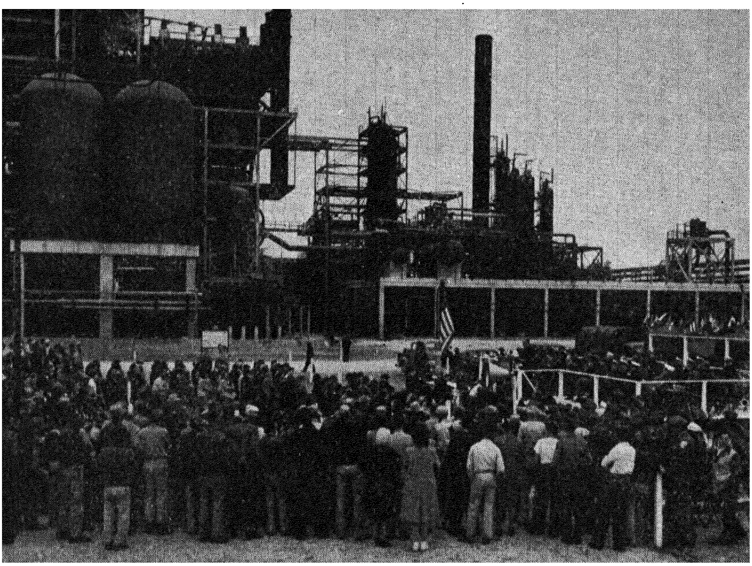

FIG. 4. Dedication ceremonies at fluid catalytic cracking unit, Texas City. (*Courtesy of Pan American Refining Corporation.*)

sible many thousands of barrels daily of high-quality gasoline from refinery gases which in the past were wasted or burned as fuel. By modifications these processes have contributed largely to the production of 100-octane gasoline. Alkylation is a brand-new development of the past few years which converts other gaseous constituents into high-quality gasoline. This reaction between isobutane and various olefins, while simple on paper, was not even considered possible a bare dozen years ago; yet today it is the backbone of our tremendous production of 100-octane gasoline. Hydroforming, hydrogenation, isomerization, and many other long-haired additions to the family of chemical processes used by our refineries came out of our research laboratories to make major contributions to the air superiority which was so largely responsible for our success in the war. Tetraethyl lead is another outstanding development of the past quarter century making for better antiknock gasoline. The single invention, tetraethyl lead, increased the available horsepower of the automobile engines made in the year 1941 by an amount equal to 75 Boulder Dams!

Owing largely, though not entirely, to improvements in the quality of gasoline and lubricating oil, the modern aviation engine is about 10 times as powerful, weighs about a quarter as much per horsepower, and has about 40 per cent greater thermal efficiency when compared with those of the First World War. These factors increased the load-carrying ability, range, and performance of military planes far beyond anything dreamed of even a dozen years ago. Similar improvements in motor gasoline have made possible increasing the average compression ratio of automobile engines by over 50 per cent—though most of this gain has been taken in the form of better performance rather than greater average mileage on the road. Technology has also been the principal factor in the general downward trend in costs and prices since 1918.

Despite the outstanding accomplishments of the new oil-finding and producing techniques which I previously mentioned, if it had not been for the developments in refining technique we would today have barely half enough crude oil to meet our gasoline demands, and the quality would be such that modern automobiles could not even operate, let alone modern airplanes.

WHAT OF THE FUTURE?

Of course, confirmed pessimists on reviewing these achievements can still say, "But these are all discoveries that have been made once and hence cannot be made again—whence will come our new methods of finding and refining petroleum?" The only answer I can give is that they will come from the same research and development organizations which have achieved these results during the past quarter of a century. I cannot predict even the nature of most of these coming developments, any more than could the scientists of 1918 have guessed at what we have seen, but I do know that we have about 50 times as many research workers as in 1918 and that they have not lost their ingenuity. Many important developments are bound to result from the scientific work of the Second World War just as occurred after the First World War Large new areas of potential oil territory are being intensively explored for the first time, and some already show real promise. Even larger areas in near-by countries have major potentialities of supplementing our own crude reserves as the need arises.

One possibility which seems certain to develop rapidly after the war is the synthesis of gasoline from natural gas, of which our proved reserves, measured as total heating value, are nearly as large as those of crude petroleum (though much of these gas reserves are earmarked for other purposes). Our known reserves of tar sands, oil shale, and coal are each enormously greater than those of oil, and better methods of handling and making refined products from these sources are certain to be developed. Even today we know how to make unlimited quantities of gasoline from each of these sources at prices lower than those prevailing after the last war, though large new investments would be required. Both investment and operating costs will undoubtedly be reduced substantially before the time these processes are really needed. Competent technical opinion assures us that given a few years of development, gasoline can be made in limited quantities from the richer oil shales, and in unlimited quantities from coal by the Fischer process, at costs not more than 5 cents per gallon above present gasoline costs! There is certainly far less present cause for concern as to future supplies of liquid fuels than there was in 1918, when we did not know that gasoline could be made from either natural gas or coal.

NEED FOR CONSERVATION AND METHODS OF ACHIEVING IT

Although I feel that all these factors afford adequate grounds for optimism as to the future of our industry and those dependent on it, I trust that nothing I have said will imply lack of need for increasing our efforts toward sound conservation practices in every branch of our industry. For one thing, technology not only has multiplied our available supplies of oil, but has also multiplied its uses as an essential raw material for making rubber, plastics, explosives, and dozens of other high-value products.

We must also never forget that, whatever our success in finding and using oil more effectively, our total underground reserves are undoubtedly being drawn upon. If we do not use effectively the means science has supplied to make conservation possible, we are not worthy of either the resources or the technology with which we have been so generously endowed. It is deplorable that some important producing states still do not have adequate conservation laws, and that an inflexible price policy is causing small wells to be shut down every week and preventing the introduction of secondary-recovery operations in many fields.

In the future, designers of automotive equipment should, and I believe will, place more emphasis on economy. To date most improvements in gasoline quality and engine design have been used to make possible roomier and heavier cars and more flashy performance, so there is much room for conservation in this field, especially in view of the better but probably somewhat more costly postwar gasolines. Slightly higher compression ratios, lower car weights, and more extensive use of automatic transmissions geared for economy could easily increase car mileage by 30 per cent without considerable increase in first cost or decrease in performance.

In view of the possibilities of catalytic cracking and hydrogenation, heavy fuel oil should probably no longer be sold on the basis of straight price competition with coal for large power installations, but where cleanliness, convenience, and labor saving are important, it can continue to be supplied as a by-product from noncatalytic cracking operations and by importation. The current shortage of household fuel has already stimulated more efficient use in most homes, and there seems to be no reason to doubt the adequacy of future supplies of this product.

Increasing importation of heavy fuel and asphaltic crudes seems desirable in order to keep our coastal industries and shipping supplied with heavy fuel at reasonable prices, and at the same time encourage American refiners to convert domestic crudes into maximum yields of gasoline and other light products. However, if such importation is to aid and not hurt the conservation of our own reserves, it must be managed so as not to keep domestic crude prices below the point which will encourage the search for new oil pools, the continued operation of stripper wells, and at the same time maximize secondary-recovery operations and many other conservation practices. Any sound national oil policy must recognize these essential facts, and be based on sound economies and technology rather than on political expediency.

THREATS TO THE FUTURE OF RESEARCH

To my mind the most serious and imminent danger to the future of our industry lies not in the possible shortage of satisfactory raw material, but in certain threats to the future of the very research and technology which is, as I have shown, the indispensable multiplier of our natural resources. Demands in certain quarters for regimentation and government domination of research, if yielded to, could easily devitalize our whole research program. Equally serious are the attacks on our patent system, without which we would lose much of the incentive to research, while most of those who did continue their research would revert to the dark ages of secret processes and cease prompt publication of their discoveries. Such action would tremendously retard the progress of science. A patent is primarily a reward for prompt and full disclosure, so that the whole scientific world can make progress in the light of the latest information in any given field. The resultant tempo of research and invention in America has made us the envy of the whole world.

Political attacks on patents urge that their abolition will aid small companies, but this overlooks three vital factors: Many of our most important companies could never have survived their early years had not patents given them protection from larger competitors who could otherwise have copied their inventions and outsold them, owing to being better known or having wider distribution. Many small companies could not finance their relatively large research programs and keep in the forefront of competition were it not for income received from licensing their patents to others. And third, many small companies prefer to minimize their own research and development expenditures and use whatever turn out to be the best processes developed by any of their competitors on a reasonable royalty basis, complete with all the know-how. Emasculation of our patent system would do far more injury to small than to large companies, as the latter could afford to continue their research regardless of patents and keep their important results to themselves as long as possible.

Were it my job as supersaboteur to destroy America's future greatness, I can think of no more effective way than to destroy our patent system. The tragedy is that if we permit impractical theorists and faddists to distort the facts and hypnotize our nation into this act of hara-kiri, all of us will suffer, and yet no adequate punishment can be meted out to those really responsible.

In other words, both the hope of, and the danger to, America lie more in the field of mind than matter. The only thing that can prevent our country from having abundant liquid fuel for many generations, and at reasonable prices—certainly much lower than those of 25 years ago—is interference with the free play of technology and competitive enterprise. I am still enough of an optimist to feel that sanity will prevail and that technology will be permitted to continue to function effectively as the multiplier of our natural resources.

CHAPTER V

OUR OIL AND NATURAL GAS RESERVES

Part 1. The Earth's Petroleum Resources[1]

By Wallace E. Pratt

Vice-president, Standard Oil Company (New Jersey)

From the earliest days of the petroleum industry America has been haunted by an uneasy conviction that the supply of this ever more indispensable commodity was soon to become inadequate. Recurrently, in times of stress like the present, these fears have agitated public opinion and have colored national policy. Yet only negative evidence supports the thesis that our petroleum resources are inadequate. Natural petroleum reservoirs are deeply buried in the earth. Until we discover their position by drilling wells into them and proving them, we cannot measure their volume. We know that our coal resources which we can see and measure aggregate thousands of billions of tons. Because our proved reserves of petroleum aggregate only a few billion tons at any one time, we assume that our total petroleum resources are of the same negligible proportions. Yet we have never made any effort to determine what the total petroleum resources of the earth amount to. Only in the United States has exploration been widespread, and even here it is far from complete. Elsewhere over the earth it has centered around a few regions where the presence of petroleum is already made obvious by natural seepages of oil or gas. The very conviction that little or no petroleum exists in the earth except at these few favored places seems to have deterred most nations from undertaking any search for petroleum. In spite of this attitude there is reason to believe that the ultimate petroleum resources of the earth are large—many times larger than the present proved reserves.

[1] Originally printed in *The Journal of Business*, New York, vol. XVII, No. 3 (1944), p. 129.

The problem society faces is the difficulty of finding and making available the undiscovered sources of petroleum on earth. An enlightened world oil policy would provide for a comprehensive exploration of the petroleum resources of the earth and the development of proved petroleum reserves to meet the world's needs. If the world really is short of petroleum we ought to know it. We could then plan to do without it. Only America and Great Britain have seriously undertaken the development of petroleum resources. Some of the principal difficulties in the way of such a program have escaped general recognition, although President Coolidge visualized them clearly as long ago as 1926, when he called upon the American petroleum industry, with the cooperation of the Federal Oil Conservation Board, to go out and set up proved reserves of petroleum in the ground, ready to be produced, and adequate for our needs over the long future.

To set up and maintain proved petroleum reserves is an enterprise which extinguishes itself automatically unless carefully shielded from the stifling influences generated by its own success. If it were not for our conviction that the welfare of society is menaced by the inadequacy of our petroleum resources, and the resulting urge to conserve these resources, we should probably refuse to consider the policies effective conservation demands. The nature of this problem and of these measures is described on later pages.

The long experience of the American petroleum industry in oil-finding, and the patterns of effective search and legal-economic balance it has designed in its effort to develop and conserve the petroleum resources of the United States, might well be woven into a larger fabric to spread over the earth at large. In the absence of some such integration of activities it will be difficult to sustain the development of petroleum reserves beyond the point of providing for the world's needs on a hand-to-mouth basis.

In the past the United States has supplied most of the oil the world has used. Over a period of 30 years, from 1860 to 1889 inclusive, we furnished 85 per cent of the world's consumption. Up to the end of 1943 about 64 per cent of the total had come from this country. Since 1860 only Russia has ever surpassed the United States in petroleum production, and her supremacy endured only over the last 4 years of the nineteenth century. How does it come about that our country has been the source of so large a part of the world's oil? Are our total supplies so much larger than those of other nations? Where are the principal petroleum resources of the world situated? Who owns them? How should we proceed best to secure our own future needs for petroleum?

If we are to pursue these inquiries, it will be helpful at the outset to establish a few reference points from which we can proceed without becoming confused. The history of the petroleum industry goes back about 87 years. While we like to believe that the world's commercial production of petroleum began with the completion of Colonel Drake's first well at Titusville, Pa., in 1859, it is probably more realistic to concede that Rumania's production of about 2,000 bbl. in 1857 marked the inception of the modern industry. Canada first produced oil commercially in 1862; Russia, in 1863.

The world's total consumption of petroleum through 1943 amounts to about 44 billion barrels; and the 1940 rate of world consumption was somewhat more than 2 billion barrels a year, or roughly 6 million barrels daily. The United States alone has consumed about 28 billion barrels of petroleum so far, and its domestic consumption in 1940 was 1.3 billion barrels, or 3.6 million barrels daily. Thus we have been by far the largest consumer of petroleum among the nations as well as the largest producer, with a total consumption approximately equal to our own total production.

War has again made us conscious of the utter dependence of modern society upon petroleum and has again aroused anxiety over the adequacy of our future supplies. Both world wars have been fought with American oil. Eighty per cent of all oil used by the combined forces of the United Nations up to about the first of January, 1944, was furnished by the United States.[1] In the earlier war

> . . . . all sources of oil supply controlled by English, Dutch and French interests, including the Admiralty's supply in Persia, had proved insufficient. "A failure in the supply of petrol would cause the immediate

[1] Brewster, Senator Ralph O., *The Petroleum Policy of the United States*, press release of an address delivered at Baltimore, Md., Dec. 1, 1943.

paralysis of our armies. . . . . The indispensable stock has fallen today to 28,000 tons and threatens to fall to almost nothing if immediate and exceptional measures are not taken and carried out by the United States. . . . ," Clemenceau once declared. Critical shortages for the French armies on the Western Front and the British Grand Fleet had been met by American supplies poured into Europe in response to Clemenceau's and Balfour's appeals to President Wilson and to the oil companies. The British government through Lord Northcliffe, then Chairman of the British War Commission in the United States, addressed its appeals directly to the Standard Oil Company, which responded promptly. To quote his words: "The people started right in there, the oil is pouring across the Atlantic with great strides and at a lower price than we have averaged over here. They could have squeezed millions out of our trouble if they had chosen. When I thanked them, they merely remarked, 'It's our war as well as yours.' "[1]

Unfortunately it is not possible to state the total volume of the earth's petroleum resources; we know only the estimated volume of the proved reserves, that is, the petroleum remaining to be recovered from the natural reservoirs already discovered, explored, and developed by wells. Geologic or scientific research alone has never actually discovered or proved any petroleum reserves for us. Only by drilling wells are we able definitely to establish proved reserves.

Because our exploration of the petroleum resources of the earth is so far from complete, our proved reserves are small in comparison with the probable total of these resources. Yet the volume of our proved reserves is the yardstick most commonly relied upon to measure our supply of petroleum for the future. Generally accepted estimates sponsored by the American Petroleum Institute fix the proved reserves of the United States on Dec. 31, 1943, at 20 billion barrels. The proved reserves of the rest of the world are variously estimated. Recently E. L. De Golyer[2] and the Petroleum Administrator for War have placed them very conservatively, I think, at 31 billion barrels, making a world total of 51 billion barrels. If we divide the amount of the proved reserves in the United States by our annual consumption, we obtain the frequently cited figure of

[1] Feis, Herbert, "Petroleum and American Foreign Policy," Stanford University, Calif., Food Research Institute, 1944, p. 5.

[2] Report to Harold M. Ickes, President, Petroleum Reserves Corporation, Washington, D.C., *Jour. of Commerce*, New York, Mar. 14, 1944, p. 10.

only 15 years' future supply of petroleum. In the same way the future supply for the world may be calculated to be equivalent to world needs for about 25 years. Thus, if we accept proved reserves as a measure of our future supply, we may well be alarmed. But are we logically justified in accepting this criterion?

Petroleum is a mineral fuel—solid, liquid, or gaseous in form—consisting of many different compounds of hydrogen and carbon (hydrocarbons) in complex mixture. It is widely disseminated in the earth's crust, and it exudes from the earth's surface as natural seepages at many places. Its observed occurrence is almost exclusively confined to the marine sedimentary rocks (rocks formed through the slow compaction and hardening of mud, sand, and dust carried into the sea from the adjacent lands by streams and winds, and deposited as sediments on the sea floor). Because of its constant association with these rocks and because of the facility with which the organic matter of marine sediments can be converted into hydrocarbons both in nature and in the laboratory, petroleum is usually considered to have its origin in the organic matter of marine sediments. It is well established, however, that hydrocarbons are present in the stony meteorites which come to us from space,[1] and astronomers have identified methane, the most common hydrocarbon of petroleum, in the atmospheres of the planets Saturn and Jupiter, where it appears to be present in abundance. It is not surprising therefore, that hydrocarbons are widespread in the earth's crust.

Time after time in the past, the seas have spread over the margins and even the central parts of each of the continents. Into these seas great loads of sediments have been carried by streams flowing off the lands which still stood above sea level. When the continents reemerged from the sea, these sediments became dry land and hardened into rock. Marine sedimentary rocks of this character constitute more than one-third of the land surface of the earth, forming a total area of 22 million square miles. The United States alone, with a total area of 3 million square miles, includes 2.4 million square miles of sedimentary rocks. Of this area, however, only about 60 per cent (1.4 million square miles) may be expected to contain oil fields;

[1] Clarke, Frank Wigglesworth, "The Data of Geochemistry," Washington, D.C., Government Printing Office, 1924, p. 746.

the remainder (1 million square miles) is eliminated from consideration for various reasons: the original organic content was too low; or the deformation and induration subsequent to deposition have been so severe as to destroy the pore spaces of the rocks along with whatever petroleum they may have contained.

While almost any porous rock layer contains some petroleum, experience has taught us to expect large accumulations in sediments that were deposited rapidly and in great thickness. Rocks which are known to conform to these specifications form an aggregate area of nearly 1 million square miles in the United States and of about 6 million square miles over the earth as a whole. Thus the land area already known to be distinctly favorable for petroleum totals about 6 million square miles, 15 per cent of which lie within the United States.[1]

Sediments accumulate in sufficient thickness to house large petroleum reservoirs only where the sea floor on which they are laid down subsides as the load increases; otherwise, the sea fills up and sedimentation comes to an end before the requisite thickness is attained. Parts of each of the continents have been covered by seas of this character in the past. Unusually favorable were those depressed mobile sectors of the earth's crust which lie between the main continental land masses. Throughout much of geologic time these intercontinental depressions have been occupied by landlocked seas, as, indeed, they are today. Over long periods these seas have teemed with marine organisms, which upon dying were promptly carried to the bottom and buried in the flood of sediments pouring in from the adjacent lands. These are the conditions which, we believe, give birth to petroleum.

If we examine the intercontinental depressions now marked by landlocked seas on earth, we are confronted at once with our principal petroleum provinces. For example, the Mediterranean region of the Old World—low-lying lands (parts of them even below sea level) surrounding the Persian Gulf, the Black, Caspian, and Red seas and the eastern end of the Mediterranean Sea—a depressed, uneasy sector of the earth's crust, caught between the continents of Africa, Europe, and Asia. Here are the

[1] These areas have been compiled by my associates, Eugene Stebinger and L. G. Weeks, "Oil in the Earth," University of Kansas Press, Lawrence, 1942, p. 47.

tremendous oil fields of the Middle East—those of Iran, the adjacent U.S.S.R., Irak, and Arabia. If we accept the conservative estimates of De Golyer, the Middle East alone, excluding the U.S.S.R., contains more than 30 per cent of the world's proved reserves of petroleum.

In the Western Hemisphere a great basin occupied by the Gulf of Mexico and the Caribbean Sea lies between the continents of North and South America. The lands which border these waters rank second among the petroleum provinces of the earth, both in proved reserves and in promise for future discoveries. The intercontinental seas of which the Caribbean and the Gulf of Mexico are remnants covered the entire northwestern lobe of South America prior to the uplift of the Andes Mountains, which only a short time ago (geologically speaking) elevated the former sea floor into a succession of mountain ranges, plains, and valleys. This province includes, therefore, Peru, Ecuador, and the adjacent parts of Brazil, as well as Colombia, Venezuela, and Trinidad. This province includes also Central America, the West Indies, Mexico, and, in our own country, the states of Florida and Louisiana, together with parts of Georgia, Alabama, Mississippi, Arkansas, and Texas.

There are already many important oil fields in the environs of the Gulf of Mexico and the Caribbean Sea. In past production and in its present producing rate this province surpasses even the Near and Middle East (excluding the U.S.S.R.). Exploration is further advanced in the Western Hemisphere than in the Near and Middle East, however; and, although neither province has been explored with any degree of thoroughness, the Middle East appears to offer better chances for additional discoveries susceptible of low-cost recovery.

Another region which has already furnished a significant part of the world's petroleum and promises to become a more important producer in the future is situated in the Far East. It includes the great islands of the East Indies—New Guinea, Java, Sumatra, and Borneo—which rise out of the shallow landlocked waters between the continents of Asia and Australia. On these islands British and Dutch companies have been producing oil for 50 years. American oil companies established themselves there much later but now occupy a position which approaches that of each of the other two nations. Exploration of this region is still in its initial stages, and the potentialities for future production are not generally recognized.

There remains to be noted a fourth region of landlocked intercontinental seas which may yet become one of the earth's important petroleum provinces, namely, the lands surrounding the Arctic Sea. We Americans usually think of the waters covering the North Pole as the Arctic Ocean. We designate them as an ocean on our maps, but they really constitute a sea, lying between, and all but surrounded by, the continents of North America, Europe, and Asia. Throughout most of geologic times, sediments have been dumped into the Arctic Sea by the rivers draining each of these great land masses. Only the forward-looking Russians have made much effort to explore the petroleum possibilities of the Arctic, notwithstanding the fact that conspicuous seepages of oil and gas mark northwestern Canada, northern Alaska, and at intervals the entire northern coast of Siberia. In this region, therefore, we have a zone 4,500 miles in length which is studded with seepages of oil and gas. Despite all this surface evidence of the presence of petroleum, the only persistent effort to develop a source of petroleum in the Arctic of the Western Hemisphere has been confined to the vicinity of Fort Norman on the lower Mackenzie River in the Northwest Territory of Canada, where a major oil field has been proved.

These four regions—the Near and Middle East in the Old World; the environs of the Gulf of Mexico and the Caribbean Sea in the Western Hemisphere; the Dutch and British East Indies in the Far East; and the lands fringing the Arctic Sea in North America, Europe, and Asia—are the most promising parts of the earth in which to search for petroleum. Each of these regions is known to include large areas of sedimentary rocks; each of them consists of rocks that normally contain petroleum accumulations; each of them is characterized by seepages of oil and gas at the surface. Two of them are already established as outstanding petroleum provinces, and the other two promise to become of first-class importance when fully explored.

In the natural distribution of petroleum in the earth's crust, as revealed by the geographical position of the four great petroleum provinces, there is a striking accommodation to the principal centers of population and consumption. The most imposing province, the Near and Middle East, is conveniently placed to serve the great industrial population of Europe as well as the peoples of Africa and Asia. The Soviet Union has her own indigenous sources of supply. North and South America both may draw expeditiously on the Caribbean–Gulf of Mexico region. In the Orient the resources of the East Indies are centrally located between Australia and Asia. To the peoples of both hemispheres the potential resources of the Arctic will be available as civilization moves northward.

There are numerous minor basins of sedimentary deposition on the continental shelf around the margins of all the continents. The seas which filled these basins have at times extended far inland, and in the rocks formed in these old seas much petroleum has been discovered. The important oil fields of California and of the interior basins of the Mississippi valley are examples, as are also the oil fields of Bolivia and Argentina in South America; of Germany and Poland on the margin of the Baltic Sea; of Austria and Hungary in central Europe; of Burma; and of Japan, Sakhalin, and Kamchatka around the seas of Japan and Okhotsk off the Pacific coast of northeastern Asia. In central Siberia and in northwestern China are other interior basins, the rocks in which are known to be petroleum-bearing. Outside of the United States, however, these smaller basins remain largely unexplored and so far have yielded but a small part of the world's petroleum.

Table 1 shows (in percentages of the world's total) the past production, the current rate of production, and the proved reserves of these and other producing regions, nations, and peoples.

Let us review briefly the positions of the three leading nations—the United States, Great Britain, and the Soviet Union—as to petroleum resources. Still dominant but gradually yielding its commanding position as a world producer, the United States holds within its own borders nearly 40 per cent of the world's proved reserves of petroleum. In addition, the interests of American nationals comprise 25 per cent of the proved reserves of other countries. Included in these foreign holdings of Americans are about one-third of the proved reserves of the Middle East (excluding U.S.S.R.) and about 70 per cent of those of

TABLE 1.—APPROXIMATE DISTRIBUTION BY COUNTRIES AND REGIONS OF WORLD'S TOTAL PAST PRODUCTION, CURRENT (PREWAR) RATE OF PRODUCTION, PRESENT PROVED RESERVES, AND PROBABLE TOTAL RESOURCES OF PETROLEUM[1]
(In percentage of world total)

Country or region	Production, per cent		Proved reserves		Total ultimate resources,[2] per cent
	Past total	Current rate	In billion barrels	Per cent	
United States	64	62	20.0	39	15
U.S.S.R.[3]	12	10	5.7	11	
Venezuela	6	10	5.6	11	
Mexico	5	2	0.5	1	
Iran, Iraq, and Arabia	4	7	16.0	31	
East Indies	3	3	1.0	2	
Rumania	2	2	0.5	1	
All other countries	4	4	2 0	4	
Eastern Hemisphere	23	24	29.6	58	65
Western Hemisphere	77	76	21.4	42	35
Near and Middle East[4]	7	10	19.0	37	
Gulf of Mexico–Caribbean[5]	32	41	16.3	34	
Far East	4	4	1.0	2	
American interests		72	28 0	55	
British interests		12	12.7	25	
Soviet interests		10	5 7	11	

[1] This table adopts De Golyer's estimate of 51 million barrels of proved reserves.

[2] A mere surmise based solely on the distribution of areas known to be favorable for petroleum.

[3] Before the Second World War, Soviet authorities claimed to possess proved reserves of petroleum about eight times as large as this estimate. If this claim were accepted, the U.S.S.R. ownership would amount to 50 per cent of the world's proved reserves.

[4] Excluding U.S.S R.; including Iran, Iraq, Arabia, Kuwait, Qatar, Bahrein, Rumania, and Egypt.

[5] Including the northern margin of the Gulf of Mexico in Mississippi, Louisiana, Arkansas, and Texas; all of Mexico, Colombia, Eucador, Peru, Venezuela, and Trinidad; and excluding that part which lies within the United States, the Gulf of Mexico-Caribbean region contains about 15 per cent of the world's proved reserves.

the Caribbean–Gulf of Mexico region. American interests at home and abroad, therefore, hold 55 per cent of the world's proved reserves, from which they were supplying 72 per cent of the world's needs when the present war broke out.

The United States is fortunately situated in relation to the petroleum resources of the Caribbean–Gulf of Mexico region and will also share largely in whatever petroleum reserves are developed in the Western Hemisphere sector of the Arctic province. Within the borders of our sister nations to the south—Mexico, Colombia, Brazil, Ecuador, and Peru—we have identified great sedimentary basins, marked by seepages of oil and gas, which are all but unexplored, although similar adjacent basins already contain important oil fields. Without industrial resources, which Americans are particularly well qualified to supply, such as oil-field experience and machinery, organization, technical skills, and capital, the development of these resources must be long delayed. Shall we not, under agreements which safeguard the national interests of our neighbors, place at their service our special qualifications for making these resources available for the common good? Surely it would be mutually advantageous if Latin Americans sent to us any exportable surpluses of petroleum which may be developed in their countries in exchange for our manufactured goods.

Our stake in the petroleum resources of the Arctic is Alaska, which includes a large part of the most promising area and some of the most impressive oil seepages. Thousands of square miles surrounding oil seepages near Point Barrow on the extreme northern coast of Alaska were set aside more than 20 years ago as a petroleum reserve for the United States Navy. An adjacent, even larger, and equally promising area is controlled by the Secretary of the Interior. Alaska is almost virgin territory as far as well drilling is concerned. Therefore it finds no place in any present compilation of the earth's proved reserves of petroleum. Nevertheless, exploration in Alaska will almost certainly prove the existence of large reserves. If America finally determines upon a policy of setting aside large underground reserves of petroleum, to be developed and maintained unused, Alaska might well be made one center of such proved reserves.

British interests hold about 60 per cent of the proved reserves of the Middle East and about 25 per cent of the total proved reserves of the world. Jointly with the Dutch, the British hold about two-thirds of the proved reserves of the East Indies and perhaps one-quarter of those of Latin America.

While the U.S.S.R. has furnished only 12 per cent of the world's past production and holds only 11 per cent of the world's proved reserves, it possesses within its own borders more imposing potential resources in petroleum than any other nation. Its proved reserves are small (as we estimate them; Soviet engineers claim much larger proved reserves), and its capacity to produce is even less adequate (600,000 bbl. daily before the war, as compared with 4 million barrels daily in the United States); but these deficiencies result from lack of development. The aggregate area characterized by seepages of oil and gas in the U.S.S.R. is immense; it includes a major part of both the Middle East and the Arctic petroleum provinces. The Soviet Union's principal oil fields are situated on the shores of the Caspian Sea in the Middle East, and much prospective territory remains to be developed in this region. But other oil fields mark the flanks of the Caucasus Mountains, and still others mark the western flank of the Urals, in a northward-trending zone that reaches clear to the Arctic coast, a distance of 1,500 miles. Throughout Siberia there are evidences of petroleum: natural seepages along the Arctic coast in northern Siberia and at many places in the great basin drained by the Lena River in eastern Siberia; partly developed oil fields on Kamchatka Peninsula and Sakhalin Island on the shores of the Sea of Okhotsk in the Far East; and, finally, abundant evidences of oil and gas over a distance of more than a thousand miles through Turkestan and along the southern border of Siberia. In all these regions Soviet engineers were engaged in exploration and development work when the war broke out, apparently bent upon making the U.S.S.R. self-sufficient as to liquid fuels.

The position of the Soviet Union illustrates the fallacy of citing proved reserves as a measure of available future supplies in the present state of development of the earth's petroleum resources. With far smaller proved reserves than the United States, the Soviet Union is at the same time generally conceded to be more nearly self-contained as to petroleum than any other nation. Her position illustrates the fact that so large a part of the probable petroleum resources of the earth remain still undeveloped that the volume of the proved reserves has little significance.

Our own experience in attempting to gauge our future supplies by the size of our proved reserves here in the United States is eloquent. In February, 1882, Samuel Wrigley, speaking before

TABLE 2.—OFFICIAL ESTIMATES OF PROVED PETROLEUM RESERVES IN THE UNITED STATES
(In billion barrels)

Year	Total prior production	Estimated reserves	Subsequent actual production plus present proved reserves	Authority
1922	6	5	42	David White, chief geologist United States Geological Survey; American Association of Petroleum Geologists (joint report)
1926	9	4.5	39	Federal Oil Conservation Board
1932	15	10	33	Federal Oil Conservation Board
1944	48	20	.	Petroleum Administrator for War

the Institute of Mining Engineers, estimated the total remaining reserves of petroleum at 96 million barrels and declared: "It is only necessary to add that the present yearly output is over 25 million barrels. . . . . Some day the cheque will come back indorsed 'no funds'; and we are approaching that day very fast." Wrigley's pioneer estimate was succeeded by a long procession of similar predictions. Table 2 shows several official estimates of proved reserves issued over the last 25 years.

It is worthy of note that our proved reserves as recorded in these estimates have increased rather uniformly over the period, in spite of our growing consumption. But at no time have the estimated reserves constituted more than a fraction of the petroleum already consumed or added to proved reserves subsequent to the date of the estimate. In 1926 our proved reserves were officially estimated at only 6 years' requirements. Even as late as 1932, the Federal Oil Conservation Board placed our proved reserves at less than one-third of the amount we have already used or added to proved reserves since that date.[1]

[1] David White, chief geologist of the United States Geological Survey, writing on The Petroleum Resources of the World, *Annals of the American Academy*, 1920, pp. 1–2, estimated the total "quantity of oil remaining available in the ground in the United States in January, 1919," at 6.7 billion barrels. In making this estimate, which included both proved reserves and resources still remaining to be discovered, White conceded that it might well

If, then, we discard proved reserves, what evidence can we cite as an index of the amount of petroleum that will be available to us in the future? Probably the best guide we have is a projection into the future of the trends established by our past experience in the search for petroleum. Over the last 85 years we have drilled more than a million wells in the United States. Of the purely exploratory wells drilled, from 10 to 15 per cent were successful in finding petroleum in commercial quantities. Of the total area definitively tested by drilling, from 1 to 2 per cent proved to be commercially productive of petroleum.[1] In some favorable sedimentary basins the productive portion is more than double this average.

The job of exploring the petroleum resources of the United States is not more than half completed. Large areas remain still undrilled; other areas already producing have yet to be explored at greater depth. At worst the average yield from the future exploration should be as large as that from the past. If in the end the entire area of promising sedimentary rocks in the United States were to be definitely tested by drilling, future discoveries of petroleum should at least equal past discoveries. These conclusions would make the ultimate petroleum resources of the United States of the order of 100 billion barrels, more than 60 per cent of which still remains in the earth.

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be in error by as much as 25 per cent; but he added: " . . . . it is highly improbable that the error is more than 50 per cent. An error of 75 per cent seems so improbable as not to justify serious consideration at present." Yet since 1919 we have consumed 23 billion barrels; and we now have in proved reserve another 20 billion barrels—a total of 43 billion barrels, already more than six times greater than the estimate! David White was a well-informed, competent scientist, deeply concerned over many years with the welfare of the petroleum industry. But like many of the rest of us he grossly underestimated the amount of oil in the earth. In commenting further on his 1919 estimate, he said: "Petroleum in the United States is a wasting asset. It is so far depleted as no longer to afford a secure foundation for the obligations based upon its assumed continued adequacy. Barring unexpected good fortune in the search for new supplies or even less expected curtailment of consumption, our petroleum production is likely not only never again wholly to meet our requirements but even to start soon on the long decline of a waning output." At the time this statement was issued the petroleum industry generally shared the views it expressed.

[1] Stebinger, E., and L. G. Weeks, *op. cit.*

TABLE 3.—PETROLEUM RESERVES OF PRINCIPAL PRODUCING COUNTRIES[1]

Country	In thousand barrels	Ownership in nationals[2]
North America:		
United States		
District 1 (East)	254,700	
District 2 (Central and Mid-Continent)	2,130,401	
District 3 (Gulf coast, including New Mexico and Arkansas)	14,006,273	
District 4 (Rocky Mountains)	495,573	
District 5 (Pacific coast)	3,195,846	
Total	20,082,793	United States
Canada	150,000	Canada, United States
Mexico	600,000	Mexico
Total, North America	20,832,793	
South America:		
Venezuela	5,600,000	United States, Great Britain
Colombia	500,000	United States
Peru	135,000	United States, British, Peru
Ecuador	45,000	British
Argentina	168,000	Argentina, British, United States
Bolivia	45,400	Bolivia
Brazil	1,000	Brazil
Trinidad	239,600	British
Total, South America	6,734,000	
Europe:		
Germany (including Austria)	68,700	Germany and United States
France	11,000	France
Italy	1,000	United States and Italy
Albania	41,000	Italy
Poland	30,000	Diverse European interests and United States
Rumania	392,000	Great Britain, United States and France
Hungary	75,000	United States, Germany, Hungary
Czechoslovakia	1,200	Czechoslovakia
U.S.S.R.	5,735,000	U.S.S.R.
Total, Europe including U.S.S.R	6,354,900	
Asia:		
Iran	5,000,000	Great Britain
Iraq	4,000,000	United States, Great Britain, France
Kuwait	4,000,000	United States, Britain
Saudi Arabia and Bahrein	2,000,000	United States
Qatar	500,000	United States, Great Britain, France
Total, Middle East	15,500,000	
India and Burma	167,400	Great Britain
Japan	36,000	Japan
Netherland East Indies	950,000	Great Britain, United States, Netherlands
Total, Asia	16,653,400	
Africa:		
Egypt	86,000	Great Britain
Total, Africa	86,000	
Other countries unspecified	41,500	
Total world petroleum reserves	50,701,800	

[1] Estimated by Petroleum Administration for War. Report of Subcommittee concerning investigations overseas; Sec. 1, Petroleum Matters, special United States Senate committee (Truman Committee) investigating the national defense, United States Government Printing Office, Washington, D.C., 1944, p. 8.

[2] This column shows prewar ownership. Naturally these lines of title have been cut in Axis-controlled countries in time of war. Generally speaking, only owners of substantial portions of the respective fields are given.

In the past we have assumed because we produced most of the world's petroleum that our resources are unusually rich and that we have been blessed by nature with greater natural stores of petroleum than other nations. Today we realize that this is not true; the truly rich petroleum resources of the earth, so far as they have been discovered, lie outside our boundaries. We have nothing to compare with the Middle East, or even with Venezuela, for example. When we review the evidence, it seems probable that the average petroleum content of the sedimentary rocks in the United States is about the same as that of the rest of the world.

Exploration for petroleum in the United States is extensive enough to make its findings significant. It has proceeded far enough to indicate what volume of petroleum may be discovered on the average by intensive drilling exploration of the sedimentary rocks of the earth. If we accept our oil-finding experience in the United States as representative, then the ultimate petroleum resources of the rest of the earth should amount to about 600 billion barrels. In other words, some 15 per cent of the area of the sedimentary basins of the earth known to be favorable for the occurrence of petroleum lies within the United States. On the same basis one would conclude that about 35 per cent of the earth's total petroleum resources lies within the Western Hemisphere.

In the face of this experience in oil finding, the present climate of opinion in the United States is again disturbed with fears that within a few years our petroleum resources will be exhausted. This opinion holds that while we were mistaken in our fears at the end of the First World War, now at last the end is really in sight. Apart from the small bulk of our proved reserves in proportion to our future needs, the principal basis for these fears is the slump in oil-finding achievement over the last 15 years. Our recent annual discoveries of new reserves are smaller than they were in the late 1920's. This reduced discovery rate is interpreted as proof that little or no petroleum remains to be discovered.[1]

[1] Petroleum and coal are related mineral fuels. Although they occur in the earth under very different conditions, both may be looked upon as the fossil sunlight of 2 billion years of earth's history. In coal, the residue of land plants, we have preserved for us part of the energy of the sunlight which

It is undeniable that the task of oil finding in the United States becomes increasingly difficult as time goes on. Fewer oil fields remain to be found each year, and the search must be stimulated and kept vigorous if it is to meet our growing needs. But the decrease in the volume of petroleum discovered since 1930 can be explained on other grounds than exhaustion of resources; we have not sustained the effort to find oil which we once put forth.

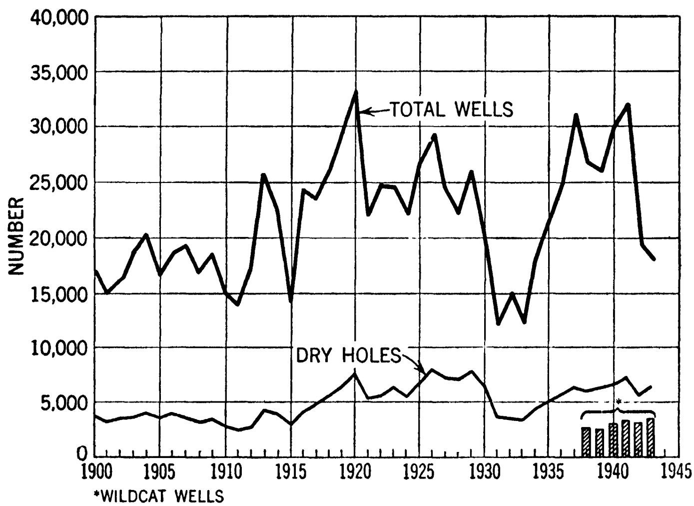

FIG. 1.—History of drilling activity in the United States.

The tempo of our exploratory activities has not yet regained the rapid pace which it assumed under the spur of high crude-oil prices after the close of the First World War, until the depression of the early 1930's slowed it down. It was inevitable under these circumstances that the volume of new discoveries should decrease, however much petroleum remains to be found.

The history of oil finding in the United States is reflected in the accompanying graphs. Figure 1 is a record of drilling activity of the American petroleum industry by years since 1900.

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bathed the old land; in petroleum we recapture the energy of the sunlight which fell upon the adjacent waters. Our proved reserves of coal we estimate confidently at some 7,500 billion long tons. Of petroleum we have proved reserves of less than 10 billion long tons. Ought we to assume under these circumstances that our total petroleum resources are so much smaller than our coal? Was the life of the old seas so meager compared to that of land?

We have found our oil fields in this country, in the last analysis, by drilling wells into the oil-bearing rocks. As a geologist, I should like to believe that science is responsible for our success in oil finding; but in fairness most of the credit must be allotted to the driller: his wells actually find our oil. For a generation Americans have gone about over their country drilling thousands of wells every year in search of petroleum. Many of these wells fail to encounter petroleum. These failures we call dry holes;

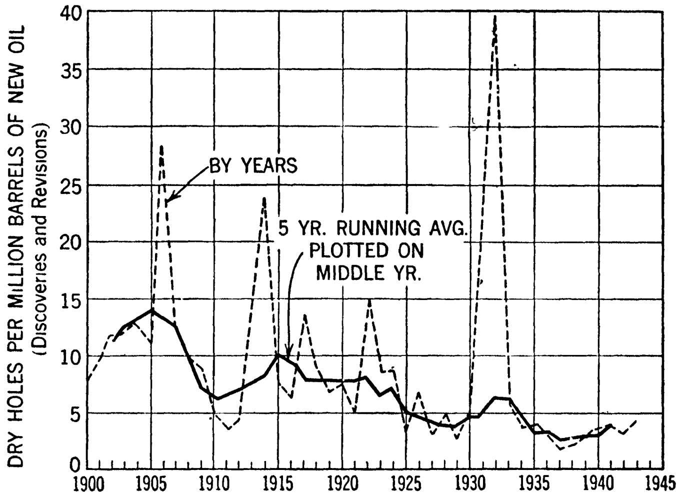

FIG. 2.—Dry holes per million barrels of new oil in the United States (discoveries plus revisions).

the more energetic our search the more dry holes we drill each year.[1] Figure 2 shows that we drilled a greater number of dry holes annually during the 1920's, when we energetically sought to replenish (and succeeded) our shrinking petroleum reserves, than we have drilled annually since 1930.

The relative success of our exploratory effort is indicated by the volume of petroleum we find for each failure we drill. Figure 2 shows this record by years since 1900. Rather uniformly since 1905, with lapses during the First World War and the recent

[1] Many dry holes are drilled on the edges, or even within the boundaries, of our producing oil fields. A special class of exploratory wells, drilled at locations remote from any producing well, are called wildcats; the record of wildcat drilling is incomplete and goes back with any accuracy only to 1935. About 85 per cent of all wildcats have been dry holes.

depression, we have drilled fewer and fewer failures for each unit added to our proved reserves.

The truth is that the success of our finding effort has itself retarded our activity. For 15 years our principal oil fields in the United States have been pinched in, their flow drastically restricted, because the market would not absorb their output. Year after year, posted prices for crude oil hung at about one-third their 1920 levels. Over this period, state and Federal authorities painstakingly prorated the available market outlet among the distressed producers. The industry, which found it necessary to import 400,000 bbl. per day in 1922 to meet its

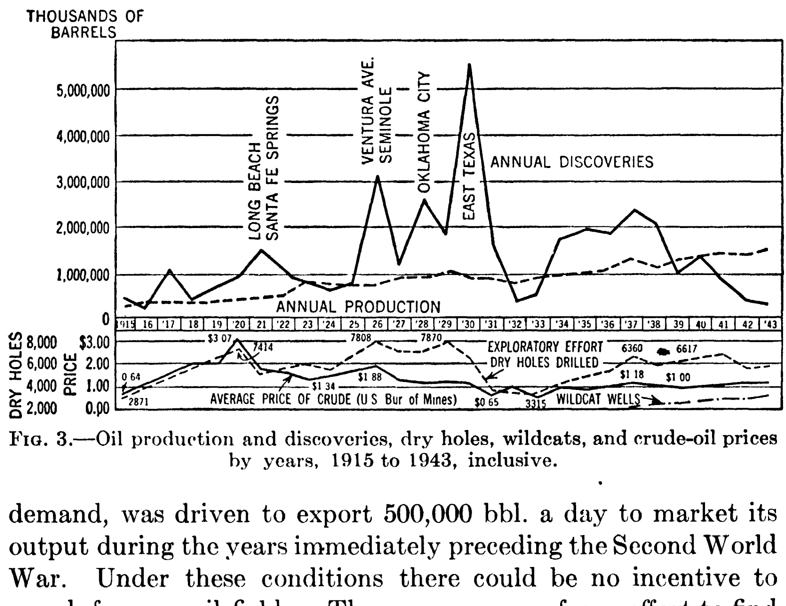

FIG. 3.—Oil production and discoveries, dry holes, wildcats, and crude-oil prices by years, 1915 to 1943, inclusive.

demand, was driven to export 500,000 bbl. a day to market its output during the years immediately preceding the Second World War. Under these conditions there could be no incentive to search for new oil fields. The very success of our effort to find stifled that effort. Figure 3 shows our annual discoveries and our annual production of petroleum since 1915, together with the dry holes and wildcat wells over the years for which this record is available. Along with the finding effort, a record of the average posted crude-oil prices is shown. Here again are reflected our decreased finding effort and our concurrently decreased volume of annual discoveries.

In considering estimates of the volume of petroleum discovered annually it is necessary to discount heavily the figures for recent years. The record reveals that estimates of proved reserves are almost invariably revised upward as each field develops following discovery. In the average case the estimate has doubled by the end of the fourth year after discovery. The unusually low values for the discoveries of the last 3 years, as shown on Fig. 3, should be viewed with this reservation in mind. They will undoubtedly be revised upward, as previous estimates have been.

The search for new oil fields in the United States has been seriously retarded over the last 15 years by the low average price

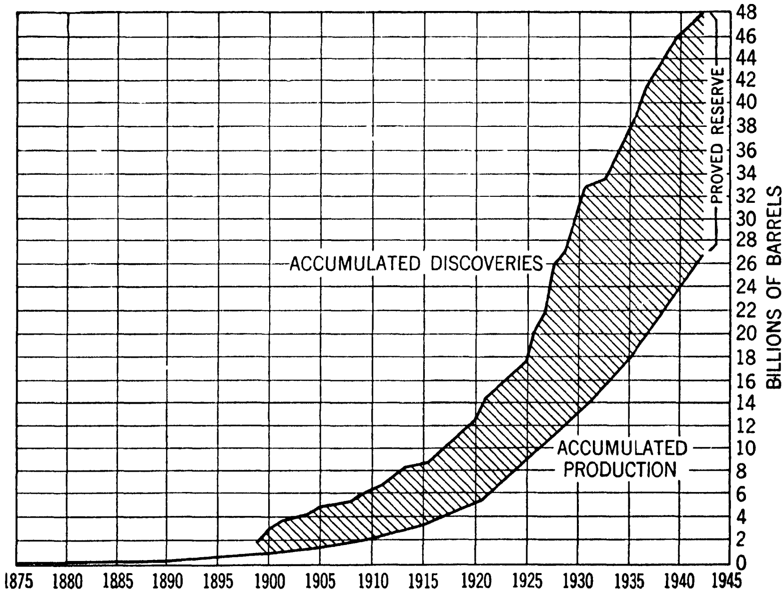

FIG. 4.—Accumulated discoveries, accumulated production, and proved reserves by years.

for crude oil. Low prices in turn resulted from the excess of supply over demand as our proved reserves of petroleum continued to increase. This gradual accumulation of reserves is shown graphically in Fig. 4. American experience over this interval illustrates the difficulty of building up adequate petroleum reserves. The pressure of already proved reserves to flow into the market overturns the very structure with which the finding effort is built up and sustained.

Thus we are driven to the conclusion stated early in this discussion: the search for petroleum reserves is a self-extinguishing enterprise; unless the principles of conservation are invoked to protect it from the natural consequences of its own success, it smothers itself before the reserves it proves are as large as our needs require.

The principles of conservation and good engineering practice dictate that withdrawals from natural reservoirs be restricted far below the maximum rates possible. Retarded rates of flow are efficient; they conserve the resources. They make possible greater ultimate recovery from a given reservoir. They make possible lower unit costs of production. But most important of all, retarded rates of flow enable the finding effort to survive and continue until it proves a volume of reserves sufficient to insure our future needs.

To meet our current consumption efficiently, our proved reserves should be equal to about 20 years' requirements. In other words, we should not remove more than about 5 per cent of its total recoverable contents from the average petroleum reservoir in any one year if we are to conserve our petroleum resources and produce our petroleum at low cost. But many oil fields are capable of pouring out 30 per cent of their total production in the first year of their life if they are permitted to flow without restraint. Thus, a few new oil fields might meet our entire demand for a year or so, even though their total original reserves were equal only to 5 or 6 years' requirements. At the end of the spree these fields would be depleted, the petroleum remaining in them recoverable only in part, over many years to come, and at high cost. In the meantime, other oil fields would have shut down for lack of market, the crude-oil price structure would have collapsed, and the effort to find oil elsewhere would have been stifled.

Gradually we have come to realize that we cannot sustain a vigorous search for petroleum to the point where adequate reserves have been proved unless we retard the aggregate flow as the reserves are developed and share the available market ratably among the oil fields already in production. If we are willing to live from hand to mouth, we can flow our developed fields without restraint. But if we believe that our resources are limited, we should conserve our developed reserves by adhering to slow withdrawals from all producing fields and stimulate exploration by allocating to each new discovery a ratable share of the total outlet.

In order to comply with President Coolidge's admonition to develop adequate proved reserves in the ground, the American petroleum industry was therefore compelled to devise some solution for this problem. Out of this dilemma there grew up the institution of proration, together with the Interstate Oil Compact. The functioning of proration—the ratable sharing of the available market among competing producers in the several oil-producing states—is too well known to require explanation here. We know that without this institution and the collaboration of oil-producing states through the Interstate Oil Compact, first established in 1929 under the sponsorship of Dr. Ray Lyman Wilbur, Secretary of the Interior, it would have been impossible to build up this nation's proved petroleum reserves from 4.5 billion barrels in 1926 to 20 billion barrels in 1943.

The same obstacles which the petroleum industry and the state conservation authorities in our own country have surmounted stand in the way of developing petroleum resources and setting up adequate proved reserves in the rest of the world. Yet it is essential to our peace of mind that this be done. As long as we believe our petroleum resources to be inadequate to meet our essential needs, we shall continue to be uneasy; other nations will share our anxiety. If we explore the petroleum resources of the earth and thereby prove the existence of enough petroleum for everyone over the long future, we shall have quieted these fears which menace the peace of the world. If, on the other hand, we prove our petroleum resources to be inadequate, we will only have confirmed that which already we are half-prepared to accept; we will be no worse off than we already fear we are, and we will at least have resolved our doubts. We can then proceed single-mindedly to the alternative procedure—commercial production of liquid fuels from sources other than petroleum.

For the comprehensive development of the petroleum resources of the earth there is needed the same freedom for individual enterprise to explore, world-wide, that Americans have always enjoyed in their own country. This means an open-door policy among nations and the relinquishment by governments of their petroleum monopolies. There is needed also an organization of petroleum-exporting nations analogous to our own Interstate Oil Compact. The recent conversations on petroleum between the American and British governments may well be the forerunner of an organization of this character. Finally, there is particularly needed among petroleum-exporting nations and individual producers in those nations a concert of action with something of the character of proration—a ratable sharing of the available market among the producing nations and the producers in those nations. Without these provisions for balance and equilibrium, proved petroleum reserves adequate to meet the world's needs can hardly be established, however large the ultimate petroleum resources of the earth may be.

The present controversial situation in the Middle East illustrates the dilemma in which the world's petroleum industry finds itself. The oil fields already discovered in the Middle East could undoubtedly supply the world's total demand for years to come if they were fully developed and produced at capacity. So produced, however, these fields would exhaust themselves prematurely, yielding less total petroleum than would have been obtained from them at retarded rates of flow. Meantime, other oil fields over the world would have been shut in, the Middle East having appropriated their markets; the financial problems of other nations which depend on the export of petroleum for their revenues would have become acute; the oil business outside the Middle East would have languished; and the further development of proved reserves—essential to conservation and efficient production practice—would have halted.

But the present situation in the Middle East is not due to overproduction; on the contrary, the immediate need is an increased market outlet. With more than 30 per cent of the proved petroleum reserves of the earth, the Middle East supplies currently only 10 per cent of the world's demand for petroleum products. Tremendous proved reserves in the Middle East, developed 10 years ago, have never yet moved a barrel of oil to market. Some of the oil fields and concessions with least adequate outlets are owned in part by Americans. The local governments from which these concessions were obtained depend for their revenue upon royalties or taxes on the petroleum sold. If no oil is marketed, these revenues are nil. Thus, the American title to these properties may be jeopardized unless more petronational concern for us, so long as there is so much uncertainty over the sufficiency of our petroleum resources, that Americans continue to own the important reserves they have discovered and developed in the Middle East.

The recent sensational proposal that the American government build a Big Inch pipe line from Saudi Arabia to the Mediterranean doubtless arose from a desire to strengthen the position of American nationals in the petroleum industry of the Middle East. The wisdom of the proposal for this purpose is debatable. An action of this character might even handicap American private enterprise in the Middle East by destroying the fine local tradition of no political ambitions which our government has long enjoyed.

To repeat, the immediate need in the Middle East is an enlarged market outlet in which each of the producing oil fields shares on a ratable basis. This problem has repeatedly confronted remote oil-producing localities in our own country. The oil producers of west Texas faced this same problem nearly 20 years ago, when the prolific Yates field was developed by a dozen competing companies, none of which had any pipe-line outlet or market. The problem in the Middle East should be solved as the problem in west Texas was solved, through direct negotiations among the several interests involved. In west Texas the oil producers by their joint efforts gradually built up a market outlet in which, with the approval of the state authorities, each shared ratably. In the Middle East the various companies involved—British, American, Dutch, and French—through direct negotiations with each other and in collaboration with their respective governments and with the local governments, should determine what market is available to the Middle East and how this market can be shared by the several producing oil fields.

The service our government can best render—and it is a service of tremendous importance—in the effort to develop more adequate petroleum reserves is the preservation of equities among the several nations which sell to the world their exportable surpluses of petroleum. In dealing with the problem of the Middle East, the welfare of other oil-exporting nations such as Venezuela, Colombia, and Peru must be kept in mind. Each of these nations has established for itself a position as an important supplier in the world's petroleum market. Each of them depends largely on its petroleum exports for revenue. It would seem to be in the interest of world peace and security to preserve some degree of equilibrium in this relationship. In this field of endeavor the governments of the world, including especially our own government, can make their greatest contribution to the development of the petroleum resources of the earth.

But returning in conclusion to the broader question of the adequacy of our petroleum resources, suppose these finally fail us in spite of their apparent abundance. Where then shall we obtain·the indispensable liquid fuels our peacetime economy and our national security demand? The confident answer is that we shall manufacture them from other natural hydrocarbons: coal, oil shale, tar sands, or—perhaps most available of all substitute raw materials and almost certainly society's ultimate source of liquid fuels—waste from growing crops.[1] In the

[1] Professor E. Berl, of the Carnegie Institute of Technology, who has worked for years on the problem of converting carbohydrates into liquid fuels and who published an encouraging report of his progress as early as 1934, makes the following exciting statement of his achievements: "One can get from cornstalks, corn cobs, sugar cane, bagasse, seaweed, algae, sawdust, Irish moss, molasses, sorghum, grass, or any other carbohydrate-containing material, by a controlled internal combustion, a material called 'protoproduct.' . . . . The protoproduct can be used as fuel oil or, with or without a simple treatment, in diesel engines. . . . . Hydrogenation of the liquid protoproduct can be carried out much more simply than that of pulverized . . . . lignites or . . . . bituminous coals. After hydrogenation about 45 per cent of the original carbon content of, for instance, sugar cane results as gasoline, kerosene, and lubrication oil."

Professor Berl also states that "altogether 70 per cent, which represents the total carbohydrate content of the sugar cane, including cellulose, can be converted into liquid fuel." To produce the volume of liquid fuel required by our 30 million prewar automobiles, according to Professor Berl, would take 10 million acres of sugar cane in the United States (about 3 per cent of the area we normally harvest), or 5.5 million acres in tropical lands such as Puerto Rico. Professor Berl visualizes the ordinary farmer producing his own liquid fuel. "In small installations, plant material could be converted into the fuel which is necessary for [the farmer's] tractor and for heating his home."

It should be noted that Professor Berl's protoproduct is not itself gasoline. To convert it into gasoline requires hydrogenation, always an expensive operation. However, the protoproduct itself, according to Professor Berl, can be used as fuel oil in diesel engines, or, presumably, in the gas turbine, our latest development in internal combustion engines, which can utilize almost any noncorrosive, thermally efficient liquid fuel. Professor Berl states that the protoproduct contains about 15,200 B.t.u. per lb., compared to about 19,000 B.t.u. for gasoline and 12,200 B.t.u. for pure alcohol. Thus, aggregate these raw materials, even if we exclude growing crops, are practically inexhaustible. We have thought in the past that the technical problems involved in manufacturing liquid fuels from these substitute raw materials were all but insoluble. Today these problems no longer seem so difficult. We have seen Germany fight a world war largely on synthetic fuels. We have thought that the costs of the manufacture of liquid fuels from coal or oil shale would be prohibitive, but today we know that gasoline from these materials can be made and sold profitably at less than the average price we paid for gasoline after the last war. We know that we can now make gasoline from substitute raw materials at costs but little higher than present costs of gasoline from petroleum, plus state and federal taxes. We are confident that costs of manufacture from substitute raw materials will be still further reduced as we gain experience and improve our technology.

There will be no sudden failure of our supply of petroleum. Too large a proportion of our producing oil fields are already in the settled-production stage, where their remaining reserves can be recovered only at very slowly declining rates over scores of years. We shall have timely warning. The new industry of making liquid fuels from other raw materials will establish itself as rapidly as the petroleum supply fails. Under these circumstances, it is hardly conceivable (unless wars are to continue unceasingly) that the United States will suffer a critical shortage of liquid fuels within the foreseeable future.

Part 2. Estimate of United States Oil Reserves

By the American Petroleum Institute

More than 2 billion barrels of new petroleum reserves were added to the oil supply of the nation during 1944 by the discovery of new oil pools and the further development of older pools, according to the annual report of the American Petroleum Institute Committee on Petroleum Reserves to the Board of Directors, dated Feb. 16, 1945.

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while the protoproduct is much superior to alcohol as a fuel, it has only 80 per cent of the thermal efficiency of gasoline; nevertheless, because of its greater density, a gallon of the protoproduct contains 34 per cent more power than a gallon of gasoline. *Science*, vol. 49, no. 2573 (Apr. 21, 1944), pp. 309–12.

Despite a record crude-oil production of 1,678 million barrels during the year, the net gain in the proved oil reserves of the country amounted to 389 million barrels in 1944. During the year Alabama became the twenty-sixth oil-producing state, while Louisiana and Mississippi led all other states in the reserves added by discovery. Texas, with reserves of 11,375 million barrels, has 55.6 per cent of United States oil reserves, with California, Louisiana, Oklahoma, Kansas, Wyoming, and New Mexico following in the order named. In 1944 the new reserves resulting from discovery amounted to 511 million barrels, the highest figure since 1938, while additions to reserves by development added another 1,556 million barrels. Crude-oil withdrawals from reserve amounted to 24.2 per cent more than those of prewar 1941.

The full report of the American Petroleum Institute's Petroleum Reserves Committee[1] follows:

The American Petroleum Institute's Committee on Petroleum Reserves herewith submits its report as of Dec. 31, 1944.

The committee estimates that the proved reserves of crude oil in the United States, as of Dec. 31, 1944, amounted to 20,453,231,000 bbl. This is derived as follows:

Total proved reserves as of Dec. 31, 1943		20,064,152,000 bbl.
Extensions (new oil) and revisions during 1944	1,556,192,000 bbl.	
New reserves (new pools) discovered in 1944	511,308,000 bbl.	2,067,500,000 bbl.
Total proved reserves as of Dec. 31, 1943, and new proved reserves added in 1944		22,131,652,000 bbl
Subtract production during 1944		1,678,421,000 bbl.
Total proved reserves as of Dec. 31, 1944		20,453,231,000 bbl.
Increase in reserves since Dec. 31, 1943		389,079,000 bbl.

[1] The Committee on Petroleum Reserves: J. Edgar Pew, Chairman, Sun Oil Co., Philadelphia.

R. F. Baker, The Texas Co., New York.

D. V. Carter, Magnolia Petroleum Co., Dallas, Tex

Frank R. Clark, The Ohio Oil Co., Tulsa, Okla.

Alexander Deussen, Consulting Geologist, Houston, Tex.

G. Clark Gester, Standard Oil Co. (California), San Francisco.

F. H. Lahee, Sun Oil Co., Dallas, Tex.

J. M. Sands, Phillips Petroleum Co., Bartlesville, Okla.

Fred Van Covern, American Petroleum Institute, New York.

Theron Wasson, Pure Oil Co., Chicago.

Fred E. Wood, Standard Oil Co. (Indiana). Chicago.

The estimates in this report, as in all previous annual reports of this committee, refer solely to proved or blocked-out reserves of crude oil (including condensate) known to be recoverable under existing economic and operating conditions. Therefore, they do not include:

1. Oil under the unproved portions of partly developed fields
2. Oil in untested prospects
3. Oil that may be present in unknown prospects in regions believed to be generally favorable
4. Casinghead gasoline extracted at natural gasoline plants in moderately low-pressure fields
5. Oil that may become available by secondary-recovery methods from fields where such methods have not yet been applied
6. Oil that may become available through chemical processing of natural gas
7. Oil that can be made from oil shale, coal, or other substitutes

Proved reserves are both drilled and undrilled. The proved drilled reserves in any pool include the oil estimated to be recoverable by the production systems now in operation (whether primary or secondary) and from the area actually drilled up on the spacing pattern in vogue in that pool. The proved undrilled reserves in any pool include reserves under undrilled spacing units which are so close and so related to the drilled units that there is every reasonable probability that they will produce when drilled.

In the case of new discoveries, which are seldom fully developed in the first year and in fact for several years thereafter, the estimates of proved reserves necessarily represent but a part of the reserves which may ultimately be assigned to the new reservoirs discovered each year. For a one-well field where development has not yet gone beyond the discovery well, the area assigned as proved is usually small in regions of complex geological conditions, but may be larger where the geology is relatively simple. In a sparsely drilled field the area between wells is only considered to be proved if the information regarding the geology of the field and the productive horizon is adequate to assure that such area will produce when drilled. The total of new oil through discoveries which is estimated as proved in any given year is comparatively small, and the total of new oil through extensions is comparatively large. As knowledge of the factors affecting production and well performance become available and as these factors are studied, reserves in older fields can be estimated with greater precision and revised accordingly. Therefore, the oil assigned to new discoveries (Table 1, column

TABLE 1.—ESTIMATED PROVED PETROLEUM RESERVES IN THE UNITED STATES
(Barrels of 42 U.S. gal.)

State	Proved reserves, Dec. 31, 1943 (1)	Changes in proved reserves due to extensions (new oil)[1] and revisions during 1944 (2)	Proved reserves in new pools discovered in 1944[2] (3)	Production during 1944, estimated (4)	Proved reserves, Dec. 31, 1944, columns (1), (2), and (3) less column (4) (5)
Alabama		.	360,000	43,000	317 000
Arkansas	296,929,000	20,423,000	5,148,000	29,441,000	293,059,000
California	3,336,823,000	242,575,000	76,925,000	311,771,000	3,344,552,000
Colorado	45,111,000	46,025,000	647,000	2,960,000	88,823,000
Illinois	294,622,000	100,661,000	2,727,000	77,296,000	320,714,000
Indiana	31,039,000	3,887,000	1,657,000	5,090,000	31,493,000
Kansas	645,852,000	42,431,000	12,498,000	99,030,000	601,751,000
Kentucky	35,190,000	15,236,000	331,000	9,677,000	41,080,000
Louisiana	1,483,826,000	107,062,000	112,055,000	129,556,000	1,573,387,000
Michigan	55,248,000	17,745,000	10,700,000	18,559,000	65,134,000
Mississippi	38,872,000	6,973,000	179,533,000	16,367,000	209,011,000
Montana	108,057,000	11,829,000	346,000	8,582,000	111,650,000
Nebraska	1,000,000	. .	.	419,000	581,000
New Mexico	653,981,000	54,101,000	2,240,000	39,556,000	562,564,000
New York	90,525,000	.	.	4,694,000	85,831,000
Ohio	32,643,000	.	1,925,000	2,944,000	31,624,000
Oklahoma	908,618,000	165,547,000	20,844,000	124,747,000	970,262,000
Pennsylvania	137,332,000			14,185,000	123,138,000
Texas	11,324,954,000	740,213,000	58,103,000	747,790,000	11,375,480,000
West Virginia	43,839,000	. .	.	3,084,000	40,755,000
Wyoming	499,394,000	89,636,000	25,269,000	32,569,000	581,730,000
Miscellaneous[3]	306,000	50,000	.	61,000	295,000
Total United States	20,064,152,000	1,556,192,000	511,308,000	1,678,421,000	20,453,231,000

[1] Extensions greatly exceed revisions.

[2] Only a limited area is assigned to each new discovery even though the committee may believe that eventually a much larger area will produce, for in this report we are concerned only with actually proved reserves.

[3] Includes Florida, Missouri, Tennessee, Utah, and Virginia.

3), plus the oil proved through extensions (Table 1, column 2), comprises the total quantity of the new proved reserves for the year.

The committee again wishes especially to stress the fact that its estimates of proved reserves cannot be used as a measure of the rate at which these reserves can be produced with or without physical waste. Oil cannot be produced from the permeable rocks in which it occurs at any desired rate, because the flow of oil through the pores of the oil-bearing rocks is definitely controlled by physical factors of the reservoir. As a matter of fact, today's known oil can be recovered only over a period of many years and at gradually declining annual rates, as has been widely demonstrated by past performance under all kinds of operating conditions. For this reason those who, through arbitrary division of the known reserves by any current rate of production or by any anticipated rate of consumption, try to estimate the life of proved reserves of oil, or the rate at which these reserves can be produced, arrive at an incorrect conclusion.

TABLE 2.—SUMMARY OF COMMITTEE'S ANNUAL REPORTS COVERING PERIOD 1937–1944
(Barrels of 42 U.S. gal.)

Year	New oil blocked out during year			Production during year	Estimated proved reserves at end of year
	Through revisions of previous estimates and extensions to known fields	Through new pools discovered during year	Total through new discoveries, extensions, and revisions		
1936	. . . .	. . . .	. . . .	. . . .	13,063,400,000
1937	2,792,790,000	928,742,000	3,721,532,000	1,277,664,000	15,507,268,000
1938	2,243,571,000	810,493,000	3,054,064,000	1,213,186,000	17,348,146,000
1939	2,058,455,000	340,667,000	2,399,122,000	1,264,256,000	18,483,012,000
1940	1,607,012,000	286,338,000	1,893,350,000	1,351,847,000	19,024,515,000
1941	1,538,989,000	429,974,000	1,968,963,000	1,404,182,000	19,589,296,000
1942	1,618,925,000	620,051,000	1,878,976,000	1,385,479,000	20,028,793,000
1943	1,202,368,000	282,418,000	1,484,786,000	1,503,427,000	20,064,152,000
1944	1,556,192,000	511,308,000	2,067,500,000	1,678,421,000	20,453,231,000

For comparative purposes we append a summary tabulation (Table 2) of the over-all figures contained in the committee's annual reports covering the period from 1937 to 1944 inclusive. Figures for 1935 and 1936, which were the first developed by the committee, are not available separately.

As in the past, this committee wishes to emphasize the fact that every effort has again been made to secure a fair, unprejudiced, and representative opinion. Each member in his district appointed a number of subcommittees to gather and study the necessary data. All previously determined factors pertaining to the various pools were examined and adjusted in the light of new information. The subcommittees, which were largely responsible for the data, were comprised of specially trained geologists and petroleum engineers with long experience in this class of work. We wish to acknowledge the valuable assistance and information received from these and other individuals, and to thank all of them for their cooperation.

Part 3. Our Natural Gas Resources[1]

By Lyon F. Terry

Second Vice-president, the Chase National Bank, New York[2]

Any long-range view of the natural gas industry must be based upon a consideration of our total potential supply of natural gas—including both the known reserves and those to be found by future discovery. This paper will review the growth of natural gas reserves and the rate of discovery. It will also discuss the prospects for discovering new gas reserves and suggest an approach to the problem of the total future supply.

PROVED RESERVES

The known reserves of natural gas in the United States are currently estimated by the Petroleum Administration for War to aggregate 110 trillion cubic feet. Total production of natural gas reached a record high in 1943 of approximately 4 trillion cubic feet, of which some 3.3 trillion were marketed. Thus our known reserves are equivalent to 27.5 times annual withdrawals on a wartime basis or about 33 times annual requirements for

[1] From a paper presented before the Natural Gas Spring Conference, American Gas Association, French Lick Springs, Ind., May 12, 1944.

[2] For suggestions used in the preparation of this paper, the author is indebted to: Joseph E. Pogue, Vice-president, The Chase National Bank, New York.

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the prewar period. While it would at first appear that the available supply of natural gas from the standpoint of the country as a whole is adequate for immediate purposes, we should also examine the rate of discovery and other indications of the probable future additions to reserves. The growth of known reserves is shown in Table 1.

TABLE 1.—GROWTH OF NATURAL GAS RESERVES AND PRODUCTION IN THE UNITED STATES
(In trillion cubic feet)

Year	Estimated proved reserves, Jan. 1, 1944	Total[1] production for year	Ratio of reserves to production
1926	23[2]	1.88[9]	12 2
1931	46[3]	2.58[9]	17.8
1935	62[4]	2.40	25.8
1938	66[4]	2.95	22.4
1939	70[5]	3.15	22.2
1941	85[4]	3.44	24.7
1943	85[6]	4.00[10]	21.2
1949	110[7]	400[10]	27.5
1944	90[8]		
1944	110[7]		

1 Gas marketed plus gas lost and wasted as reported by U.S. Bureau of Mines.
2 Private estimate.
3 By Earle P. Hindes.
4 By Ralph E. Davis.
5 By Lyon F. Terry.
6 By Ralph E. Davis, as of Oct. 1, 1942.
7 By PAW, including solution gas and gas-cap gas reserves.
8 By Ralph E. Davis. Mr. Davis' estimates do not in general include solution gas primarily available for oil-field operations.
9 Marketed production per U.S. Bureau of Mines plus our estimate of losses and waste.
10 Preliminary estimate.

The growth of discoveries and reserves is also shown in Fig. 5, where cumulative discoveries at any date are plotted as equal to the sum of cumulative production plus proved reserves. The chart is based upon marketed production only. It should be noted that including gas lost in operations, not accounted for on the chart, the total past discoveries of natural gas in this country have been approximately 200 trillion cubic feet.

RATE OF DISCOVERY

The quantities of new gas reserves discovered and developed by periods since 1925 are indicated in Table 2. For comparative purposes, increases in reserves are based upon the Davis estimates.

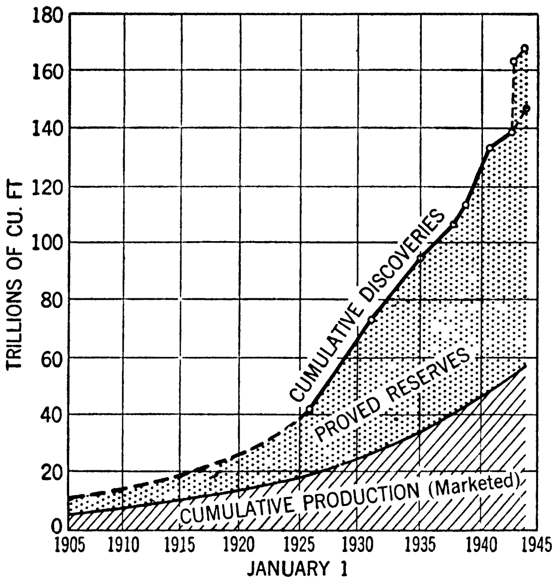

FIG. 5.—Growth of natural-gas discoveries and reserves in the United States

TABLE 2.—NEW GAS RESERVES DISCOVERED AND DEVELOPED, COMPARED WITH PRODUCTION
(In trillion cubic feet)

Periods	Number of years	Increase in proved reserves	Total gas produc-tion	New reserves dis-covered and developed		Ratio of new reserves to pro-duction
				Total	Per year	
1926–1930	5	23.00	12.91	35.91	7 18	2.78
1931–1934	4	16.00	9.51	25.51	6.38	2.68
1935–1938	4	8.00	10.84	18.84	4.71	1.74
1939–1943	5	20.00	17.64	37.64	7.53	2.13
1926–1934	9	39.00	22.42	61.42	6.82	2.74
1935–1943	9	28.00	28.48	56.48	6.28	1.98
1926–1943	18	67.00	50 90	117.90	6.55	2.32

While the figures for additions to reserves should be considered only relative, being based upon rough estimates of national reserves at successive intervals, the following trends may be observed:

1. For the period 1926–1934, which included the development of the Panhandle field and the discovery of Kettleman Hills and Hugoton, the rate of discovery and development of new gas reserves averaged 6.82 trillion cubic feet per year, or approximately 2¾ times the rate of withdrawals.

2. During the 1935–1943 period, including the discovery and development of important deep gas reservoirs in the Gulf coast and Rio Vista in California, additions to reserves averaged 6.28 trillion cubic feet per year, or approximately twice the rate of production. Thus for a number of years new gas reserves have been discovered and developed in quantities considerably greater than withdrawals from the fields, which has resulted in the building up of a substantial backlog of available reserves.

DISCOVERY PROSPECTS WITH DEEPER DRILLING

As we drill deeper in the search for oil and gas, the effect of the compressibility of gas becomes of special significance. Reservoir pressures are, of course, normally proportional to depth, and while at great depths both the deviation from Boyle's law and the effect of higher temperatures tend to reduce the direct effect of pressure, the net result is all in favor of the existence of larger reserves of gas at greater depths. Other things being equal, an acre-foot of pore space filled with dry gas encountered at a depth of 10,000 ft. should contain roughly 1¾ times the quantity of gas in a similar reservoir at 4,000 ft.

In oil fields the ratio of gas in solution to the oil found in place varies with depth and pressure in a relationship somewhat similar to that stated above for dry gas. Hence deeper drilling may be expected to reveal increasing proportions of solution gas per barrel of new oil reserves discovered in the future. And the continued improvement in methods of conserving gas in oil-field operations should also add to the supply of natural gas available from this source.

Reported studies of changes in the nature of oil and gas with depth of the reservoir rocks offer no suggestion that gas will be less abundant or that the ratio of gas to oil will decrease with deeper drilling. The variation in the characteristics of oil with increasing depth and geologic age has been investigated for the Gulf coast area to a depth of 7,000 ft. by Barton.[1] In general

[1] Barton, Donald C., Evolution of Gulf Coast Crude Oil, A.A.P.G., vol. 21 (1937), pp. 914–946.

he found an "increase in the percentage content of the lower boiling (lighter) fractions and decrease in the percentage content of the higher boiling (heavier) fractions with increasing depth and age"; (2) "increase of the A.P.I. (Beaumé) gravity (decrease of the specific gravity) of all fractions of the crude oil with increasing depth and age; . . . " While he stated no definite conclusions as to natural gas itself, his findings may justify the expectation that exploration at greater depths will reveal increasing proportions of condensate and of solution gas, compared with crude oil.[1]

There is evidence also that with deeper exploration the proportion of natural gas to crude oil discovered has been increasing. A notable increase in the discovery and development of condensate fields has occurred in recent years, particularly in the deeper developments of the Gulf coast. This is well indicated by the results of exploration in the Gulf coastal area, where the number of gas and condensate discoveries out of total successful wildcat completions increased from 7 per cent in 1933 and 24 per cent in 1934 to 52 per cent for 1943, as shown in Table 3.

TABLE 3.—TREND OF EXPLORATORY DRILLING IN SOUTH ARKANSAS, LOUISIANA, AND TEXAS GULF COAST, AFTER PAW
(Successful exploratory completions in per cent of total number)

Year	Oil	Gas	Condensate	Total
1933	93	7	0	100
1934	76	13	11	100
1935	80	10	10	100
1936	72	16	12	100
1937	74	5	21	100
1938	66	7	27	100
1939	63	12	25	100
1940	66	9	25	100
1941	61	14	25	100
1942	56	14	30	100
1943	48	16	36	100

PAST PRODUCTION AND DISCOVERIES

Natural gas produced and delivered to consumers from 1906 to the close of 1943, as reported by the Bureau of Mines, amounted

[1] See also Pratt, Wallace E., Hydrogenation and the Origin of Oil, "Problems of Petroleum Geology," A.A.P.G. (1934), pp. 235–245.

to 51.4 trillion cubic feet. Marketed production for the Appalachian fields prior to 1906 has been estimated by Roth[1] at 4.8 trillion cubic feet. Together with smaller quantities produced in Indiana, Kansas, and elsewhere prior to 1906, we have a fairly accurate estimate of total marketed production in the United States to Jan. 1, 1944, of 57 trillion cubic feet.

Since 1935 the bureau has also reported losses and waste, stated as: "gas (mostly residue gas) blown to the air, and transportation losses, but does not include direct waste on producing properties except where data are available." During recent years such reported losses have averaged 20 per cent of total reported production exclusive of gas stored in the ground and used for repressuring. Prior to the enforcement of effective gas conservation laws by the principal gas-producing states, beginning in 1935 (California in 1931), the unconserved gas incident to natural gas and natural gasoline operations had been considerably higher. Including estimates of specific losses in the Panhandle, Oklahoma City, and California fields, it is believed that such losses have amounted to at least 20 trillion cubic feet.

There were also great quantities of gas blown to the air in the oil fields of this country in the days before the establishment of conservation measures. The volume of such gas production will never be known. However, some idea of its magnitude may be formed by considering the solution and gas-cap gas that has been released with the 28 billion barrels of oil produced in this country to date, with due allowance for the portion of such gas utilized by the natural gas industry, especially since the advent of casinghead-gasoline practice some 30 years ago. The unconserved gas incident to oil-field operations has been largely remedied in recent years by the state conservation acts and the proration of production, and also through the application of pressure maintenance and recycling processes. Thus the loss of gas such as occurred at Spindletop, Glenn Pool, Cushing Pool, and Burbank will not be duplicated in the oil fields to be discovered in the future; and insofar as past production may provide an index to the quantity of future discoveries, the excessive volumes of unconserved gas formerly produced in oil fields, which

[1] Roth, E. E., "Natural Gas Reserves Appalachian Natural Gas Province," American Petroleum Institute meeting, Pittsburgh, Apr., 1938.

would have been conserved under present and future practice, should be included in figures of total gas production.

Summarizing the above items of production, it is believed that the total effective quantity of natural gas produced to Jan. 1, 1944, in the United States has been at least 90 trillion cubic feet. Adding the known reserves of 110 trillion, as estimated by the Petroleum Administration for War, indicates total discoveries to Jan. 1, 1944 of approximately 200 trillion cubic feet.

FUTURE DISCOVERIES

The most important part of our natural gas resources are those undiscovered reserves that undoubtedly will be revealed by future exploration for both oil and gas. Future discoveries of natural gas, of course, cannot be estimated. Predictions that have been made at various times in the past as to the future production of oil and gas in the United States have in all cases proved to have been much too low. For example, in 1919 it was predicted that the future recoverable and marketable reserves in discovered and undiscovered pools might reach a maximum of 15 trillion cubic feet.[1] Since that time 44 trillion feet have been produced and marketed.

While there is no way of foreseeing with any accuracy what future exploration may reveal, the problem may be approached along the following line of reasoning. Extensive studies have been made by qualified geologists of the proportion of marine sedimentary lands already tested to the prospective areas still available for further exploration, and of the finding experience for the portions of such lands found productive to date. The investigations indicate that of the total acreage in this country which may be expected to be ultimately productive, about half has been proved for oil to the present time. As described by Pratt[2] and others, the results of these studies point to the probability that additional reserves of oil will be found in this country in quantities at least equal to total past discoveries.

In general, the discovery of gas has run parallel to that of oil and naturally so, since these hydrocarbons originate from the

[1] Shaw, Eugene W., Income and Expense of Natural Gas Production, *Proceedings*, Natural Gas Association of America, vol. 11 (1919), pp. 479–502.

[2] Pratt, Wallace E., in recently published statements, particularly in an address before the Oil Heat Institute of America, New York, Mar. 13, 1944.

same sources and are found in similar and coincident reservoirs and sedimentary rocks. Considering also, in the case of gas, the effects of the compressibility of gas under reservoir pressures found at increasing depths, the significance of the variation in the character of oil to be revealed by deeper drilling, and the recent trend towards the discovery of an increasing proportion of gas fields compared to oil fields, there appears to be all the more reason to conclude that natural gas reserves to be discovered in the future will at least equal and may exceed the 200 trillion cubic feet discovered to date.

Referring again to Fig. 1 it may be observed that fulfillment of this forecast requires that the graph of cumulative discoveries will ultimately reach the 370 trillion ordinate at the top of the chart. Judging from the slope and proportions of the curve, this goal would seem to be within the range of possibilities.

FUTURE SUPPLY

Thus on the basis of our assumption that future discoveries of natural gas will at least be equal to total discoveries to date, the total potential resources of natural gas in the United States may be stated in round numbers as composed of known reserves in excess of 100 trillion cu. ft and assumed future discoveries of at least 200 trillion, or a total of 300 trillion cu. ft. or more.

Part 4. Cost of Storage of Military Reserves of Crude Petroleum or Products

By F. W. Abrams

Vice-president, Standard Oil Company (New Jersey)

Assurance of adequate military reserves of petroleum products has one basic objective—that there be available for military emergency a supply of petroleum products in the ample quantity required for prolonged military operations. Anything less means insufficiency and lack of staying power. Maintenance of a strong and virile petroleum industry ready as a going concern with oil wells and modern refineries operating efficiently is by far the best way to attain this objective. Only thus will there be provided assurance of both current and long-time supply. The performance of United States industry during both the First and Second World War, supplying in the latter conflict some 90 per cent of all United Nations petroleum needs, provides a classic example of what a strong industry means to military power.

The abundance of petroleum products enjoyed by our own forces contrasts with the scarcity in the Axis nations and gave us immeasurable advantage. It was said of the First World War that the Allies floated to victory on a sea of oil. In the Second World War the metaphor was many times more justified, with petroleum making up nearly two-thirds of all tonnage of supplies shipped to the fronts from this country.

There have been various proposals for holding special areas of known or potential oil possibilities as a reserve for future emergency. Certain naval reserves, for example, have been held aside for Navy use for many years, but interestingly enough they have been able to contribute next to nothing to the needs of the services. The reason is simple. Undeveloped lands require development to get the oil, and this means time, which obviously defeats the prime purpose. It is something like building ships after a war has started. Invaluable time is lost which at best means unnecessary loss of life and at worst may mean defeat.

It has been suggested that pumping imported petroleum into old depleted oil fields could be adopted as a form of underground storage. This has a multitude of technical objections involving possible loss of much of the oil and the factor of double cost, for the oil would have to be recovered a second time in this type of project. But the major drawback to this idea as a source of large-scale emergency supply is that oil so stored would take years to recover. Such restored oil fields would not even remotely approach the producing ability of new fresh fields.

The proposition that large above-ground storage facilities should be provided as military reserve is frequently raised and superficially has merit. But analysis of the many aspects of this problem shows that it is not too satisfactory. Not the least objection is the obvious factor that today's products stored for tomorrow's use may and even certainly will be useless for tomorrow's machines. So rapid is technical progress that today's aviation engines, built to run on the 100-octane-plus fuels of recent years, could not even operate on the fuels of 10 years ago. Additionally, cost of large-scale storage would be great and place a serious burden on the nation's peacetime economy. Only in isolated areas, unable safely to depend on the flow of products from fields and refineries, would large-scale surface storage seem to warrant consideration.

To illustrate the cost of carrying out a program of large above-ground storage for military purposes, estimates have been made of the initial investment in storage facilities in dollars and in steel, the area required, and the operating charges resulting

TABLE 1.—STORAGE FACILITIES[1]
(Cost and description)

Type	Description	Capacity, bbl. per tank	Steel, lb. per bbl.	Cost, dollars per bbl.
Cone roof....	150-ft. diameter × 48-ft.-high cylindrical steel tank located above ground with no foundation.	150,000	6.7	0 75
Spheroid.....	Steel spheroids 155 ft.-in. diameter located above ground with circular concrete foundation ring.	120,000	7.5	0.95
Engineering...	100-ft.-diameter × 30-ft.-high cylindrical steel tank located underground with 1-ft. concrete slab top and bottom and 5 ft. of earth on top. Will require more area than cone roof.	40,000	16.0	2.75
Concrete......	105-ft.-diameter × 30-ft.-high cylindrical reinforced concrete tank located underground; lined with steel for gasoline.	105,000	5.0	1.60
Basin.........	Earthen pit with gunite lining, 12 ft. deep with wood roof	500,000	3.3	0.45

[1] In 20 million barrel tank farms each will require about 1,000 acres.

from maintenance of the facilities, refreshment of stocks through periodic renewal, and evaporation. These have been combined into a total sum that would be the investment after 5, 10, and 20 years in each barrel stored when providing for interest at the rate of 2.5 per cent compounded annually.

The cost of the facilities for storage will vary as indicated in Table 1 according to the type required when assembled in units of 20 million barrels capacity, covering an area of about 1,000 acres. The installation cost covers all items inside the tank farm, such as lines, pumps, fire protection, and fencing. If economy rather than safety from a military standpoint is controlling, the following would be the types recommended for each product:

Aviation gasoline (unleaded).	Spheroids capable of withstanding 2.5 lb. vapór pressure.
Motor gasoline (unleaded)...	Spheroids because of the saving in evaporation losses as compared to other types of tankage.
Other products.............	All other products could be suitably stored in cone-roof tankage. The basin-type tankage made as an earthen pit with gunite lining and wooden roof is the lowest cost from the standpoint of initial investment and would be suitable perhaps only for very heavy fuel oil which would not be absorbed in the earth should a leak develop. Products capable of forming explosive mixtures could not be stored in the basin type with safety.

As shown in Table 3, if a total of 20 million barrels of separate products are stored in the proportions currently estimated as required against military demand, the minimum initial investment for tankage and products based on refining cost at the United States Gulf would amount to $63,100,000. These product costs are based on current crude prices and do not allow for profit on, or amortization of, refining investment, but include normal depreciation on refining equipment and construction in peacetime. Lead would be added upon withdrawal of gasoline in facilities provided (in the estimated investment) for this purpose. After taking account of evaporation losses, refreshment, handling, and maintenance for 20 years, this amount would more than double if interest is computed at 2.5 per cent. The details of the calculations for individual products are shown in Table 3. If a reservoir of 2 billion barrels were stored for 20 years, the cost at the end of 20 years would thus amount to a minimum of 12.8 billion dollars in total payments if present prices are maintained and 2.5 per cent were the marginal (net) interest rate for long term United States bonds.

If the tankage as described is constructed outside of the United States, it is estimated that the cost would be increased by at

TABLE 2.—PERCENTAGE LOSSES BY EVAPORATION OF DIFFERENT TYPES OF STORAGE

Product	Per cent of loss				
	Cone roof	Spheroid	Engineering	Concrete	Basin
10-lb.-vapor pressure gasoline	2.2	0 59	0 21	0 21	
7-lb.-vapor pressure gasoline	1 5	0 41	0 15	0.15	
3-lb.-vapor pressure crude oil	0 5	0 00	0 00	0.00	0.5

Handling (shipping and receiving by tanker):	Per cent	
10-lb.-vapor-pressure gasoline	0 590	Based on renewal each year
7-lb.-vapor-pressure gasoline	0 410	Based on renewal each year
Gas oil	0 015	Based on renewal every 3 years
Fuel	0 120	Based on renewal every 5 years

least 25 per cent. Also, transportation of the products to such points would have to be provided. If military protection at those points is a factor, underground storage would no doubt have to be provided. It is possible that the engineering type of storage (that recommended by an Engineering Committee on Oil Storage of the Council of National Defense in 1940) would suffice in some instances. In this construction, steel tankage is set underground upon a concrete slab and covered with a concrete slab, with 5 ft. of earth on top. In a foreign location it is estimated that this type of storage tank would cost $3.45 per barrel of capacity. The initial cost of 20 million barrels of the assorted products in this storage would be $116,400,000, and after 20 years would amount to 232 million dollars after providing as above for maintenance, handling, evaporation, and interest, but before providing for transportation from the United States Gulf.

Crude oil could be stored at a substantially lower cost. Both the initial and ultimate cost of storage in the field at the point of production is approximately two-thirds of the cost of the assorted products obtained from refining this crude at the United States Gulf. The cost would be higher, of course, if military protection had to be provided, employing, for example,

TABLE 3.—INVESTMENT REQUIRED
(Crude vs. product storage at United States Gulf)

Stock				Type of storage	Cost of 20 million bbls., in dollars	
Type	Barrels daily	Per cent	Unit cost		Initial	After 20 years
Crude[1]	. . .		$1.25 per bbl.	Cone roof	40,000,000	81,000,000
Products:						
Aviation gasoline[2]	500,000	27.8	8 0 cents per gal.	Spheroid	24,200,000	49,600,000
Motor gasoline[3]	400,000	22 2	6.0 cents per gal.	Spheroid	15,300,000	33,300,000
Distillate fuels	200,000	11 1	3.5 cents per gal.	Cone roof	5,000,000	10,000,000
Lubes: aviation	20,000	1 1	33.0 cents per gal.	Cone roof	3,100,000	5,200,000
other	30,000	1 7	28 0 cents per gal.	Cone roof	4,000,000	6,800,000
Fuel: Navy special[4]	350,000	19 4	$1 11 per bbl.	Cone roof	7,200,000	14,400,000
heavy	300,000	16 6	$0 85 per bbl.	Basin	4,300,000	8,800,000
Total	1,800,000				63,100,000	128,100,000

[1] Storage in field.
[2] 70 per cent grade 130; 30 per cent other grades.
[3] United States Army 80-octane unleaded.
[4] Navy fuel composed of 60 per cent heavy fuel, 40 per cent distillate.

TABLE 4.—FUTURE VALUE OF CRUDE AND PRODUCTS FOR DIFFERENT TYPES OF STORAGE

	Crude oil[1]			Aviation oil[1]			Motor oil[1]			Gas oil[1]			Fuel oil[1]			
	Cone roof	Engineering	Concrete	Spheroid	Engineering	Concrete	Spheroid	Engineering	Concrete	Cone roof	Engineering	Concrete	Cone roof	Engineering	Concrete	Basin
Tankage investment, dollars per bbl	0.75	2.75	1.60	0.95	2.75	2.00	0.95	2.75	2.00	0.75	2.75	1.60	0.75	2.75	1.60	0.45
Evaporation loss, per cent[2]	0.5 Pn	0.5 Pn	0.5 Pn	0.41P	0.15P	0.15P	0.59P	0.21P	0.21P							
Handling loss, per cent				0.41P	0.41P	0.41P	0.59P	0.59P	0.59P	0.02P	0.02P	0.02P	0.12P	0.12P	0.12P	0.12P
Storage cost, dollars per bbl	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
Maintenance (2 per cent), dollars per bbl	0.015	0.055	0.032	0.019	0.055	0.040	0.019	0.055	0.040	0.015	0.055	0.032	0.015	0.055	0.032	0.009
Receiving and shipping, dollars per bbl				0.016	0.016	0.016	0.016	0.016	0.016	0.005	0.005	0.005	0.003	0.003	0.003	0.003
Original investment, dollars per bbl.:																
Product (P)[1]	1.25	1.25	1.25	3.40	3.40	3.40	2.50	2.50	2.50	1.50	1.50	1.50	0.85	0.85	0.85	0.85
Tankage	0.75	2.75	1.60	0.95	2.75	2.00	0.95	2.75	2.00	0.75	2.75	1.60	0.75	2.75	1.60	0.45
Loss by evaporation on crude[2]	0.006n	0.006n	0.006n													
Total[2]	2.00 + 0.006n	4.00 + 0.006n	2.85 + 0.006n	4.35	6.15	5.40	3.45	5.25	4.50	2.25	4.25	3.10	1.60	3.60	2.45	1.30
Annual charges, dollars per bbl.:																
Losses				0.028	0.019	0.019	0.030	0.020	0.020				0.001	0.001	0.001	0.001
Storage, receiving and shipping	0.007	0.007	0.007	0.023	0.023	0.023	0.023	0.023	0.023	0.012	0.012	0.012	0.010	0.010	0.010	0.010
Maintenance	0.015	0.055	0.032	0.019	0.055	0.040	0.019	0.055	0.040	0.015	0.055	0.032	0.015	0.055	0.032	0.009
Total	0.022	0.062	0.039	0.070	0.097	0.082	0.072	0.098	0.083	0.027	0.067	0.044	0.026	0.066	0.043	0.020
Value after n years, dollars per bbl.:																
10 years—$1.28 × investment	2.64	5.20	3.72	5.57	7.87	6.91	4.42	6.72	5.76	2.88	5.44	3.97	2.05	4.60	3.14	1.66
$11.2 × annual charges	0.25	0.69	0.44	0.78	1.09	0.92	0.81	1.10	0.93	0.30	0.75	0.49	0.29	0.74	0.48	0.22
Total	2.89	5.89	4.16	6.35	8.96	7.83	5.23	7.82	6.69	3.18	6.19	4.46	2.34	5.34	3.62	1.88
20 years—$1.64 × investment	3.48	6.76	4.87	7.14	10.10	8.86	5.66	8.61	7.38	3.69	6.97	5.08	2.62	5.90	4.01	2.13
$25.6 × annual charges	0.56	1.59	1.00	1.79	2.48	2.10	1.84	2.51	2.13	0.69	1.72	1.13	0.67	1.69	1.10	0.51
Total	4.04	8.35	5.87	8.93	12.58	10.96	7.50	11.12	9.51	4.38	8.69	6.21	3.29	7.59	5.11	2.64
30 years—$2.10 × investment	4.58	8.78	6.36	9.14	12.91	11.34	7.25	11.03	9.45	4.73	8.94	6.52	3.36	7.56	5.15	2.72
$44.0 × annual charges	0.97	2.73	1.72	3.08	4.27	3.61	3.17	4.31	3.65	1.19	2.95	1.94	1.14	2.90	1.89	0.88
Total	5.55	11.51	8.08	12.22	17.18	14.95	10.42	15.34	13.10	5.92	11.89	8.46	4.50	10.46	7.04	3.60

[1] P = price of product, dollars per bbl.
[2] n = number of years.

the engineering type of storage. Crude oil does not, however, provide any assurance by itself of meeting an immediate large-scale demand for petroleum products.

The rate at which products could be accumulated for storage would be at a maximum equal to the total production from all refineries when operating at capacity remaining after satisfying current demand. Since the products, particularly gasoline, are of special quality, specific limitations to output would be imposed. In the immediate postwar period there would seem to be a surplus of refining capacity in relation to the commercial needs for aviation gasoline. Therefore, this product or components thereof could be manufactured and stored without an immediate extension of refining capacity. Present capacity now completed and available to the Allied nations could be fully employed in the postwar period upon replenishment of the automotive and other fuel-consuming capacity, except for the refining equipment that would then be obsolete in terms of age, applicability in meeting demands from the standpoint of quality, and economy. Consequently, storage of products at a rate sufficient to provide a reserve commensurate with probable war demands would require a proportionate increase in refining capacity. Whatever is required to provide this would be additive as an investment to the amounts indicated above. The product costs employed are for refining at the United States Gulf and may be considered sufficient to provide compensation for operating costs and maintenance of refining capacity over a period of time.

Consequently, the total cost of carrying out a program for storage of 2 billion barrels of assorted products could amount at the end of 20 years to sums varying from 13 to 25 billion dollars, depending upon the location and type of storage selected. Such a storing up of wealth in terms of materials, labor, and other items against a contingency that may never develop could consequently detract seriously from the capacity of the United States and its allies, present and prospective, to fulfill the objectives of a peacetime economy: namely, an assurance of a better standard of living.

CHAPTER VI

OUR RESERVES OF COAL AND SHALE

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INTRODUCTION

It has been assumed for the purposes of this report that all substances from which present technology can provide substitutes for petroleum or petroleum products are considered supplemental reserves; these reserves include coal, oil shale, tar sands, natural gas, and agricultural materials. This definition does not mean, however, that petroleum substitutes made from these substances are now available or, necessarily, that they can be made available under existing conditions any more than metals such as gold or silver can be used as a practical substitute for lead, even though the properties of gold and silver make them adaptable to many of the purposes for which lead now is used.

Some of the supplemental reserves have been referred to carelessly or ignorantly as a resource that may adequately protect the nation in time of emergency or in the event of shortage of petroleum. It is highly important that the difficulties and limitations involved in replacing part or all of the country's petroleum requirements with products obtained from these supplemental reserves should be understood and appreciated. This is vital to effective planning for national defense and for national stability and progress.

A very cursory tabulation of the quantities of oil shale, coal, and tar sand in this country and Canada makes it apparent that if the products that will satisfactorily replace petroleum products

[1] From a pamphlet, *Basic Statistics of North-American Supplemental Petroleum Reserves*, The Gulf Companies, Pittsburgh, May 15, 1944.

could be secured from these materials at a price which would not seriously handicap the present consumers of petroleum products, domestic requirements would be met for generations. The problem therefore is not one of scarce raw materials in the form of oil shale or coal, but is instead an economic one, which may or may not be solvable as long as crude petroleum is obtainable either in this country or abroad at current or materially higher prices. These supplemental reserves must be regarded as existing but unavailable until technology develops methods for securing from them substitute petroleum products at prices not greater than those of equivalent products made from crude petroleum.

In time of emergency, cost might play only a minor part, because very great reserves of man power and raw materials of kinds now considered critical would be essential to develop from these supplemental reserves enough petroleum substitutes to meet a significant part of the emergency demand, and the development would require the even more critical element, time. It is important that all of the critical factors should be appreciated.

The present report does not pretend to furnish estimates of the amounts of these supplemental reserves with greater accuracy than previously, nor does it present novel or hitherto unpublished material relating to the procedures and costs involved in securing petroleum substitutes from these reserves. It does, however, attempt to furnish a coherent picture which will indicate what these reserves are, something of their magnitude, some of the economic factors involved in their development, and some of the present uncertainties with regard to their most effective utilization.

The available data on these reserves are far from complete. In regard to coal, no commercial coal-hydrogenation plants or Fischer-Tropsch plants have ever been built in the United States, and the data on European commercial operations are inadequate. Coal carbonization has drawbacks for large-scale use because of extremely large by-product production of coke. No definitive shale-oil research has been conducted in the United States since 1929, and the literature on the subject, while voluminous, is conflicting and incomplete. Data on oil and tar sand reserves are quite limited and conjectural. Natural gas can be used as an inexpensive raw material for Fischer-Tropsch synthesis, but resources are even more limited than those of petroleum, and no commercial plants are at present in operation. Agricultural materials hold little promise as a source of economic liquid-fuel substitutes for the United States or as a source of fuel oils and lubricants.

Despite the limitations on the available data, it has been possible to find fairly representative figures on many of these

TABLE 1.—ROUGH SUMMARY OF DATA

	Coal hydrogenation[2]	Coal-Fischer-Tropsch	Oil shale	Tar sands	Natural gas	Crude petroleum
Total North-American reserves, billions of tons of source material	4,000	4,000	> 400	> 500	> 3	?
Percentage of total source reserves most practical for exploitation	26	100	?	1	10 to 25	?
Potential yield from reserves suitable for exploitation gasoline, billions of barrels	1,000	6,000	50	> 2	2 to 4	10
Cost of gasoline[3] cents per gallon	15[1] to 24	9[1] to 18	10[1] to 15	8 to 12	5[1] to 9	5
Investment[4] dollars per barrel gasoline per day	6,500[1] to 13,500	2,800 to 10,000	3,200	1,355 to 3,300[1]	2,200 to 4,770	1,400[5] to 2,800

[1] The reported figures which appears more credible.

[2] Coal hydrogenation is based on subbituminous coal alone. Coal-Fischer-Tropsch is based on all coal including subbituminous. Oil shale reserves include only the material that is known to be rich and accessible. This is true also of tar sands.

[3] The costs of synthetic gasoline are without more than very rough relative significance because they do not take into account such important factors as transportation and markets for by-products. The cost of gasoline from natural gas, for example, is based on a gas cost corresponding to petroleum at 27 cents per barrel (B.t.u. basis). The value of coal and shale is merely the mining cost.

[4] Figures on investment are based on little more than guesswork, since all published detailed calculations are based on technology that is already obsolete.

[5] For crude petroleum the investment figure is based on 1937, when the net plant investment in crude-oil production was 3,210 million dollars and in refining, $848,500,000 (investment in transportation facilities and marketing being disregarded to keep estimates parallel). Some 519 million barrels of straight-run and cracked gasoline were produced in that year (during which 93 per cent of the oil produced was refined domestically, making adjustment to allow for this factor of little significance). These figures would yield an investment estimate for petroleum-production and refining facilities of $2,800 per daily barrel of gasoline, but this figure is disproportionately high since it fails to distribute any of the investment to products other than gasoline and involves a gasoline yield for 1937 of only 44 per cent; this figure could have been increased had gasoline been the sole desired product. It might appear fair to divide the investment burden among all products, thus halving the high figure; this procedure, however, would not be strictly parallel to that followed for the other materials. In any case a comparable estimate lies between the two extremes if it may be assumed that 1937 figures are acceptable.

supplemental reserves. In many cases, however, it was necessary to extrapolate data from estimates for small plants. Figures obtained may be compared only with extreme caution, but Table 1 presents a rough summary of some of the data compiled in this report. Reference should be made to the text for the interpretation of each figure.

Possible Trend of Development.—Since it is dangerous to prophesy in technical matters, the following analysis is offered merely in an attempt to polarize thought in connection with the general statistical study.

1. Petroleum companies are likely to build and operate Fischer-Tropsch plants for the conversion of natural gas to specialized petroleum products. The experience gained from this work will be applicable to the broader problem of the Fischer-Tropsch synthesis from coal.
2. Industry or government will make an intensive study of the continuous gasification of low-grade coal above or below ground with the idea of getting into large-scale production of gasoline by Fischer-Tropsch synthesis. Subbituminous coal or lignite will be used.
3. Unless or until radically new technology is discovered, high-pressure hydrogenation of coal to gasoline will not be developed, but hydrogenation of tars and residual oils may be practiced widely.
4. The Fischer-Tropsch process will not yield a cheap heavy fuel oil. This can be made either by low-pressure hydrogenation of coal or by the retorting of oil shale.
5. For a long time to come, no important amount of coal other than subbituminous and lignite will be used for synthesis.
6. Tar sands and oil shales will be worked but will not be an important source of substitute petroleum in the near future.

COAL

Much more is known about the coal resources of the United States and Canada than is known about oil shale and tar sand, the other important supplementary petroleum reserves. Their nature, extent, methods of mining, and many uses have been intensively studied by scientists and industrialists alike.

Coal made an important contribution to the emancipation of this country from industrial domination by Europe. It supplied the energy that activated the machines in factories and mills, that permitted the mining and the smelting of our minerals, that carried raw materials and finished products to all parts of our own country and to all parts of the world. Even in this day of enormous production and use of petroleum and natural gas and remarkable development of water power, more than half of the total energy used in the form of power, light, and heat in this country comes from coal. The nation's expanding civilization, however, has become dependent on some products which thus far have been produced in quantity only from petroleum; it is not impossible, however, that on some future day coal will provide many if not all of these products which have become so indispensable.

The essential component of all coal is carbon, associated with variable amounts of volatile matter. All coal also contains moisture, some sulphur, and inert material or ash. On the basis of the proportionate amounts of fixed carbon, volatile matter, and moisture, coals are ranked as anthracite, bituminous, subbituminous, and lignite. Coals are also classified as types, depending on appearance: bright, semisplint, splint, cannel, and Boghead. Thus a bituminous coal may be a bright coal, or a splint coal, or a coal of some other type.

The chemical composition of coal is determined not only by its rank but also by its type. For example, a bright bituminous coal may contain 61 per cent fixed carbon and a splint coal from the same bed in the same mine may contain 74 per cent fixed carbon. The bright coal may contain more than twice as much sulphur as the splint coal, and the heating value of the one may be substantially different from the heating value of the other.

Coals are relatives belonging to the same family, but this does not mean that they all look alike, behave in the same way, or that they will be equally useful as a supplementary petroleum reserve. On the contrary, it may be anticipated that experience will allow the classification of coals in terms of their suitability for conversion into liquid hydrocarbons. Presumably the characteristics that best will adapt a coal for conversion by one process will not necessarily prove to be the same as those that will adapt a coal for conversion by another process. This fact has been indicated by tests in which coals of different ranks and types were hydrogenated under standard conditions of temperatures, pressure, and time, and with the same catalysts. Some coals yielded twice as much liquid hydrocarbon as did others, but gave more process difficulties than did the lower-yielding coals. There is no doubt therefore that some coals will prove far better suited for conversion into synthetic oil than will others.

Geographic Distribution of Coal.—The accompanying map shows the general distribution of the known and probable coal

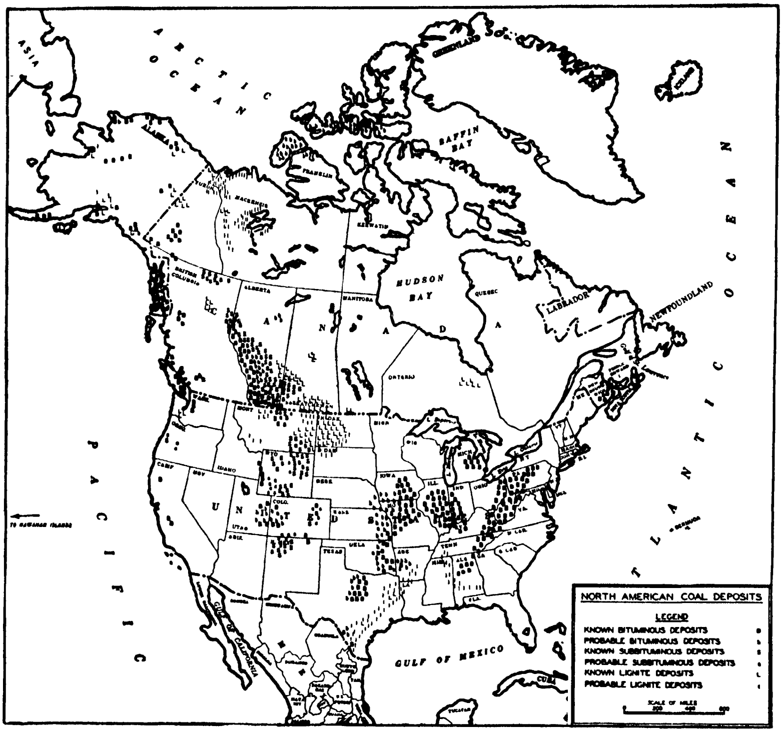

FIG. 1.—Location of North American coal deposits.

deposits in the United States and Canada. Anthracite is not shown on this map since its value as a residential fuel, its limited supply, and its relatively high cost of mining combine to establish a price level above that of other coals. It seems improbable that producers of synthetic petroleum would pay a premium for anthracite when their needs could be better supplied by a cheaper coal.

Bituminous coal is more valuable for most of the purposes for which coal now is used than are subbituminous or lignite coals.

These lower-rank coals have higher moisture contents, lower heating values, and deteriorate more rapidly when stored than does bituminous coal. It would be advantageous from many standpoints to use lignite and subbituminous coal rather than bituminous coal for the production of synthetic oil, and it happens that present technology indicates that processes can be designed which will make them even more suitable for synthetic-oil production than the higher ranking coal.

Geologic Occurrence.—Most of the coal in the world is found in rocks of Mississippian age or younger. The greatest deposits are in formations belonging to the Mississippian, Pennsylvanian, Cretaceous, and Tertiary periods. No coal is present in the older Cambrian, Ordovician, and Silurian rocks, and there is little in the Devonian rocks, because coal was formed from accumulations of plant material, and no evidence can be found that land plants existed prior to Devonian time. During subsequent periods, there were tremendous forests which supplied the plant material for the coal deposits.

The geologic evidence is clear that most of the coal in the world was formed in fresh-water swamps and, as would be expected, the associated rocks are shales and sands deposited by the streams which flowed into and near such swamps. This is in contrast to petroleum, which characteristically occurs in beds that were laid down under the sea. Petroleum is found in many localities, either in porous limestone or associated with thick limestone formations, whereas the coal-bearing formations are characterized by a scarcity of limestones.

Individual beds of coal range in thickness from a fraction of an inch to more than 100 ft. Some beds, like the Pittsburgh coal of Pennsylvania, underlie hundreds or even thousands of square miles; others have small lateral extent. As a general rule, several separate mineable beds are found in a coal-bearing area. The beds of coal may be horizontal, inclined, or even vertical, conforming in attitude with the associated rocks.

The great coal-bearing areas are regional synclines or structural basins, but local disturbance of the strata may tend to obscure the regional relationships. There may within the regional syncline, be uplifts or anticlinal warpings of the formations that, although minor when compared to the great synclinal depression, are themselves tens of miles in length.

Since many of the oil fields of the world also are located in great structural basins, oil fields and coal fields may exist in the same general area, in some instances the one overlying or underlying the other. Neither, however, can be used as an indication of the probable presence of the other. Oil is found in some regions where there is no coal at all, and conversely, coal occurs in many areas where there is no oil.

Procedure by Which Tonnage of Coal Has Been Estimated.—The estimates made for the U.S. Geological Survey in 1928 by the late M. R. Campbell have stood unchanged and unchallenged since they were made and are used in this report. It is unlikely that they are exact in detail, but an error of a few million or even a few billion tons would be lost in the huge total. There is little prospect that new discoveries will change the estimate. No important fields have been discovered during the past 16 years, and geologic conditions in this country are so well known that only a remote possibility survives for the discovery of deposits that would modify even slightly the existing estimate.

In preparing the estimate, all known beds of coal of mineable thickness were included. Beds of anthracite and bituminous coal 14-in. thick were considered minable, while the minable thickness arbitrarily assumed for subbituminous coal and lignite was 2 ft. It also was assumed that no coal would be mined at a depth of more than 3,000 ft. below the surface of the ground. There will be some exceptions, but they should not seriously affect the estimate.

The estimate makes no allowance for coal that will be lost in mining. In strip mines, where a thin overburden is removed and the coal is recovered by steam shovel or drag line, the loss is insignificant, but losses in underground mining may be as much as 50 per cent, and according to estimates made in 1923 by the U.S. Coal Commission they averaged at that time 34 per cent. Recent years have been marked by improved mining technique, and further improvements are to be expected. If the total reserves are reduced by 30 per cent, the minable reserves should be approximately indicated.

Availability of the Supplementary Reserves of Coal.—Knowledge concerning location, extent, and methods by which coal may be mined are adequate. The existing coal mines of the United States can supply a greater tonnage of coal than can be consumed by our peacetime industry when that industry is operating on the 1940 scale. At least some raw material could therefore be made available for the production of synthetic hydrocarbons without opening new mines or establishing a new mining industry, although the surplus that could be secured from existing mines would supply but a comparatively small part of the petroleum requirements of this country, and there are no substantial mining facilities for the types of coal that appear to be best suited to hydrogenation.

Furthermore, processes by which coal can be converted to liquid fuel and other petroleum products are in operation in other countries, and American technologists have the information that would allow them to install these known processes if such installations were justified by national security without reference to economics. Coal, however, is not and cannot be considered an available supplementary reserve in an economic sense until liquid hydrocarbons and, in particular, synthetic gasoline can be secured from it at a price no greater than these same products can be secured from other sources. The processes for liquifying coal, as they are now known, cannot force their products through this economic barrier.

Furthermore, coal cannot be considered a safeguard against a sudden emergency demand for a large increase in our available oil until an industry of some magnitude has been established, experience has been gained, and a large group of technologists and workers have been educated in the business of constructing and operating the plants to convert coal into gasoline and some of the other very essential products that are now secured from petroleum.

COAL HYDROGENATION

Discussion of Data.—An example of the incomplete character of present knowledge is illustrated by the fact that the only detailed cost data which can be found in the literature applies to the hydrogenation of bituminous coal, a grade which the Bureau of Mines has found difficult to handle. It is probable that a plant based on present knowledge would use subbituminous coal and would yield at least 1 bbl. of gasoline from 1 ton of coal (including coal requirements for power generation, steam, hydrogen, and process material). The bituminous grade would give a higher yield, but suitable process conditions are not now known. Lignite would give a lower yield.

The presently known United States reserves of subbituminous coal are believed to be about 800 billion tons, which would mean about 800 billion barrels of gasoline. Canadian subbituminous coal reserves, perhaps 500 billion tons, would add an additional 500 billion barrels of gasoline. At the moment, the large reserves of bituminous coal and lignite should be regarded as only secondary sources.

The man power for operation and mining per barrel of synthetic gasoline should range from about the same as present man-power requirements for gasoline from petroleum (other products neglected) to about twice this value. The steel requirements for the construction of coal hydrogenation plants are at least four times those of conventional petroleum refineries per barrel of gasoline per day.

The investment required for coal-hydrogenation plants per barrel of gasoline per day would probably be about $5,000, while the investment in mining operations would add about $1,500.

Ordinarily, coal would be hydrogenated directly to gasoline, and substantially no other petroleum products would be obtained. It is technically possible, however, to secure diesel fuels also, some sort of lubricating oil, and wax. A cheaper hydrogenation process can be applied to coal for the production of heavy fuel oil alone.

By conventional high-pressure hydrogenation of subbituminous coal, a gasoline of 70 to 75-octane number can be produced in 20 to 25 per cent yield (based on total coal), and by a type of hydroforming (or second catalytic hydrogenation) this can be increased to 85 to 90-octane number with about 25 per cent reduction in yield. The gasoline is highly aromatic rather than isoparaffinic.

The middle oil fractions (boiling 210–330°C.) contain about 20 per cent tar acids, which are a potentially valuable although too abundant source of phenols. After removal of these phenols, the raffinate is said to be suitable for diesel fuels. The heavier oils can be either recirculated for gasoline production or can be put through a series of expensive steps for the manufacture of an inferior lubricating oil.

Coal Reserves for Hydrogenation.—According to present technology, subbituminous coal is the only grade of coal which would be used for hydrogenation unless or until improved processes are developed. Anthracite coal can be disregarded, not only because of its small amount and its high price but also because of its process difficulties. Bituminous coal is capable of giving a higher yield of liquid fuel but presents operating difficulties. Lignite gives a lower yield of liquid fuel but could be used after the supply of subbituminous coal had been substantially depleted.

The available subbituminous coal of the United States is said to be about 818 billion tons, and reserves of lignite are believed to total about 939 billion tons. These materials are geographically distributed as follows:

TABLE 2.—GEOGRAPHICAL DISTRIBUTION OF UNITED STATES DEPOSITS OF SUBBITUMINOUS COAL AND LIGNITE
(In billion tons)

State	Subbituminous	Lignite
Idaho and Oregon	1.8	
Colorado	104 0	
Montana	62 8	315.5
New Mexico.	1.9	
North Dakota		600.0
South Dakota		1.0
Texas		23 0
Utah	5 2	
Washington	52 4	
Wyoming	590 0	
Total	818 1	939 5

It is interesting to note that 85 per cent of the subbituminous coal is in Wyoming and Colorado and that nearly all of the lignite is in Montana and North Dakota. Neither material is found in the East.

Canadian reserves of subbituminous coal have been estimated to total as high as 500 billion tons (believed to be a very high estimate), while deposits of lignite are believed to contain an additional 100 billion tons.

Oil Yields.—According to the testimony given by Bruce K. Brown (Assistant Deputy Administrator, PAW) at recent hearings on the subject of synthetic liquid fuels (1, p. 105),[1] 1 short ton of high-volatile bituminous coal will yield from 1.43 to 1.79 bbl. of gasoline, 1 short ton of subbituminous coal will yield approximately 1.11 bbl. of synthetic gasoline, and 1 short ton of lignite will yield approximately 0.8 bbl. of synthetic gasoline. These figures are based upon the recycling of oils heavier than gasoline and include coal requirements for power generation, steam, and hydrogen, as well as the coal charged as raw material. According to a reliable source (8) the actual gasoline yield from coal should approximate 2 bbl. per ton. Table 3 presents the data on oil yields from coals assayed in the Bureau of Mines' experimental plant (1, p. 176). Particular attention should be paid to the columns headed "Yield of assay oil," "Ultimate yield of gasoline," and "Net yield of gasoline"; the last gives figures comparable to those previously quoted. It might be noted further that it is generally conceded that the high-yielding bituminous coals are at present the hardest to liquefy, while the subbituminous and lignite coals in general liquefy more easily (1, p. 426).

Costs of Production.—Robert P. Russell (Executive Vice-President, Standard Oil Development Company) recently testified (1, p. 39, 56) that operating costs, including depreciation, for coal-hydrogenation plants using bituminous coal at $2.75 per ton would range from 15.5 to 22.6 cents per gallon of gasoline (for 30,000-bbl.-daily plants and 3,000-bbl.-daily plants, respectively). Mr. Russell's estimates are the only ones in the readily obtainable literature which are based upon detailed cost data. He presented no estimates for the use of other types of coal and was not willing, when questioned, to extrapolate his data. In general, the recent literature has revealed cost estimates for gasoline from coal hydrogenation ranging from 10 to 25 cents per gallon; the lower figure is based upon future potentialities which may be realized only by considerable research. Reference (8) states that 15 cents per gallon is accepted at present.

It is not practical to estimate costs per barrel of oil produced, since the hydrogenation of coal usually proceeds in two steps when gasoline is the desired product; the first step is designed to liquefy coal and recycle the heavy oil formed, while the second step

[1] Number and page in parentheses refers to bibliography at the end of this chapter.

hydrogenates the middle oil from the first step and recycles all fractions heavier than gasoline. It is possible to hydrogenate coal in one step to yield fuel oils as the desired product instead of gasoline, or it is possible to obtain gasoline, kerosene, and fuel oils by variations in the two-step process, but comparable data on a cost basis are not at hand.

Man-power Requirements.—In 1941, the average production of bituminous coal per man-day was 5.2 tons (14). It should be noted that in certain localities, especially by strip mining, the amount of coal producible per man is greatly increased (14.23 tons per man-day in 1938, with some localities reporting as much as 68.54 tons per man-day), but the figure of 5.2 tons per man-day was the 1941 national average. No figures as to the man-day output of subbituminous coal are immediately available, but assuming for the sake of an estimate that they are the same as for bituminous coal, it may be estimated that 17,300 men would be required to produce subbituminous coal for 100,000 bbl. daily of synthetic gasoline.

Average production of lignite in 1941 was 9.54 tons per man-day (3), so that approximately 13,200 men would be required to mine the coal (125,000 tons) needed to produce 100,000 bbl. of synthetic gasoline daily. Again, fewer men would be required for stripping operations.

Dr. Gustav Egloff of the Universal Oil Products Company has testified (1, p. 121) that the British plant which produces 3,000 bbl. of gasoline daily requires 6,000 men to produce the coal, de-ash it, wash it, grind it, and process it through the hydrogenation plant. On this basis 200,000 men would be required for the entire work of producing 100,000 bbl. of gasoline per day, but of course this figure has little or no value since it is based upon a small plant.

Little published data are available as to the man power which would be required to operate coal-hydrogenation plants other than the figure given by Dr. Egloff, who stated further that it could be greatly reduced in America. There is little reason to believe that man power requirements would greatly exceed those for modern production and refining operations. The drilling and production of some 1.25 billion barrels of oil in 1939, which yielded upon refining some 550 million barrels of gasoline, required about 170,000 workers for drilling and producing and 100,585

TABLE 3.—COALS ASSAYED IN BUREAU OF MINES EXPERIMENTAL PLANT

Origin and rank of coal					Analyses, per cent					Yield of assay oil				Ultimate yield of gasoline[1]				Net yield gasoline, gallon per ton of total coal used in process
					As mined			Moisture and ash-free		Weight, per cent		Gallon, per ton[2]		Weight, per cent		Gallon, per ton[2]		
State	County	Coal bed	Mine	Rank	Moisture	Ash	Volatile matter	Carbon	Oxygen	Moisture- and ash-free coal[3]	Coal as mined	Moisture- and ash-free coal[3]	Coal as mined	Moisture- and ash-free coal[3]	Coal as mined	Moisture- and ash-free coal[3]	Coal as mined	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Alabama	Jefferson	Mary Lee	Sayreton	Bituminous, high-volatile anthracite	4.2	9.8	27.0	86.9	5.0	60	52	159	138	42	36	122	106	55
West Virginia	Monongalia	Upper Freeport	Indiana Colliery no. 21	Bituminous, high-volatile anthracite	3.2	8.0	30.0	86.6	5.7	70	62	185	164	49	43	142	126	66
Pennsylvania	Allegheny	Pittsburgh	Bruceton[4]	Bituminous, high-volatile anthracite	1.6	6.3	37.0	84.2	6.8	70.5	64	187	170	49.5	45	148	130	68
Alabama	Walker	Black Creek	Empire[5]	Bituminous, high-volatile anthracite	2.7	2.9	36.0	84.3	7.5	70.5	66[5]	187	175[5]	49.5	46[5]	148	134[5]	70
Utah	Carbon	Lower Sunnyside	Columbia	Bituminous, high-volatile bituminous	5.5	4.9	38.8	82.1	9.5	75	67	199	178	52.5	47	152	136	71
Alaska	Matanuska	Upper Shaw	Eska[5]	Bituminous, high-volatile bituminous	3.7	6.8	41.8	81.0	10.5	73	67[5]	193	178[5]	51	47[5]	148	136[5]	71
Indiana	Vigo	Indiana no. 4	Saxton no 1	Bituminous, high-volatile coal	13.6	7.3	34.2	80.9	9.5	70	55	186	146	49	38.5	143	112	58
Illinois	Franklin	Illinois no. 6	Orient no 2	Bituminous, high-volatile coal	7.8	6.5	33.7	80.6	10.0	70.5	60	187	159	49.5	42	143.5	122	63
Washington	King	Strain-Upper McKay	Black Diamond	Bituminous, high-volatile coal	9.6	3.7	40.1	78.6	12.5	68.5	59	182	156	48	41	139	120	62
Colorado	Weld		Puritan	Subbituminous, bituminous	24.1	4.1	29.1	76.6	16.4	63	45	167	119	44	31.5	128	91	63
Montana	Rosebud	Rosebud	Colstrip	Subbituminous, bituminous	25.1	7.6	28.5	76.7	16.2	60	40	159	106	42	28	122	81	42
Wyoming	Sheridan	Monarch	Monarch no. 45	Subbituminous, bituminous	23.2	3.9	31.2	75.6	16.9	68.5	49	182	130	48	34	139	100	52
North Dakota	Mercer	Fort Union	Beulah[4]	Lignite	34.9	8.0	26.0	73.0	19.4	54.5	31	144	82	38	22	110	63	33
North Dakota	Ward	Coteau	Velva[4]	Lignite	39.5	4.5	26.0	72.0	21.4	52	32	138	85	36	22.5	106	65	34

[1] Calculation based on assumption of 70 per cent by weight of assay oil converted to gasoline.
[2] Assay oil assumed to have 265 gallons in 1 ton (2,000 lb.) and gasoline, 290 gal.
[3] Calculation based on moisture- and ash-free coal.
[4] Name of town.
[5] Figures are for "coal as mined and washed" for Columns (12), (14), (16), and (18) for Utah and Alaska coals.
Source: A. C. Fieldner, Chief of Fuels and Explosives Service, Bureau of Mines, Department of the Interior (1, p. 176).

workers for refining (transportation employees omitted). Thus, for the production of 100,000 bbl. daily of crude oil, approximately 4,960 men were required in 1939, while the total man power required for producing 100,000 bbl. of gasoline daily was approximately 18,000 men. This last figure is high, of course, since it disregards the fact that an equal volume of products other than gasoline was produced.

An extrapolated figure for coal hydrogenation, based on private data on England's small plant (8), yields a rough figure of 6,000 men for a plant to produce 100,000 bbl. of gasoline daily, and this source (8) states further that since this estimate is based on a small-scale plant, a more exact guess might be 2,000 men. The range between 2,000 and 6,000 is wide, but no better figures are available.

It may therefore be said that man-power requirements for gasoline production by coal hydrogenation (including mining) would be at least as large as those for gasoline production from petroleum (including oil production), or possibly twice as high.

Steel Requirements.—Various estimates have been presented (1, p. 38, 175) as to the amounts of steel which would be required for the construction of plants to produce gasoline by coal hydrogenation. These estimates vary from 8.3 to 14.1 tons per daily barrel of gasoline; hence plants to produce 100,000 bbl. of synthetic gasoline daily would require from 830,000 to 1,410,000 tons of steel, with the probable figure much closer to the lower estimate. Gasoline production from petroleum (other products disregarded) requires from 0.7 to 2.0 tons of steel per daily barrel; hence coal-hydrogenation plants require for the same gasoline output at least four times as much steel as petroleum refineries.

Investment Required.—According to Robert P. Russell (1, p. 36) the investment required for plants to produce 100,000 bbl. of gasoline daily would be between 750 million and 1,280 million dollars (for plants producing 30,000 bbl. daily and 3,000 bbl. daily respectively). Dr. H. H. Storch of the Bureau of Mines (1, p. 196, 203) has testified that to produce 1,750 bbl. of gasoline daily a plant would cost about 50 million dollars at present cost levels; on this basis, plants to produce 100,000 bbl. daily of synthetic gasoline would require an investment of 2,860 million dollars. The discrepancy between such estimates lies in the fact that the former are for much larger plants; Dr. Storch states (privately) that 500 million dollars might not be far wrong, and since the other estimates are based on European designs, this last estimate may be accepted as very credible.

The range of $1 to $10 per ton-year covers the investment required for coal mining (the low figures being for strip mining and the high ones for shaft and difficult drift mining). On the basis of a 300-day work year, using coal requirements as given by Bruce K. Brown (1, p. 105), and accepting $5 per ton-year as the investment required for everything, including the houses for workmen and railroad spurs, coal mines for hydrogenation plants to produce 100,000 bbl. of gasoline daily would require an investment of approximately 140 million dollars for subbituminous coal and 190 million dollars for lignite.

It would seem therefore that the investment required for coal-hydrogenation plants per barrel of daily gasoline (including mining operations) would approximate $6,500; this figure is more than three times the average estimated amount required for gasoline-production and -refining facilities (which figure probably falls somewhere between $1,400 and $2,800).

FISCHER-TROPSCH SYNTHESIS FROM COAL

Discussion of Data.—The Fischer-Tropsch process from coal involves two steps: (1) the gasification of any kind of coal or lignite, and (2) the catalytic conversion of the synthesis gas to petroleum products. The potential United States reserves of coal are said to approximate 3 trillion tons, with Canadian reserves perhaps as high as 900 billion tons. The yield of gasoline from bituminous would be about 2.3 bbl. per ton and that from subbituminous about 1.7 bbl.; the yield from lignite would be somewhat lower. The gasoline from the total North American reserves therefore would figure at several thousand billion barrels. The cost might run as low as 8 or 9 cents per gallon.

Man-power requirements for operation and mining per barrel of synthetic gasoline would be about the same order of magnitude as present man-power requirements for petroleum, or at least less than twice as high; they would be less than for coal hydrogenation.

It is believed that steel requirements for the construction of Fischer-Tropsch plants of the latest design might not be much higher than those for conventional petroleum refineries, although with modern catalytic refining of the synthetic crude, total steel requirements might possibly be about 50 per cent higher.

It has been recently estimated that Fischer-Tropsch plants might require an investment as low as $1,000 per barrel of gasoline daily. This figure is based on recent European methods of continuous coal gasification, about which little is known in this country. Based on conventional coking, the investment might be as high as $7,500 per daily barrel; in any case mining investment might add about $1,500 and catalytic cracking perhaps another $1,000.

In combination with modern refining processes, the Fischer-Tropsch process appears to be quite flexible and can be used to produce a variety of high-quality products. The straight-run Fischer-Tropsch gasoline fraction, constituting about 60 per cent of the total, has an octane number of about 50 to 55, or with 2.5 cc. of lead, 75. As an example of the older-type thermal processing of Fischer-Tropsch primary product, the total material about 400°F. can be thermally cracked and blended with the straight-run 400°F. end-point gasoline to produce an 80 per cent yield of finished gasoline having a 68- to 70-octane number. By a combination of polymerization of the C_3-C_4 fraction, catalytic reforming of the 175 to 400°F. naphtha, and catalytic cracking of total material above 400°F end-point, it is possible to obtain gasoline yields of about 85 per cent by volume. About 60 per cent of this could be used for aviation-fuel-base stock, and the remaining 40 per cent would be suitable for motor gasoline.

The primary products contain about 22 to 23 per cent of high-quality, 100-cetane-number diesel oil. This material can be blended with 60 to 70 per cent of low-cetane-number petroleum oils to produce a 50- to 60-cetane-number diesel fuel. By mild cracking of Fischer-Tropsch wax, it is also possible to produce a diesel fuel fraction of about 85-cetane number.

Excellent lubricating oils probably can be obtained from the Fischer-Tropsch primary products, either by polymerization of high-boiling olefins or chlorination and alkylation of suitable paraffin fractions. For maximum lubricating-oil production, the C_3-C_4 fraction together with the cracked product boiling at about 150°C. can be made to produce a 50 per cent yield of finished lubricating oil and a 30 per cent yield of motor-fuel stock.

The primary wax, amounting to 10 to 20 per cent, can be converted into waxes of various melting points. A 195°F.-melting-point wax was being produced commercially in Germany before the war, and waxes of even higher melting points can be made.

Fischer-Tropsch products are too high-grade to be used for heavy-fuel purposes.

Reserves.—The earlier Fischer-Tropsch process was limited to coal which had reasonably good coking properties, but the more recent process of continuous gasification is said to apply to all kinds of coal. From a technological standpoint, domestic coal reserves for this process can be considered to be the total coal reserves, but naturally the cheapest grades would be used first unless some offsetting-process advantage is found for more expensive grades.

TABLE 4.—COAL RESOURCES OF NORTH AMERICA

Rank	Reserves (billions of net tons)		
	United States[1]	Canada[2]	Alaska[3]
Anthracite	15	(3)	>4
Bituminous	1,406	260	>2
High-volatile	1,353		
Low-volatile	53		
Subbituminous	818	522[3]	4
Lignite	939	98[3]	>14
Total	3,178	880	>22

[1] Data from (1, p. 98, 171). Estimates are believed to be accurate.

[2] Data from Moore, E. S., "Coal," John Wiley & Sons, Inc., New York, 1940, p. 358, 413. Estimates are only approximate, and those for Canada may be quite high.

[3] From data at hand it was impossible to differentiate between anthracite and semi-bituminous statistics, since deposits lie close together. Similarly, the statistics for sub-bituminous coal and lignite were not clearly differentiated, so that all joint deposits (11 billion tons) were lumped under subbituminous coal.

The total coal reserves of North America are shown in Table 4. The geographical distribution of the coal reserves of the United States is shown in Table 5 (1, p. 98); both Table 4 and Table 5 are in amplification of the earlier presented map.

Oil Yields.—According to Dr. A. C. Fieldner of the Bureau of Mines (1, p. 172) and Bruce K. Brown of PAW (1, p. 108), approximately 0.70 ton of bituminous coal is required to yield the coke needed per barrel of Fischer-Tropsch motor fuel and to provide the power, steam, etc. needed for the process; this figure checks closely with estimates of Robert P. Russell (1, p. 35) and Fred Denig (1, p. 234). Thus the yield of gasoline per ton of bituminous coal used in the older form of Fischer-Tropsch synthesis would be approximately 1.43 bbl.

Abroad, the synthesis gas used in the second step of the process is frequently made by gasifying lignite, subbituminous coal, and

TABLE 5.—AVAILABLE COAL RESOURCES OF THE UNITED STATES[1]
(In billion tons)

State	Anthracite coal	Bituminous coal	Subbituminous coal	Lignite
Alabama	. .	66.63		
Idaho and Oregon	.....	0.69	1.75	
Arkansas . .	0.22	1.29		
Colorado . . .	0.09	12.62	104.05	
Georgia .		0.92		
Illinois ...	. .	197.79		
Indiana	.	51.97		
Iowa. . .	.	28.69		
Kansas. .	. .	29.65		
Kentucky. .	.	121.55		
Maryland..		7.68		
Michigan		1.93		
Missouri. .	.	83.68		
Montana.	.	2.61	62.85	315.47
New Mexico. .		18.81	1.86	
North Carolina..		0.07		
North Dakota .		. .	.	599.95
Ohio		91.96		
Oklahoma	.	54.76		
Pennsylvania	14.59	103.30		
South Dakota.		. .	. . .	1.02
Tennessee.		25.29		
Texas..		7.98	......	22.93
Utah...	.	87.98	5.15	
Virginia..	0.49	20.65		
Washington.		11.25	52.42	
West Virginia.... ...		147.75		
Wyoming...	. ...	30.31	590.00	
Total.............	15.39	1407.82	818.08	939.37

[1] Data presented by W. E. Wrather, Director, Geological Survey, Department of the Interior (1, p. 98).

other varieties of coal (instead of coke) in continuous generators. Using continuous gasification of bituminous coal instead of coke formation first, it is said (8) that a yield of 2.3 bbl. of gasoline per ton of coal is obtainable; for subbituminous coal the yield is 1.7 bbl. of gasoline. The yield from lignite would be still lower, but so might be the cost.

As regards primary products of Fischer-Tropsch synthesis, Dr. A. C. Fieldner (1, p. 172) states that 4 to 4½ tons of coke (5 to 6 tons of bituminous being required to yield the coke) are required to yield 1 ton of primary products. Assuming that the specific gravity of the average crude is about 0.71 (8), it would seem that about 1.4 to 1.7 bbl. of primary products are obtained per ton of bituminous coal used in this process for all purposes. When continuous gasification is used, a much higher yield may be anticipated—perhaps as high as 2.9 bbl. Yields for subbituminous coal and lignite would be somewhat lower.

Costs of Production.—Robert P. Russell (1, p. 39) has stated that a Fischer-Tropsch process of the coking type but of present European design, using bituminous coal at $2.75 per ton, would yield gasoline costing 19.2 cents per gallon, including depreciation (which amounts to 4.5 cents per gallon in his figures). Fred Denig (1, pp. 242–246) estimates that the cost of Fischer-Tropsch gasoline from coke (from bituminous coal) would be 24.4 cents per gallon, and that the cost would be 18.2 cents per gallon from coke from subbituminous coal. All these estimates are the results of detailed calculations but deal with the older European designs. It has been stated (8) that costs actually might be as low as 8 or 9 cents per gallon for plants using continuous gasification of subbituminous coal and lignite.

Man-power Requirements.—According to previous calculations, between 43,500 and 70,000 tons of bituminous coal would be required for a daily production of 100,000 bbl. of gasoline, depending upon the process for producing synthesis gas. In 1941, when production of bituminous coal averaged 5.2 tons per man-day, this gasoline production would have required a mining man power of 8,370 to 13,500 men. In terms of 100,000 bbl. per day of primary products instead of gasoline, as many as 10,000 to 15,000 men might be required (a rough estimate). For subbituminous coal for the modern process, approximately 11,300 men would be required to mine the coal needed for the daily production of 100,000 bbl. of gasoline. Man-power requirements for lignite are not at hand.

Based on data (8) to the effect that one German plant producing 35,000 tons per year of crude oil (from which 25,000 tons of gasoline are obtained) has a staff of 230 men, and an estimate that the crew could be halved for large-scale plants (this plant producing only 1,000 bbl. per day), the production of 100,000 bbl. of crude oil daily would require operating man power of less than 11,500 men, while the production of 100,000 bbl. of gasoline daily would require a staff of approximately 16,400 men. Since it is generally known that Fischer-Tropsch synthesis requires less man power than coal hydrogenation, these figures are quite high and probably can be taken as upper limits.

Compared with the production of gasoline from petroleum, therefore, it would seem that the production of Fischer-Tropsch gasoline from coal (including coal mining) would have man-power requirements equivalent to the preparation of gasoline from petroleum (including production), or perhaps 150 per cent as great.

Steel Requirements.—Various estimates have been presented as to the amounts of steel which would be required for the construction of plants to produce gasoline by Fischer-Tropsch synthesis. These estimates vary from 8.9 to 14.3 tons per daily barrel of gasoline, hence plants to produce 100,000 bbl. of synthetic gasoline daily would require from 890,000 to 1,430,000 tons of steel. These estimates include cracking plants and accessories, which, however, constitute only about 3 per cent of requirements. Robert P. Russell (1, p. 38, 57) presented the lower estimate, while Fred Denig (1, p. 246, 247) and Dr. A. C. Fieldner (1, p. 175) agreed closely as to the higher figure.

For modern plants using continuous gasification and thus avoiding coke production and use, it has been estimated (8) that these earlier figures may be as much as 10 times too high. If this is correct, steel requirements would be the same order of magnitude as those for gasoline production from petroleum.

Investment Required.—According to Robert P. Russell (1, p. 36), the investment required for plants to produce 100,000 bbl. of Fischer-Tropsch gasoline daily from coal (according to the present European design) would be approximately 760 million dollars. Fred Denig (1, p. 243) presented figures which yield an estimate of 618 million dollars (for prewar economic conditions, as are all his estimates). Bruce K. Brown (1, p. 111) gave figures which would yield an estimate of 1 million to 1,667 million dollars.

It has been roughly estimated (8) that for plants of modern design the figure might be as low as 100 million dollars per 100,000 bbl. of gasoline daily—approximately one-fifth the corresponding figure for coal-hydrogenation plants.

Taking 2 bbl. per ton of coal as a rough estimate for modern plants, and $5 per ton-year as a rule-of-thumb investment figure for coal mining, the production of 100,000 bbl. of gasoline per day would require an investment in coal-mining facilities of about 150 million dollars for a 300-day working year. Much less would be required for strip mining, of course.

It may therefore be seen that total investment requirements may be as low as $2,500 per daily barrel of gasoline, considerably less than those for coal hydrogenation, and possibly the order of magnitude as those required for gasoline production from petroleum.

COAL CARBONIZATION

The consensus is that neither low- nor high-temperature carbonization of coal can be deliberately used as a method for producing very large quantities of synthetic liquid fuels. This opinion results from the fact that yields per ton are low, and vast amounts of coke are produced. Such coke is a very valuable smokeless fuel, it is true, and it is probable that low-temperature carbonization processes can yield liquid fuels at lower costs than by the hydrogenation of coal when markets for this coke can be found. There has been some discussion of linking low-temperature carbonization with Fischer-Tropsch synthesis to make use of the coke, but modern coal-gasification processes would seem to be much preferred.

A. C. Fieldner has recently presented a clear analysis of low-temperature carbonization (1, pp. 168–170). His figures show that "the average yield of gasoline that might be made per ton of high-volatile *A* bituminous coal carbonized without hydrogenation would be about 20 gal.;[1] and utilization of the same amount of coal in direct hydrogenation without carbonization would yield about 60 gal. of gasoline. It is seen therefore that hydrogenation produces six times[1] as much gasoline as low-

[1] These figures do not agree. It seems possible that the gasoline yield per ton should read 10 instead of 20 gal.

temperature carbonization, and it does not depend on the marketing of smokeless solid fuel as the principal product."

George W. Carter of the University of Utah (1, pp. 353–356) has estimated that a low-temperature carbonization plant with modern oil-cracking facilities would cost on the order of $4,000 per barrel of gasoline daily (for a plant to produce 1,000 bbl. of gasoline per day). Only 6 gal. of better than 70-octane-number gasoline would be produced per ton of coal, along with 0.67 ton of smokeless fuel and 10 gal. of phenols. The proposed process would be even less efficient than first appears, for it is proposed to produce the 6 gal. of gasoline by cracking 15 gal. of the neutral tar to coke. Carter states that the cost of coal carbonization would be $2.50 per ton of coal, figuring the cost of coal as $1.55 per ton. Allowing a value of $4.25 per ton of smokeless fuel produced, and 94 cents per barrel of oil at the plant, and removing 40 per cent of the tar in the form of phenols, Carter estimates that the 6 gal. of gasoline produced by cracking would cost about 10 cents per gallon. A gallon of benzol scrubbed from the carbonization gases raises the total motor-fuel yield to 7 gal. per ton of coal. These yields are below the figures given by Fieldner.

I. C. Karrick (1, pp. 334–340) has also presented data on the subject. He shows much higher oil yields for many Rocky Mountain coals, and his estimates would yield very low gasoline-production costs. Frank Mueller, President of the American Lurgi Corporation (1, p. 145), Walter H. Wheeler, a consulting engineer (1, p. 155), and K. L. Storrs, President of the Coal Logs Company (1, p. 387), have also presented recent data on the subject.

Without going into the necessary calculations it is clear

1. That oil and gasoline yields are much lower than for other processes.

2. That man-power requirements would be staggering for use on any large scale (unless the coke were used for Fischer-Tropsch synthesis, which would raise the cost of coal-carbonization fuels by lowering the by-product credits).

3. That costs per gallon of gasoline might be lower than for the hydrogenation of coal under favorable circumstances.

4. That the investment per daily barrel of gasoline would be on the same order of magnitude as for coal hydrogenation, or

OIL SHALE

An oil shale is a shale containing little or no liquid oil or hydrocarbons that can be removed by ether, chloroform, or carbon tetrachloride (under normal conditions of treatment), but from which larger quantities of oil can be obtained by destructive distillation. This broad definition describes not only the deposits that have been classed as oil shale in publications which have described the rocks from which liquid oil to supplement petroleum may be secured, but also countless billions of tons of shale from which traces of from 3 to 4 gal. of oil per ton of shale can be recovered. Therefore, the distinction between what may be considered a supplementary reserve and that which will fall within the technical definition of an oil shale is economic.

Factors that Determine Whether or Not a Given Deposit May at Some Future Date Become a Supplementary Reserve.—1. Richness—the amount of liquid hydrocarbon which may be recovered from a unit of shale.

2. The cost of mining a unit of this oil shale. This factor depends on the mechanical operation of digging and loading the rock, its accessibility, the method which must be employed in mining, the availability of an adequate water supply to permit effective mining operations, the cost involved in disposing of the spent shale or waste, and other factors.

3. The cost of distilling a unit of this oil shale.

4. The products which may be secured from the oil recovered by distillation.

5. The location of the deposit with relation to markets. The costs of operation that can be borne by any deposit of oil shale will be determined by the cost of hydrocarbon products from other sources of supply. Oil shale can be worked wherever and whenever the cost of securing hydrocarbon products from it is no greater than the cost of securing them from other sources. Thus the oil shales of Scotland were profitably exploited prior to the time when crude petroleum in great quantities was imported by England from the oil fields of the United States, South America, and the Near East.

If the cost of transporting the product to market is very low, high costs of mining and distilling or low yields per ton may be compensated for to some extent by a negligible cost of distributing the finished product. Thus the oil shales in Ohio and Kentucky, where there is a large adjacent market for hydrocarbon products, have a transportation advantage over the richer shales in western Colorado, Utah, and Wyoming, which are remote from large centers of consumption.

6. The size of the deposit. The value of the liquid hydrocarbon that can be secured by mining and distilling the shale in a

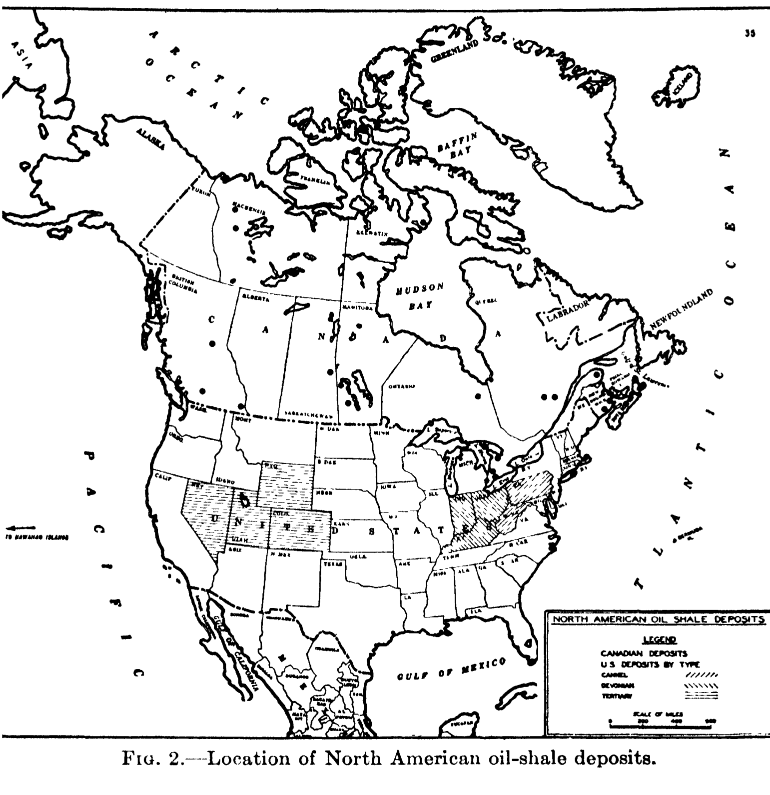

FIG. 2.—Location of North American oil-shale deposits.

given deposit must exceed the original investment and the estimated operating costs. This precludes working very small deposits, even though the shale in such deposits may be phenomenally rich.

Geographic Distribution of Oil Shales in the United States and Canada.—The geographic distribution of the deposits of oil shale that now seem most important is shown on the accompanying map (p. 181). The map does not indicate areas known to be underlain by oil shale at depths ranging from several hundred to a few thousand feet, nor does it outline large areas where oil shales that will yield only a few gallons of oil per ton are known to exist. Known Canadian deposits are indicated by dots; the extent of these deposits is not known.

Geologic Occurrence of Oil Shale in the United States and Canada.—Shales which will yield oil on distillation are found in rocks belonging to each of the major geologic periods. The richest and most extensive deposits, and the ones that are therefore most nearly commercial, are in rocks belonging to the Devonian, Mississippian, and Tertiary periods. These shales are the bottom sediments that accumulated below extensive bodies of shallow water, which might be either fresh or saline. In these shallow-water bodies flourished a remarkable growth of water plants, dominantly algae, some of them very similar to the algae that are popularly but incorrectly called slimes or mosses, which may today be observed growing beneath the water surface in streams, pools, and lakes. The waxy, fatty, and resinous parts of these water plants together with organic material that might be blown into the water bodies and the remains of insects and in some instances of fish, all settled to the bottom along with the clay and very fine sand that was washed into the water bodies and was fine enough to remain suspended for a period in the comparatively quiet water and be widely distributed throughout its expanse. Judging from the thickness of the accumulated oil shales, some of these lakes must have persisted for hundreds of thousands of years before they were either dried up by change of climate or terminated by earth movements which destroyed the barriers that had permitted the water to accumulate.

The richest oil shales are those where the bulk of the rock comprises the remains of the algae and other plants, with a comparatively small per cent of mineral matter, which represents the clay and fine sand in the water bodies beneath which the shale accumulated. The leaner shales contain a comparatively high percentage of mineral matter, with the remains of plants, insects, and other organisms comprising a minor part of the rock as a whole.

There is no sharp line between oil shales and the types of coals known as cannel coals and Bogheads. The cannel and Boghead coals might be called ultrarich oil shales, since they are composed almost 100 per cent of the products that resulted from the decomposition of water plants that grew in bodies of water which were so protected that practically no mud or sand was mixed with the organic matter.

Procedure by Which Tonnage of Oil Shale Has Been Estimated.—All past estimates of the tonnage of oil shale in the United States and Canada have been approximations based on assumptions that may or may not be valid. They do not accurately tell how much oil shale actually is available, or how much liquid hydrocarbon can be obtained from it. They do serve, however, to leave no doubt that the total tonnage of oil shale is very large and that it contains far more oil than has been produced from the oil fields of the world.

The most dependable of these studies seem to be those by Dean E. Winchester, especially one on the "Oil Shale of the Rocky Mountain Region," published in 1923 by the United States Geological Survey, and a later report on the entire country, published in 1928. Most of the estimates of the oil shale in other parts of the United States have been based on even less work and involve more questionable approximations than do the estimates by Winchester in the first report. The extent to which approximations may affect these estimates is well illustrated by two other estimates of the oil that may be recovered from the black shales of Kentucky and adjoining states. One author, writing in 1927, estimated that there were enough shales which would yield 13 gal. of oil per ton and easily available for mining to yield 60 billion barrels. Another author, writing in 1928 and assuming a yield of 10 gal. per ton of shale, estimated that the minable deposits might be expected to yield only about 18 billion barrels. At the moment this difference is unimportant, since existing technology will not permit oil from shales yielding only 10 to 13 gal. per ton to compete with petroleum products.

The procedure followed by Winchester in the Rocky Mountain region was to determine the approximate outline and extent of the areas where oil shale occurred at or close below the surface. The thicknesses of exposed beds of oil shale were measured at selected points. In this rugged region thousands of feet of strata are exposed in deep canyons and on the abrupt slopes of mesas and mountains, so that there were many localities where accurate measurements could be made and samples of the exposed oil shale could be secured.

It was assumed that the measurements thus made were representative of the entire deposit, or that from them increases or decreases in the thickness of layers of oil shale could be estimated. Many samples collected from many beds of oil shale were distilled to determine the yield of liquid hydrocarbon. Fragments of these same samples were then heated in glass test tubes, and observers were trained to correlate the test-tube results with those obtained by distillation. Subsequently, by using the quick test-tube method the approximate yield of hundreds of additional samples was determined. It was assumed that the beds that were sampled would be uniform in yield of liquid hydrocarbons, or that by averaging the yields secured by sampling the same bed at widely separated points the approximate yield of the stratum as a whole could be estimated.

It is believed that the estimates of yield determined by these approximations were low, since Winchester depended in great part on samples taken from beds that had long been exposed to the weather, and more recent work has demonstrated that fresh samples taken from drifts or tunnels yield more oil than do the samples from the outcrops. However, for present purposes it is immaterial whether the estimates of tons of oil shale present and of barrels of oil which this oil shale contains are somewhat higher or somewhat lower than the actual amount.

The figures in all published estimates depend on the factors which the estimator believed would determine the minability of the deposits. Whether or not a deposit can be mined depends on the cost of the mining operation and on the value of the material which is mined. Technology may lower costs, and scarcity may increase value. These factors may ultimately make many of the existing estimates appear ultraconservative.

No existing estimate gives any value to the great tonnage of oil shales that occur at depths of from a few hundred to a few thousand feet below the surface. For example, much of eastern Oklahoma and eastern Kansas are underlain by the Kinderhook formation, which corresponds in age and characteristics to some of the oil shales that crop out in Kentucky.

Availability of the Supplementary Reserves of Oil Shale.—No significant part of these reserves are available at present, nor will they be commercially available as long as consumers of petroleum products can satisfy their needs at a lower cost than these needs can be filled by products from oil shales.

It is a fallacy to think of all or even most of domestic oil shales as available. For example, if all the oil shales of western Colorado, eastern Utah, and southwestern Wyoming were mined, a desert 200 miles long and 150 miles wide would be created that would surpass in complete desolation anything the world has ever seen. The rivers that drain this area would not only be loaded with the fine-grained material from the expanse of spent shale, but also with the chemicals that had been rendered soluble by distilling this shale. This would affect regions as far away as the Imperial valley of California.

Similar limitations will affect the utilizing of oil-shale deposits in other parts of the United States. Oil shale that underlies communities or valuable surface lands cannot be extracted under existing conditions except by mining methods that will completely protect the surface. There must be provision for the disposal of the spent shale, and pollution of streams and ground water by chemicals leached from the shale must be prevented.

Some of the oil shale of the Rocky Mountains will be economically unavailable for an indefinite time because of the great difficulty and expense that would be incident to developing roads and water supply to make available oil-shale deposits in remote and rugged areas.

Discussion of Data.—The proportion of our oil-shale reserves which might be considered a primary source or substitute fuel depends largely upon geologic factors and location. It would seem that around 100 billion barrels of crude would be not too difficult to secure, or perhaps 50 billion barrels of gasoline.

The mining of oil shale is said to be somewhat cheaper per ton than the mining of average coal, but the yield of crude oil per ton of oil shale is only about one-half (in some cases). Even so, the investment cost of oil-shale mining has been figured at only about $1.50 per barrel of crude per year, compared with a possible mining investment of $5 per barrel of gasoline by coal hydrogenation and $2.50 for Fischer-Tropsch.

Crude shale oil is produced from oil shale by retorting. · The cost of this crude is made up of mining and retorting costs, and estimates have been as low as $1.75 to $2 per barrel. Shale oil, however, is a low-grade crude, so that the cost of converting this crude to gasoline might be comparable with the cost of processing a heavy natural petroleum.

Man power for mining and operation to obtain crude oil would be somewhat higher than man-power requirements for the production of petroleum. Additional man power would be required for refining the crude, but requirements would not be much greater than for petroleum refining.

Steel requirements would not be much higher than for conventional petroleum refineries.

The investment required for retorting has been figured at about $700 per barrel of crude per day. To this should be added about $400 for mining, and more for refining the crude. Per daily barrel of gasoline, the investment would total about $3,200.

By cracking to a heavy residuum it is possible to obtain gasoline yields from shale oil ranging from 35 to 55 per cent, while cracking to coke results in 50 to 60 per cent yields. Octane numbers (A.S.T.M.) range from 55 to 75, depending on the shale oil and the cracking process. Higher yields (about 80 weight per cent) of gasoline (65- to 67-octane number) can be produced by hydrogenation. These hydrogenated gasolines have high lead susceptibilities, and with 3 cc. of lead may have octane numbers in the range of 83 to 85.

By hydrogenation may also be produced diesel fuel, lubricating oil, and paraffin-wax fractions in yields of almost 100 weight per cent. The hydrogenated diesel fractions are reported to have cetane numbers in the range of 60 to 75, and the lubricating oils are said to resemble Pennsylvania machine oils. It appears that hydrogenation is the most successful method of refining shale oil, although possibly not the cheapest method for gasoline production.

As in the case of the products from coal hydrogenation, shale oil is potentially an important source of organic chemicals. By-products include nitrogen bases, present to the extent of 2 to 5 per cent, and phenols, which may be present in even larger amounts.

Reserves.—Oil-shale reserves of the United States have been estimated to total some 400 billion tons (16). These reserves are said to contain some 100 billion barrels of recoverable oil. Almost all these estimates are based upon a survey made many years ago by the late Dean E. Winchester. His estimates by his own admission were conservative, and Martin J. Gavin, chief of the refining section of the foreign division of PAW, has testified (1, p. 130, 131) that certain tests made by the Bureau of Mines in a rather limited area in Colorado and Utah bear out this contention. The need for a more modern survey has been discussed in some quarters (1, p. 127). W. E. Wrather has testified (1, p. 99) that since Winchester's survey large additional Ordovician oil shales have been discovered in Nevada. It is known that oil-shale deposits also exist in Tennessee, Alabama, Montana, and other states, but the extent of these deposits is not known exactly, nor are they as rich in oil as those listed on Table 6.

Table 6 is adapted from Winchester's report. As can be seen, he subdivided the oil shales into three classes: Tertiary oil shales of the Rocky Mountain region, Devonian black shales of the eastern states, and the cannel shales of the eastern states. As A. J. Kraemer, senior refining engineer of the Bureau of Mines, has stated (1, p. 313, 314), Winchester based his recoverable-oil estimates on varying factors of market accessibility, mining costs, mining losses, etc., for each of the three classes; his estimates, incidentally, were made at a time when average well oil was valued at $5 to $6 per barrel, and hence in some cases may be too high.

For the Tertiary oil shales, because of the present remoteness from markets and "the probable added cost of mining due to the possible necessity of using underground mining methods," Winchester stated that "no (Tertiary) oil shale was considered minable if it was less than 1-ft. thick or if it would yield less than 15 gal. of oil to the ton, or less than 3,000 bbl. of shale oil per acre of shale land." As Kraemer states, this means that "a shale stratum 4-ft. thick and yielding 15 gal. of oil per ton of shale, or a stratum 1-ft. thick yielding 60 gal. of oil per ton is minable" (1, p. 313). To be ultraconservative, Winchester estimated his recoverable oil on the basis that only 60 per cent of such shale would reach the retorts. He actually believed it not at all impossible that 95 per cent of the minable shale could be used, and Kraemer states that "in the best operations, using the most economic, large-scale mining methods, the percentage (60) doubtless would be larger."

TABLE 6.—ESTIMATE OF OIL RECOVERABLE FROM OIL SHALES[1]
(In thousand barrels of 42 U.S. gal.)

State	Total oil	Recoverable oil
Tertiary oil shales:		
Colorado	79,625,998	47,625,598
Nevada	6,039	3,623
Utah	48,800,000	25,680,000
Wyoming	3,044,000	1,826,400
Total Tertiary oil shales[2]	125,476,037	75,335,721
Devonian black shales:		
Indiana	7,680,000	6,912,000
Kentucky	10,978,500	9,880,704
Total Devonian black shales[3]	18,658,560	16,792,704
Cannel shales:		
Pennsylvania	13,800	8,280
West Virginia	13,800	8,280
Total cannel shales	27,600	16,560
Grand total	144,162,197	92,144,985

[1] Source: Winchester, Dean E., "The Oil Possibilities of the Oil Shales of the United States," Appendix 1, Report 2 of the Federal Oil Conservation Board to the President of the United States, January, 1928, Washington, D.C., 1928.

[2] This estimate does not include small amounts of oil shale known or reported in the states of California, Montana, and Oregon.

[3] No estimate is made for the states of Ohio and Tennessee, although it is recognized that undoubtedly there are areas of minable oil shale in these States.

A large percentage of the Devonian black shales of the eastern United States are said to lie near the surface and to be minable by open-cut methods. They lie near markets, supplies, and labor, "thus enhancing their value and making it probable that thin strata and lean shales can be worked" (1, p. 313). Winchester stated in his estimate that "no (Devonian black) shale was considered minable if it was less than 1 ft. thick or if it would yield less than 10 gal. of oil to the ton of shale or less than 2,000 bbl. of oil per acre." As Kraemer states, "only oil shale that might be mined by open-cut steam-shovel methods was considered in making the estimates; consequently, it was estimated that 90 per cent of the shale in the ground would reach the retorts for treatment."

The cannel shales of the coal measures, which lie in Pennsylvania, West Virginia, and Missouri, are said to be high-ash cannel coals. Kraemer states that the deposits are "characteristically lenticular and local" and that Winchester estimated that not more than 60 per cent of the cannel shale in the ground would reach the retorts.

From these figures it can be seen that the oil-shale regions of Colorado, Utah, and Wyoming, far from the major present sources of petroleum, contain some 75 billion barrels of recoverable oil, while the Indiana-Kentucky region contains some 17 billion barrels. Most estimators agree that these figures are conservative.

It is impossible to estimate Canadian oil-shale reserves from the literature; in fact A. A. Swinnerton of the Canadian Bureau of Mines stated in 1938 (2) that "sufficient development work has not taken place to determine the oil-shale reserves in even the most favorably situated deposits." From what little is known, Canadian reserves do not appear at all comparable to those of the United States.

Oil Yields.—Scottish shale-oil operations have long used shales with an oil yield of 22 to 24 gal. per ton. "There are billions of tons of shales in the Colorado deposits (and elsewhere) which will yield double this amount of oil, and 'vast quantities' that will yield from 50 to 60 gal. per ton. In addition to these are immense tonnages which will equal the Scotch in oil content" (11). The Bureau of Mines' experiments at Rulison, Colo., used shales with an assay value (including 10 per cent dilution) as low as 23.8 gal. of oil per ton of shale and did not term these uneconomic (10). A. J. Kraemer (1, p. 299) recently stated that "deposits of sufficient size and richness to warrant utilization range in assay value from about 25 to 45 gal. (0.595 to 1.07 bbl.) of oil to the ton." Whether he meant this to include all United States shales is not clear.

It is obvious that the richest shales (when available in large deposits) will be used first for oil production, so that with the improvements in technology that are certain to occur it may eventually be practical to recover oil from shales whose oil contents are now considered too lean. It would seem fairly safe therefore to consider as relatively economic those appreciable deposits of oil shales whose oil content exceeds 20 bbl. per ton. Retorting operations in general yield 95 per cent of the oil in the shale being processed. On this basis, 220,000 tons of shale with an assay value of 20 gal. to the ton would have to be mined per day to yield 100,000 bbl. of oil per day. Only 177,000 tons of shale would be needed for shale with oil-assay value of 25 bbl. per ton, and only 98,300 tons for shale with an oil-assay value of 45 gal. per ton.

"Yields of gasoline (of 225 to 437°F.—end-point) of from 35.2 to 55.3 per cent have been obtained by cracking American, French, Australian, and Scottish shale oils to residuum at 414 to 449°C. (1033 to 1096°F.) and at pressures of 120 to 175 lb. per sq. in. The yields obtained depended upon the nature of the oil, the cracking conditions, and the quality of the residuum. Cracking to coke gave gasoline yields of 50 to 60 per cent" (16). A. J. Kraemer (1, p. 317) has stated that cracking to coke and gas (on the basis of 1929 technology) can yield 25 gal. of gasoline (23 gal. after treating) per barrel of crude shale oil (60 per cent), and that higher yields probably can be obtained by use of modern processes. Hydrogenation of shale oil, incidentally, gives volumetric yields of gasoline on the order of 100 per cent, although probably at slightly higher costs.

It is highly probable that shale oils would not be cracked completely to gasoline, as most of them contain varying percentages of the entire range of petroleum products, but assuming that gasoline were the sole desired product and using the 60 per cent yield basis, some 366,000 tons of shale with an oil-assay value of 20 gal. per ton would be required to yield 100,000 bbl. of gasoline per day. For oil-assay values of 25 bbl. and 45 bbl. per ton respectively, 296,000 and 164,000 tons of shale would be required daily for the same gasoline production.

Costs of Production.—The available cost data for no other petroleum substitute are more conflicting than are those for shale oil. In regard to mining costs, estimates range from $0.71 to $1.22 per ton for Colorado shales (1, p. 131, 132, 315). Based on further data (1, p. 315, 316), A. J. Kraemer states that shale oil produced from these oil shales would cost from $1.75 to $2.00 per barrel (all costs on a 1942 basis). Extrapolating figures obtained in the literature and reported in (16), it would seem that other estimators (on less reliable data, perhaps) have made estimates ranging from $0.91 to $1.83 per barrel, with probable costs in the order of magnitude of the latter figure. All these figures are based on technology known prior to 1929 which, however, is the last year that any serious work has been reported in the

United States. L. C. Karrick, formerly of the Bureau of Mines, has stated (1, p. 334) that shale oil could be manufactured profitably for about 75 cents per barrel by use of underground treatment; no details were given to substantiate this estimate.

In regard to gasoline costs, A. J. Kraemer (1, pp. 316, 317), using data from the Colorado experiments of the Bureau of Mines (prior to 1929) for cracking crude shale oil to coke, obtained estimates of 9.7 to 10.7 cents per gallon of finished gasoline. It might be assumed that advances in refining technology since that date will cancel out increases in construction, labor costs, etc.; hence these figures seem acceptable as fairly reasonable cost estimates.

Man-power Requirements.—E. D. Gardner and Charles N. Bell of the Bureau of Mines, in a very detailed study of the methods applicable to mining Colorado shales and the costs for such operations (5), have estimated that for two-shift shale-mining operations producing 5,000 tons and 2,000 tons of shale daily, labor requirements (including supervision) would be on the order of 0.0614 and 0.0835 men, respectively, per daily ton of shale mined. These calculations include labor for crushing operations and delivery of shale to mill sites near the Colorado deposits, but the number of laborers required for above-ground work of all types in neither case was 30 per cent of the total. Table 7 summarizes approximate man-power requirements for various outputs, accepting an estimate of 0.07 man per daily ton of shale as a rough average.

TABLE 7.—APPROXIMATE MAN-POWER REQUIREMENTS FOR SHALE MINING

Type of Production	Men Required
For production of 100,000 bbl. of crude shale oil daily:	
From shale assaying 20 gal. per ton.	15,400
From shale assaying 25 gal. per ton..	12,400
From shale assaying 45 gal. per ton... ..	6,900
For production of 100,000 bbl. of gasoline daily:	
From shale assaying 20 gal. per ton..	25,600
From shale assaying 25 gal. per ton..	20,700
From shale assaying 45 gal. per ton.. .	11,500

No estimates are currently at hand for operating man power. The operation of retorting might be comparable to that of petroleum production in man-power requirements; it is not complex. Total man-power requirements, therefore, would definitely be larger than those for petroleum production and refining.

Steel Requirements.—According to A. J. Kraemer (1, p. 295) 7,500 tons of steel are required for retorting plants to produce 5,750 bbl. of crude shale oil per day from 10,000 tons of shale having an assay value of 25.4 gal. of oil per ton; thus steel requirements are 1.3 tons of steel per barrel of oil. Warwick N. Downing (1, p. 295) states that steel requirements for mining operations would be negligible. On this basis the production of 100,000 bbl. of crude shale oil from shale of this richness would require 130,000 tons of steel. No other figures are at hand, but it is obvious that less steel per barrel would be required for richer shales, since lower tonnages would have to be retorted per barrel.

Carrying these calculations a step further and assuming a gasoline yield of 60 per cent and that refining plants to produce gasoline would require 2.0 tons of steel per daily barrel of gasoline, the production of 100,000 bbl. of gasoline daily would require plants containing 417,000 tons of steel for shale with an assay value of 25.4 gal. per ton. A reliable source (8) states that this estimate is rather high. At any rate, steel requirements appear in line with those for petroleum production and refining.

Investment Required.—A. J. Kraemer (1, p. 316) has presented investment data for mining 6,250 tons per day and 10,000 tons per day of Colorado oil shales having assay values, respectively, of 35.4 and 23.8 gal. per ton of shale. From his figures an investment for mining facilities of between $208 and $210 would be required per ton of shale mined daily (*i.e.*, investment costs per ton are almost identical regardless of shale richness). Thus, to mine enough shale of an assay value of 20 gal. per ton to yield 100,000 bbl. of oil daily, an investment for mining facilities of approximately $45,100,000 would be required (on the basis of earlier assumptions). To produce 100,000 bbl. of gasoline daily from shale of this richness, an investment in mining facilities of $75,200,000 would be required. For shale having an assay value of 25 gal. per ton, the figures for the corresponding amounts of oil and gasoline would be 37 million dollars and $61,700,000, respectively, and for shale with an assay value of 45 gal. per ton the figures would be $20,500,000 and $34,300,000, respectively.

Continuing to use A. J. Kraemer's data (1, p. 316), it would seem that retorting facilities require an investment of $700 per daily barrel of oil when processing shales of an assay value of 35.4 gal. of oil per ton, and $1,020 for shales with an assay value of 23.8 gal. per ton. Thus, retorting facilities to produce 100,000 bbl. of crude shale oil per day would require an investment on the order of 70 million to 102 million dollars. Retorting facilities to produce the crude shale oil required for the production of 100,000 bbl. of gasoline daily on the basis of a 60 per cent yield, would cost from 117 million to 170 million dollars for the above shales.

The data on investments quoted from A. J. Kraemer so far has come from Table 8 (1, p. 316). The capital-investment figures of $1,160 and $1,670 per barrel of shale oil daily are good median figures to those reported in the literature (16); such estimates range from $375 to $3,000 per daily barrel of shale oil (the higher

TABLE 8.—COSTS OF AN OIL SHALE PLANT OF COMMERCIAL SIZE[1]

Size of operation:		
Shale to be retorted per day	6,250 tons	10,000 tons
Oil to be produced per day	5,000 bbl.	5,380 bbl.
Capital investment:		
Mining	$1,300,000	$2,100,000
Retorts	3,500,000	5,500,000
Other	1,000,000	1,400,000
Total	5,800,000	9,000,000
Per ton of shale a day	925	900
Per barrel of shale oil a day	1,160	1,670

[1] Data presented by A. J. Kraemer, senior refinery engineer, Bureau of Mines, Department of the Interior (1, p. 316).

estimates being the oldest). Taking Kraemer's figures per daily barrel as reasonable estimates, therefore, it would seem that an investment of 116 million to 167 million dollars would be required for the production of 100,000 barrels of crude shale oil per day.

Assuming an investment of $1,000 per barrel of gasoline daily for a modern petroleum refinery; assuming, as a guess, that the investment for refining facilities for gasoline from shale oil would be about the same; and again assuming a 60 per cent yield of gasoline from shale oil (only the case for maximum gasoline production along with coke), these figures yield an estimate of 294 million to 379 million dollars for the investment required to produce 100,000 bbl. of gasoline daily. This total is not much larger than the comparable investment in petroleum production and refining facilities.

TAR SANDS

The terms "tar sand," "oil sand," "bituminous sand," and "asphalt rock" have been used interchangeably. No one of them accurately describes the entire range of occurrences to which they have been applied. Rocks other than sands carry tar, or bitumen, and the term asphalt does not in all instances describe the impregnating substance. In this report tar sand has been used because of its general acceptance, even though in some instances it is a misnomer.

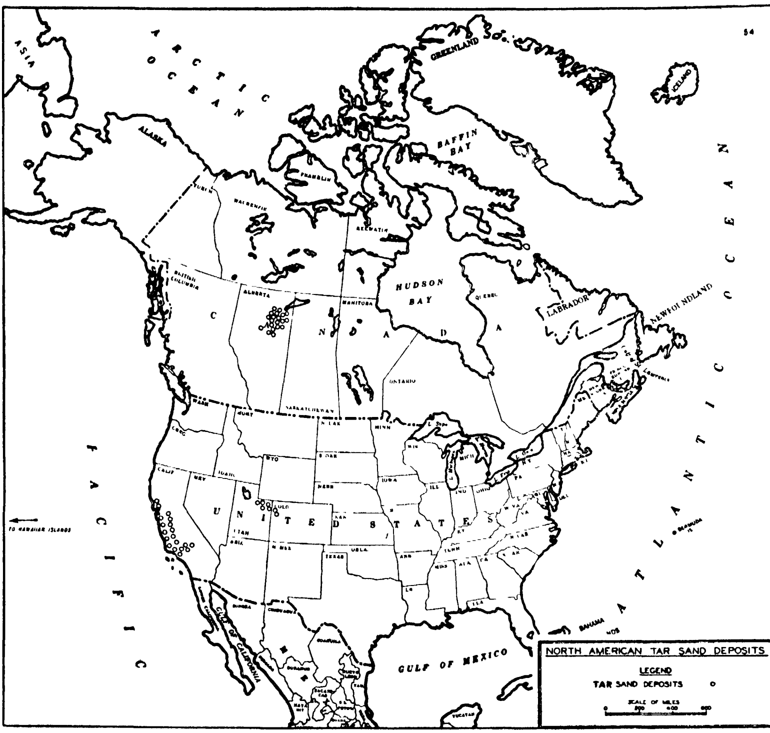

Fig. 3.—Location of North American tar-sand deposits.

Geographic Distribution.—The geographic distribution of the most extensive deposits of tar sand in the United States and Canada is shown on the accompanying map. There are a multitude of minor occurrences, believed in each instance to amount to no more than a few thousand tons, and the locations of these relatively unimportant occurrences have not been indicated.

Except for the tar sands of the province of Alberta in Canada, the map does not indicate the location of occurrences that are not revealed by surface exposures, although such occurrences may comprise some of the most important potential reserves. In the oil-yielding areas of the United States there are many sands heavily impregnated with asphalt or bitumen at depths ranging from a few feet to more than 100 or 200 ft. These concealed tar sands have not been included in any of the published estimates of the potential reserves represented by tar sands, and no further reference to them will appear in the present discussion.

Geologic Distribution.—Tar sands are found in either the United States or Canada in rocks belonging to all geologic periods. With a few outstanding exceptions, they occur in regions in which some oil fields have been found. In such areas the tar impregnations are found either in rocks which yield true petroleum in nearby fields, or in beds above or immediately below those which contain true petroleum in the oil fields of the area.

Most of the oil fields of the United States and Canada are found in rocks of Ordovician, Devonian, Mississippian, Permian, Cretaceous, and Tertiary ages. The same is true of the bituminous rocks.

Rocks of Cretaceous and Tertiary ages have yielded more great fields in the United States and in Canada than have the rocks of other ages. The greatest known accumulations of tar sands are also in rocks of Cretaceous and Tertiary ages.

Origin and Nature.—With the exception of the very extensive tar sands of Alberta, Canada, and of the tar sands in northeastern Utah and adjacent Colorado, these deposits appear to be residues of petroleum that once was liquid and reached its present position when it was fluid and capable of moving appreciable distances through porous rocks. Many of the occurrences can appropriately be called "fossil oil fields." In these fossil oil fields it is apparent that oil once filled a porous rock stratum on top of an anticline or other structural trap. Erosion of the overlying formations exposed the oil-bearing stratum, and all that now remains is a porous rock impregnated with heavy bitumen. It has been assumed that the light constituents of the original petroleum escaped by evaporation, but this has not been proved. Oxidation and other chemical action may have played an important part.

Other occurrences of bituminous rock are in beds now inclined or tilted, but where there is no obvious anticline or trap. Liquid petroleum apparently migrated up the slope of a porous bed, and when the outcrop was reached, the light components were lost by evaporation, perhaps aided by chemical action. The remaining tar, or asphalt, plugged the pores of the rock so that later increments of migrating oil could not escape. In some instances true petroleum occurs against this dam of bitumen, but in others all that now remains is an extensive volume of bituminous rock.

Some deposits of tar sands are in rock that is not as permeable or open-textured as either sandstone or porous limestone. In such occurrences the rock apparently was rather extensively shattered so that petroleum could reach and impregnate large volumes. As in the other instances mentioned, this original petroleum later was modified to tar or asphalt.

The tar sands of an area in northeastern Utah and adjacent Colorado, centering near the town of Vernal, originated in a different manner, and the bitumen in the sands may be quite different in nature from that in deposits which had a different origin. These tar sands were not impregnated originally with liquid petroleum. The bitumen was hard, or plastic asphaltic material before it was incorporated in the sands. The geologic evidence suggests that adjacent to the area in which the tar sands occur, great oil fields in anticlines or other oil traps were exposed by erosion. The oil escaped from these fields into streams that drained the area, and that which did not evaporate settled to the bottom of the water and was transported in the form of little cylinders, balls, or pellets of soft asphalt mixed with sand, rolling or tumbling along with other debris carried by the streams. These streams discharged into a wide, flat area where the material —sand, mud, and asphalt—that had been carried mechanically by the water settled and formed beds of sand and conglomerate, with pellets of asphalt and grains and pebbles of sand indiscriminately mixed.

The Athabaska tar sands of the province of Alberta, Canada, comprise the most extensive known deposit of bituminous rock. No theory which has been proposed for the origin of this deposit seems to fit adequately all the observed conditions. On the basis of the geologic relations it is difficult to assume that the bitumen in this rock was ever a true petroleum. This tentative conclusion is supported by the present chemical nature of the bitumen, or tar. It has been suggested that the tar content of these sands is a product intermediate between the original vegetable debris and true petroleum.

Availability of the Supplementary Reserve of Bituminous Rock. No significant part of this supplementary reserve can be considered immediately available, since the cost of quarrying, or mining, crushing, and recovering the bitumen is substantially greater than the current cost of petroleum in most of the areas where these rocks are found. Also, it appears unlikely that the heavy bitumen can be converted into some of the important refined products obtainable from petroleum at a cost that will compare favorably with that of securing these same products from crude petroleum at the present time, or until the cost of crude petroleum is substantially increased.

Discussion of Data.—While the known deposits of tar sands are enormous in extent, it is fallacious to consider the bulk of such material as a potential reserve unless some new methods of recovery, *in situ*, can be developed. The proportion of the tar-sand reserves which can be used by conventional methods represents perhaps only 1 per cent of the total, or from 1 to 2 billion barrels of oil—an almost negligible potential reserve.

The average tar sands yield about ½ bbl. of oil per ton. The cost of mining and recovering oil from the easily accessible rich sands (those yielding as high as 1 bbl. per ton) is said to be around $1.50 per barrel, and some estimates are lower than this.

The investment said to be required per barrel of gasoline per day ranges from $1,335 to $3,300; the latter figure seems more credible. Little has been published on the conversion of crude to gasoline and other petroleum products, but modern refining methods are being studied by several petroleum companies.

Man-power requirements should not be out of line with other substitute sources. No estimates have been made of steel requirements, but these should not exceed the working of oil shale.

Reserves.—The total oil reserves contained in known Western Hemisphere tar and oil sands have been estimated by Robert P. Russell as 38.5 billion tons of oil or about 275 billion barrels (1, p. 44). The largest single deposit of tar-saturated sands in this hemisphere is found in the northern part of Alberta province, Canada, extending along and back from the Athabaska River and its tributaries. Estimates of the oil content of these deposits made by a number of United States and Canadian geologists range from a minimum of 100 billion barrels to 250 billion barrels, with some estimates being even higher. By far the greater part of these beds is buried beneath 500 to 1,800 ft. of shale, sandstone, and glacial drift, and their mining would entail not only the cost of shafting and expense of hoisting, but also expensive timbering costs, making the cost of underground mining prohibitive. Even along streams where the tar sands lie almost completely exposed, some sections are covered with too thick an overburden for mining under present economic conditions, the top economic limit for removal of overburden being about 1 cu. yd. for each ton of sand mined. About 10 to 20 square miles of the deposits, containing between 500 million and 1 billion barrels of oil, are said to be workable by open-pit mining; and it is these which are considered possible sources of additional petroleum. While the presently recoverable oil in the Athabaska field amounts to only ½ to 1 per cent of the total oil estimated in the field, it still represents a sizable figure (4).

Tar-sand deposits are found extensively in California. In the San Luis Obispo region, an area comprising nearly 50 square miles, the tar-sand reserves have been evaluated as enormous. Massive formations of oil-impregnated shales and silts of varying thicknesses occur in the Casmalia area. Bituminous sandstone, about 14 to 16 per cent of which is crude oil, is found in the Santa Cruz Mountains area about 5 miles northwest of Santa Cruz. Along the southern base of San Rafael Range in the Santa Margarita formation of the San Luis Obispo region is a highly enriched sandstone covering an area of approximately 6 square miles and averaging 200 ft. in thickness. The deposit has been estimated to comprise over 50 million cu. yd. of bituminous sands. In general, it may be said that the principal tar-sand deposits in California occur in the immediate region of the Coast Range on both the east and west slopes and at several points within the range. In addition, the oil-bearing sand outcrops near McKittrick and Maricopa in western Kern County are promising sources of recoverable oil (15).

Utah possesses large deposits of tar sands, particularly in the Uintah Basin. The governor of the state, Herbert B. Maw, has stated that there are sands in this basin "one ridge of which has been studied, and it has been established in that one ridge that there are from 1.5 billion to 3 billion barrels of oil" (1, p. 277).

According to Bert Dyer of the Geological Survey, Department of the Interior, "the oil sands of Utah are found in the Uintah Basin and near the Colorado line south of the Uintah Basin, some on the San Rafael Swell, and at Sunnyside, Utah. In one strip in the Uintah Basin there is an outcrop of about 12 miles; one strip is about 2½ miles long and about 1½ miles from the outcrop, which would yield 600 million barrels" (1, p. 329).

Oil Yields.—Tar sands vary in oil content up to about 25 per cent by weight. In addition, the size of the sand grain and other factors determine the susceptibility of the sand to separation by the action of hot water. The addition of sodium silicate or other alkaline reagent is often made to the water to facilitate the extraction. Bearing in mind that tar-sand deposits vary in oil content from each other and even within each deposit from spot to spot, some figures may be given on the amount of oil recoverable from these sands.

In the Athabaska field a plant which processes 600 tons of tar sand per day recovers about 550 bbl. of oil therefrom, or about 0.92 bbl. per ton of sand processed (12). Because of the sensitivity of this oil to heat, yields of 25 to 35 per cent gasoline can be obtained without pressure cracking. So far as is known, no actual pressure-cracking tests have been made, but other small-scale experiments lead to the belief that high yields of 80-octane gasoline may be produced (4). The present sands being treated are high grade, containing about 16 per cent bitumen and 5 per cent sand of less than 200 mesh. The average sand would more likely contain about 12 per cent bitumen and a higher percentage of sand below 200 mesh, probably about 25 per cent. The significance of the fine-sand content is, of course, that it complicates the separation process (5).

Tests made a number of years ago on California tar sands from the San Luis Obispo region indicate a yield of about one-half barrel of oil per ton of sand. The shales and silts of the Casmalia area contain up to 20 gal. of oil to the ton (0.475 bbl. per ton). Surface samples taken at random from the impregnated sandstone at the base of the San Rafael range showed bitumen contents equivalent to 15 to 20 gal. of oil per ton (0.36–0.48 barrel per ton). The bitumen content of the sandstones of the Santa Cruz district, as indicated by samples taken from several quarries, averages about 14 to 16 per cent by weight (15).

No figures were found for yields or estimated yields from the tar sands of Utah.

Costs of Production.—Since no large-scale operations for the recovery of oil from tar sands have been undertaken anywhere, and the only operations which might even be called pilot-scale are those in the Athabaska region, data on costs of production are spotty and highly extrapolated. Based on experience gained in operating the previously mentioned 550-bbl.-daily plant, it has been proposed to build a plant in the Athabaska field which would be capable of producing 10,000 bbl. daily of digested crude oil (bitumen from tar sand, the viscosity of which has been reduced by short treatment at moderate temperature). This oil would be hauled or piped to Edmonton and there refined. The statement has been made that the cost per gallon of 76- to 78-octane gasoline from this operation would be competitive with the cost at Calgary of gasoline made from crude from the Turner Valley fields (4). The field price of 44° A.P.I. Turner Valley crude is about $1.55 per barrel (13). It would appear, then, that the cost of gasoline from the economically obtainable portion of the Athabaska sands would not differ greatly from that refined from United States crude oils. Evaluating these same sands, another source has stated that assuming oil from the sand deposits remains steady, operations on a scale of 10,000 bbl. daily could lay crude down at the refinery for about 75 cents per barrel (4). Based on information and experience available in 1941, the Abasand Company estimated that a plant to produce 10,000 bbl. of crude daily from Athabaska sands would necessitate a total investment of about $4,850,000, and that a refinery to process the crude would cost about $3,150,000, the total investment being about 8 million dollars. It was estimated that the plant would give a steady supply of products from 10,000 bbl. of 20 to 22° A.P.I. crude per day for 20 years, with another 20 to 30 years of production for a comparatively small expenditure in moving the site of the extraction plant in order to get at new sands (6).

In 1936 it was proposed to build a plant to separate oil from the sands in a chamber dug underground in the sand area near McMurray, Alberta, to facilitate handling some of the sands covered by thick overburden. If this is ever done, it may point the way to the placing of machinery for treating the tar sands underground in oil fields. The cleaned sand and other waste material would probably be used as backfill. Costs, it was estimated, would not be excessive; and when the industry actually needs all the oil in the oil fields, it was thought that serious consideration might well be given to underground mining and treating of tar sands (7).

The tar sands of California in a number of regions average as high in oil content as Athabaska sands, but an important factor in the cost of production of oil from them is their susceptibility to the hot-water extraction process. Recent tests on samples of Kern River sands have shown they are amenable to water separation. There are some indications that sands from regions which were formed by marine deposits may not be so readily susceptible to water treatment. No figures were found for the cost of production of oil or gasoline from California sands, but it would seem safe to say that the best regions could compete favorably with those of Athabaska.

The extent to which the crude from tar sands must be processed in order to obtain aviation gasoline, diesel oil, and fuel oil is not known. An answer to this question is necessary before much can be said about refinery costs. It is understood that tests are being made on hydrogenation, thermal cracking, and catalytic cracking of tar-sand crudes in the laboratories of at least two United States petroleum companies (5).

Man-power Requirements.—The number of men required to mine and process enough tar sand to supply a refinery of specified size depends primarily on two factors: (1) the method of mining which may be employed; and (2) the method of separation usable. The consolidation of the sands and the amount of overburden determine the former, and the size of the sand particles and character of the bitumen influence the latter. Based on the small plant operating in the Athabaska field, 600 tons of sand have to be mined and processed to obtain 550 bbl. of crude. By straight extrapolation of this figure to a plant capable of putting out 100,000 bbl. of crude a day, the amount of sand to be handled would amount to approximately 110,000 tons. The preferred method of mining the sand is by light blasting, loading with power shovels, and trucking to the separation plant. The presence of overburden or the necessity for mining sandstones, shales, or sands to which the above method is not applicable, will naturally increase further the man-power requirement.

The man power necessary to operate an integrated extraction-refinery setup is difficult to estimate, for no figures are available for the man-power requirements of the mining and extraction operations. It would seem that the total man power to produce the crude would be made up in by far the greatest share by those engaged in mining and transporting the sand to the extraction plant, since the actual separation process would require only a few men to control the operation of the pulpers, quiet-zone settlers, diluent mixers, and oil settlers. Refinery man power probably could be expected to be about the same as that necessary to produce the same amount of equivalent products from ordinary crudes. Exceptions to this assumption must be made to the extent that special operations such as hydrogenation may be necessary to obtain the desired products.

Steel Requirements.—Although no total steel requirements were given, the number and sizes of pieces of equipment necessary for a 550-bbl.-daily plant are available. This information is included in case one versed in process equipment may care to extrapolate the requirements of this plant to those of full-scale operation. As used in the small plant, the pulper consists of a rotating horizontal steel cylinder about 8 ft. in diameter and 20 ft. long, resting on trunions and rotated by a chain drive. It is in this that the hot water and sand are brought into contact and separation takes place. Two flotation cells are used, a diluent mixer, and an oil settler. Much of this equipment is steam-jacketed. A boiler plant would of course be necessary, though no figures on the size needed are available.

Investment Required.—The investment required to produce 100,000 bbl. of crude per day from tar sands comparable to the easily accessible sands of Athabaska would probably be in the neighborhood of $48,500,000. This estimate is based on the assumption that 10 plants of 10,000-bbl.-daily capacity would be used to obtain such production, as estimated costs are available only for a plant of this size (6).

Refinery investment to process 100,000 bbl. daily of tar-sand crude by the same straight-line extrapolation would be about $31,500,000, making a total investment for obtaining and refining the crude of about 80 million dollars (6). Expected gasoline yields are a minimum of 35 per cent even before cracking, so, taking 60 per cent as a rough guess, $52,500,000 would be required for refinery facilities to produce 100,000 bbl. of gasoline per day; and the total investment for mining, extraction, and refining tar sands to yield this production would be $133,500,000. This figure seems ridiculously low as compared with the comparable investment for petroleum production and refining facilities. It seems possible that the actual investment required might be twice this value; this would certainly be the case if hydrogenation were to be used instead of the thermal process. A recent investment estimate of $3,300 per barrel of gasoline seems more credible; for 100,000 bbl. of gasoline per day, by this estimate, 220 million dollars would be required.

NATURAL GAS

Discussion of Data.—If all of the known and estimated natural gas reserves of the United States were used for the Fischer-Tropsch synthesis of petroleum products, some 15 billion barrels of oil might be obtained. It is believed, however, that natural gas is not likely to be diverted from its present valuable uses and that only a small proportion will be available as a substitute source. On the other hand, natural gas in moderate supply appears to offer the cheapest starting point for synthetic petroleum, and several oil companies may build and operate plants to secure specialized petroleum products and at the same time to obtain commercial experience in the second phase of the Fischer-Tropsch process—a phase which is common to the process as applied to coal.

From 10,000 to 12,000 cu. ft. of gas are required for 1 bbl. of gasoline. It has been estimated that the gasoline might cost from 5 to 9 cents per gallon with gas at 5 cents per thousand cubic feet.

Man-power requirements should compare favorably with normal petroleum refining, and steel requirements have been estimated as low as 2.8 tons per bbl. of gasoline per day. The investment required may be as low as $2,200 per barrel per day.

Reserves.—The data presented at the recent hearings of the O'Mahoney Senate subcommittee (1) are representative of the literature. G. G. Oberfell of the Phillips Petroleum Company (1, p. 351) stated that, conservatively, reserves are about 100 trillion cubic feet or slightly over 2.25 billion tons on a weight basis, more than 70 per cent of the weight of estimated crude-oil reserves. Annual production approximates 3 trillion cubic feet, which on the basis of 0.60 specific gravity weighs as much as 488 million barrels of 36° A.P.I. crude oil (72 million tons). On a B.t.u. basis, "the annual production of natural gas is nearly 40 per cent of the crude-oil production and about 25 per cent of the bituminous coal production"; at 5 cents per 1,000 cu. ft., "this compares with 36° A.P.I. crude oil at 27 cents per barrel

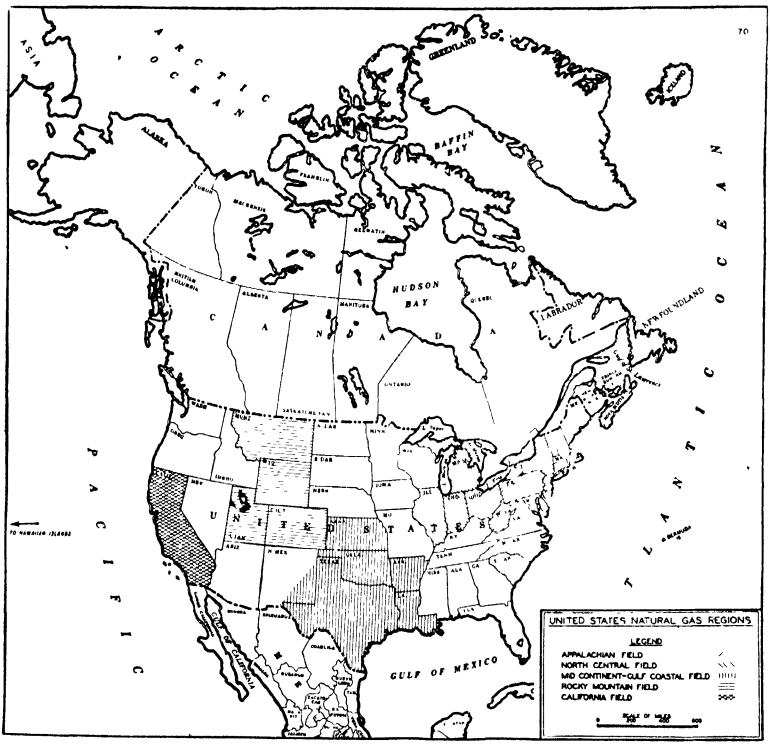

FIG. 4.—Location of United States natural-gas regions.

at the well and bituminous coal at $1.09 per ton f.o.b. cars at the mine tipple."

Dr. Gustav Egloff (1, p. 129) has stated that known reserves are about 85 trillion cu. ft. and that potential reserves are about the same order of magnitude. In a recent article Dr. O. W. Wilcox (17) has elaborated upon this figure. He states that "natural gas geographers recognize five major areas in which gas is produced and consumed in the United States." These include: (1) the Appalachian field, lying within the states of New York, Pennsylvania, West Virginia, and Ohio, with proved reserves of about 5 trillion cubic feet ("a possibility of another 5 trillion cubic feet remains to be discovered" (17), although Ralph E. Davis (9) states that "potential reserves are of small magnitude even though commercially they will be important"); (2) the North Central field, comprising the states of Michigan, Illinois, and Indiana, "containing only an estimated 2 trillion cubic feet, with potential reserves of a similar amount"; (3) the Mid-Continent–Gulf coastal field, including Texas, Louisiana, Arkansas, Oklahoma, Kansas, and southeastern New Mexico, possessing proved reserves amounting to about 70 trillion cubic feet (about 80 per cent of known reserves) and possibly potential reserves of an equal amount; (4) the Rocky Mountain states, comprising Montana, Wyoming, Colorado, and Utah, with proved reserves of perhaps 1.5 trillion cubic feet and potential reserves possibly of a large order; and (5) the California fields, with proved gas reserves of about 9 or 10 trillion cubic feet and uncertain but large potential reserves; Dr. Wilcox's totals are thus the same as Dr. Egloff's. The accompanying map diagrams the geographical distribution of these natural gas resources.

A recent PAW estimate indicates that present reserves total over 100 trillion cubic feet. Assuming that gas marketed in the past, plus wastage, loss, and consumption in oil operations, may have totaled around 100 trillion cubic feet, discoveries to date would approximate 200 trillion cubic feet. If it were assumed that future discoveries would approximate 50 per cent of this figure, at least 100 trillion cubic feet might be added to present reserves. Other data on natural-gas reserves and rates of consumption have been presented by Robert P. Russell (1, p. 44), A. C. Fieldner (1, pp. 46, 160), W. E. Wrather (1, p. 100), and Bruce K. Brown (1, p. 103). On the basis of limited data, Canadian reserves appear to approximate 5 to 10 trillion cubic feet, roughly comparable to those of California.

It is felt by many that natural gas is too valuable a substance in its own form to be considered as a supplemental reserve for the production of a synthetic petroleum, and it is obvious that even were it commercially feasible, the total national reserves, approximated at 170 trillion cubic feet, could serve to provide (if used as Fischer-Tropsch raw material) no more than about 15 billion barrels of a synthetic petroleum if all other uses were disregarded. It is true that many of the largest gas fields are far removed from consuming centers and at present are not even accessible to pipe lines, but many feel that the economic value of such gaseous fuels is so high that they should be reserved for use in their present physical form. Nevertheless, a vast amount of attention has been paid to natural gas by petroleum companies in this country, for it is now generally accepted that it constitutes the cheapest raw material for the synthesis of a synthetic petroleum—potentially competitive with natural petroleum perhaps. There is a definite feeling that no government research should be devoted to such developments, although the synthesis step in the Fischer-Tropsch process is the same for any raw material which yields the desired water gas in the first step. It appears very likely that several private companies will build plants in the immediate postwar period, but it does not appear probable that such plants can ever constitute a major market factor. These plants at least will pioneer the commercial development of the common (second) stage of the process; synthesis of the reaction gases will undoubtedly make use of the well-known catalytic methane-steam reaction.

Oil Yields.—According to Robert P. Russell (1, p. 35), a European-designed Fischer-Tropsch plant using natural gas instead of coal would require 505 lb. (11,950 cu. ft.) of natural gas per bbl. of gasoline, while a plant of possible future design might require only 440 lb. (10,450 cu. ft.). Bruce K. Brown (108) has stated that the yield of crude oil is 3 to 5 gal. per 1,000 cu. ft. of natural gas. On the basis of barrels per ton of natural gas, these figures yield rough estimates of between 3.4 and 5.65 bbl. of crude oil per ton and between 3.96 and 4.55 bbl. of gasoline per ton.

Costs of Production.—Robert P. Russell (1, p. 39) has stated that a Fischer-Tropsch plant of European design, using natural gas costing 5 cents per 1,000 cubic feet, would produce gasoline at a cost of 8.8 cents per gallon, including depreciation. A plant of possible future design would yield gasoline at a total cost of 4.8 cents per gallon. The first figure conflicts sharply with an estimate of Fred Denig (1, pp. 242, 244, 246) based on a smaller plant of European design using natural gas; this estimate was

17.4 cents per gallon of gasoline, but Mr. Denig testified that it could be lowered by future developments.

Man-power Requirements.—No data are immediately at hand. Man-power requirements for natural-gas production would be low. For the crude oil and gasoline production steps, such requirements should be somewhat lower than for Fischer-Tropsch synthesis from coal.

Steel Requirements.—Robert P. Russell (1, p. 38) has testified that a Fischer-Tropsch plant of European design using natural gas would require 6.5 tons of steel per daily barrel of gasoline, while one of possible future design would require only 2.8 tons of steel per daily barrel. For the production of 100,000 bbl. of gasoline per day, therefore, some 280,000 to 650,000 tons of steel would be required for construction purposes. These figures are comparable to those for petroleum refining.

Investment Required.—Robert P. Russell has stated (1, p. 36) that the investment required for the production of 100,000 bbl. of synthetic gasoline per day from natural gas would range from 220 million dollars (for a plant of possible future design) to 477 million dollars (for a plant of European design). These figures are not very much higher than the investment figures for petroleum production and refining.

AGRICULTURAL MATERIALS

Agricultural materials offer small reason for detailed attention at present, since the current war has conclusively shown that the ethyl-alcohol industry (including beverage distillers) is having trouble finding agricultural raw materials to permit an output of about 600 million gallons of ethyl alcohol per year (approximately the capacity of existing plants); this amount, even if available for fuel purposes, would only fractionally supplement the 620 million barrels of gasoline consumed annually in 1942 and 1943, and alcohol could not be used as a source of fuel oils and lubricants. Experimentation is under way on processes to produce ethyl alcohol (1) from the waste sulphite liquors of paper mills (which could add a theoretical maximum of 100 million gallons of ethyl alcohol per year), and (2) from sawdust or wood chips. The chief appeal of these processes seems to be the aid they may lend in time of war (for synthetic rubber and munitions) if plants using them can be placed in operation in time; potential ethyl alcohol costs of 20 cents or less pre gallon are often mentioned, but so are estimates of 50 cents per gallon, at least at first.

Ethyl alcohol from grain, incidentally, is costing well over 50 cents per gallon, a prohibitive price were it to be considered as a gasoline substitute. The supply of blackstrap molasses, long the cheapest agricultural raw material, is strictly limited even in times of peace, since it is a waste product in sugar manufacture; the use of invert molasses (molasses containing extractable sugar) increases costs considerably.

Other fuels than ethyl alcohol, of course, may be synthesized from agricultural materials by fermentation. Abroad, ketone-alcohol mixtures are being so prepared and used. Such fuels appear no more economic than alcohol, however, and again no fuel oils or lubricants are formed.

Some attention has recently been given to a process for the production of protoproduct—methane homologs, gasoline, kerosene, lubricating oil, and asphaltlike material—from agricultural materials such as sugar cane, wood, potatoes, and agricultural wastes by carefully controlled internal combustion under high pressures and moderate temperatures, followed by hydrogenation or cracking if products other than heavy oils are desired. Data on this process are too incomplete and conflicting to justify consideration in this report.[1]

Agricultural raw materials, except possibly waste products, are notoriously undependable substances for chemical synthesis, since bad growing seasons can decimate crops. Whatever consideration they warrant should be directed toward research on the use of waste cellulosic materials, although even here economic potentialities seem far poorer than for any other liquid fuel substitute.

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[1] See *Science*, vol. 99, No. 2573, 1944, p. 309 and *The Bulletin of the American Association of Petroleum Geologists*, vol. 24, No. 11, p. 1865 (1940).

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CHAPTER VII

OIL FROM COAL AND SHALE[1]

By Robert E. Wilson

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The recent approval by the Congress and the President of a major research and development program of the Bureau of Mines looking toward the development of alternative sources of liquid fuels, together with numerous other suggestions regarding government coordination or regulation of research, makes it particularly timely and pertinent to attempt to analyze the proper functions and cooperative relationships between government and private research in an economy such as ours. Too much of the recent discussions of this problem has been in the fields of theory or of politico-economic controversy in which the writer does not care to participate. It does seem, however, that a serious attempt to analyze a concrete problem such as the production of motor fuel and other liquid fuels from sources other than petroleum, in which the public interest is great but its reliable information is inadequate, would be of value to both the scientific world and the public generally.

Although the views expressed and the program recommended cannot be attributed to any group, they are believed to be generally in line with the opinions of a majority of technologists in this field, though they will obviously not satisfy the many non-technical extremists, some of whom hold that the government should not do any research, and others that the government should dominate all research.

In discussing the present status of the technologies in the field the intent is not to give a detailed and quantitative view of the various alternative methods of making liquid fuels, but rather

[1] Originally printed in *Chemical and Engineering News*, American Chemical Society, vol. 22, p.1244, Aug. 10, 1944, under the title, Liquid Fuel from Nonpetroleum Sources.

an up-to-date general view of the technologies and economics of the principal processes and the trends which are clearly visible, pointing out in each case the type of additional information which is needed to make further progress in the development of these processes.

In discussing in considerable detail the possibilities of making liquid fuel from tar sands, oil shale, or coal, the writer does not wish to give the impression that he considers large-scale use of these alternatives imminent or definitely necessary to oiling the next war. Recent papers by the author (2) and others (1) present the basic facts of the petroleum supply situation. However, in view of the four outstanding facts that (1) oil is the prime essential of modern warfare; (2) discoveries of crude reserves in this country have been slowing down; (3) foreign sources of crude, however plentiful, might not be readily available in the event of another war; and (4) known domestic reserves of oil shale and coal both far exceed known domestic reserves of petroleum and natural gas, it seems obvious that serious attention should be given to developing the technology of various possible methods of making liquid fuels from these latter sources, and also from the tar sands which are so plentiful in central-western Canada. Accordingly, as a minimum safe program it would appear that at least enough research and development should be focused on each of these three alternative sources to establish more definitely which is likely to be our principal reliance in case a crude shortage should become really imminent, and to demonstrate on at least a semicommercial scale the more promising methods of making liquid fuels from whichever appears to be the most promising source.

Such research and development will doubtless include both laboratory and pilot-plant work along numerous alternative lines, and should eventually culminate in one or more demonstration plants of the minimum size, which will allow the government to furnish industry the necessary cost and engineering data for the development of a synthetic-liquid-fuel industry as provided in Public Law 290. Contrary to widespread impression, neither the act nor the Bureau of Mines technologists contemplate the building of large stand-by plants, commercial operation of a plant of any size, or the premature construction of even demonstration units as above defined, until much more laboratory and pilot-plant research is carried out, supplemented if possible by additional information from foreign sources.

However, such a government-financed program will probably not constitute the principal source of new technology in this field. For example, long before the above-mentioned probable ultimate

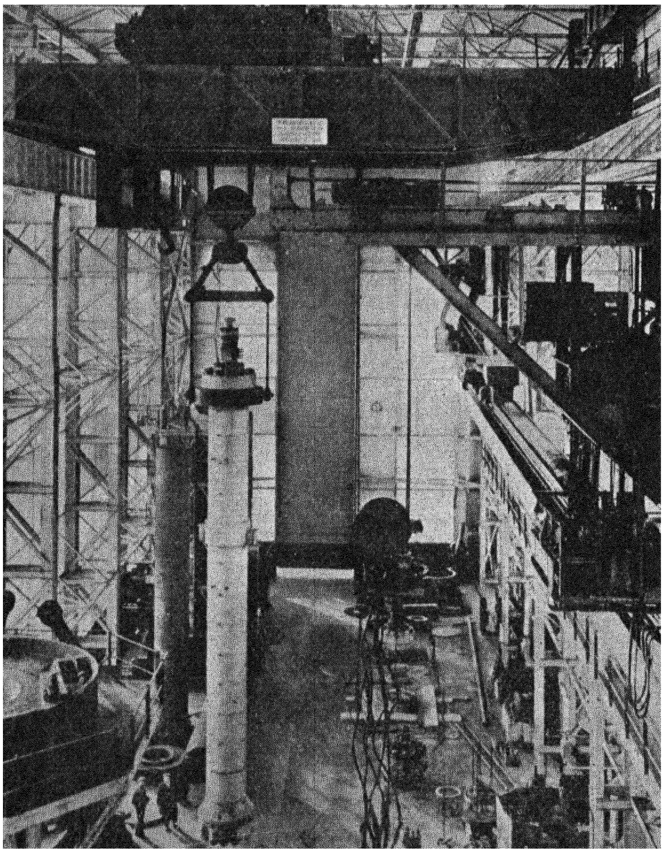

FIG. 1.—Coal-hydrogenation converter in maintenance shop, ICI plant, Billingham, England. (*Courtesy of U.S. Bureau of Mines.*)

sources of liquid fuels become of commercial importance, there are many intermediate technologies, such as the hydrogenation of petroleum fractions, the conversion of natural gas into gasoline, and other processes which will come into the picture in a substantial way. To illustrate how such technical developments are worked out naturally in a free economy, the two above-mentioned intermediate technologies likely to come into commercial use within the next few years are closely related to the most promising processes for converting coal into oil. The development and increasing use by industry of these intermediate processes, which are certain to come long before there is any need to go to the conversion of coal, will lead to a great accumulation of new information applicable to coal-conversion operations which would be impossible to achieve in the research laboratory alone, or even in a few demonstration units built according to present knowledge. The same general situation exists with regard to catalytic refining processes in general, whose development and use by the petroleum industry are still in the early stages with important advances already in progress in many different fields, several of which will be useful in making better quality products from coal or shale. Also, much of the new refining equipment will be of great value in handling the crude products obtained from shale or coal.

This natural and competitive development of substitute processes, plus information from abroad, has already shown us how to make unlimited quantities of gasoline from coal at prices lower than those prevailing after the First World War, and if allowed to continue a natural course, it will almost certainly reduce the costs of gasoline made from coal or the richer oil shales to a figure not over 5 cents per gallon above present gasoline costs from crude petroleum. In the light of these facts, there is certainly less need for concern as to the future of our liquid fuel supplies than there was after the First World War, when pessimistic estimates of crude reserves caused widespread concern, and we did not even dream of the possibilities of making gasoline from coal, at any price.

If crude prices should show a gradual uptrend after the war, industrial research on substitute sources for fuel would be greatly stimulated and could be relied upon to carry the ball with little or no government assistance. On the other hand, if increased importation of relatively cheap foreign crudes kept domestic crude prices low, industry research on substitute sources would tend to lag and a government-supported program would be more necessary, even though it could not fully offset the reduced rate of development work by the industry. Technical developments in this field, particularly in connection with handling solid materials on a large scale, do take time and money, and from the viewpoint of broad national interest it would be foolhardy not to get started on a substantial program well in advance of any certainty as to the need therefor.

INTERMEDIATE PROCESSES FOR PRODUCTION OF LIQUID FUELS

Long before there is any need to go to the utilization of oil shale or coal as a major source of liquid fuels, there will be increasing use of various intermediate processes to help stretch available petroleum supplies and make products at costs similar to those now prevailing. Among the principal possibilities are:

Conversion of Petroleum Residues into Higher Grade Fuels.— In considering substitute sources of liquid fuels, the primary concern should be to meet those liquid fuel requirements for which the user can afford to pay a premium over the price of coal on a heat-content basis. In the past much of our heavier petroleum residues have been burned by large power plants in competition with coal on essentially a B.t.u. per dollar basis, and one of the first things to occur, if and when the petroleum supply situation tightens, will be the installation of equipment to convert these heavier residues into the lighter and more valuable liquid fuels (including gasoline). The large-scale installation of catalytic-cracking units in this country in connection with the 100-octane aviation-gasoline program is an indirect step in this direction, since the catalytic-cracking process produces more gasoline and light fuel oil, and much less residual fuel oil, than does thermal cracking. In addition to catalytic cracking, the technology of directly converting petroleum residues (or catalytically cracked light fuel oils) almost entirely into gasoline by hydrogenation has been thoroughly developed, and its general use by industry would increase rapidly if the present differential between the price of crude and that of residual fuel oil should increase by about 1 cent per gallon.

In other words, the advent of catalytic cracking and the availability of hydrogenation are taking residual fuel oils out of the class of unavoidable by-products, and giving them a definite and substantial value as a crude substitute. The tendency will accordingly be for the price of such fuels to keep within less than 2 cents per gallon of the price of crude in a given area, and if and when the crude price rises, they will gradually pass out of uses where they are in direct price competition with coal. The process will be gradual because of the time required to build hydrogenation plants, and because of the effect that higher crude prices would have on increased discovery rates and increased importation, both of which will tend to prevent any very rapid increase in

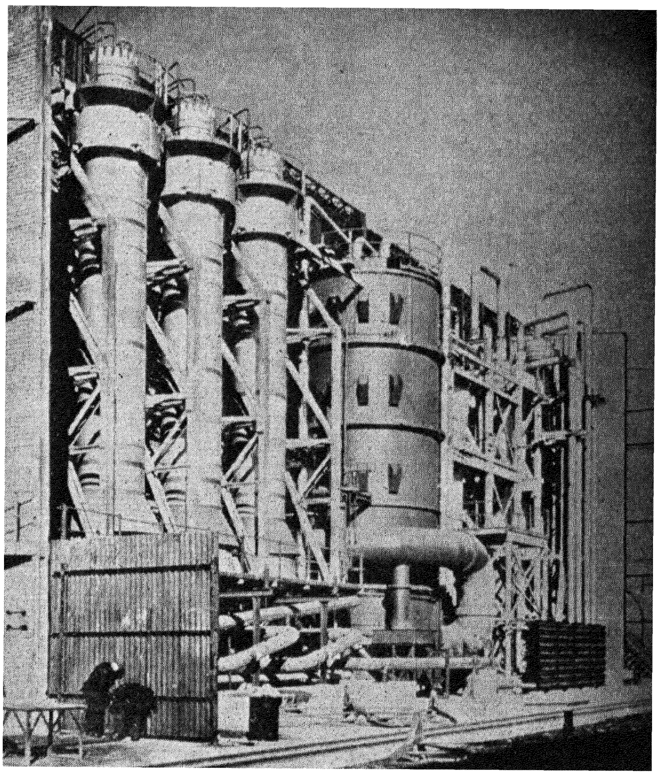

FIG. 2.—Hydrogenation converters and preheaters at Billingham plant. (*Courtesy of U.S. Bureau of Mines.*)

the price of crude. The burning of heavy fuel in large stationary power plants will be the first to go, but users who can afford a reasonable premium for oil on account of its cleanliness or labor-saving characteristics will have adequate quantities of heavy fuel, from one source or another, for many years to come, and at prices not much higher than at present.

Conversion of Natural Gas to Liquid Fuels.—The most immediately promising source of liquid fuels, other than crude oil, is natural gas. The most promising method for the conversion of gaseous to liquid fuel is based on the Fischer synthesis, whereby a mixture of carbon monoxide and hydrogen (as in water gas made from coke and steam) is converted by catalysis at moderate pressures and temperatures into a series of hydrocarbons similar to those in petroleum. To this basic process have been added processes for making the carbon monoxide-hydrogen mixture catalytically from steam and natural gas. Pilot-plant work on both these steps is being actively carried on by several different industrial laboratories. It is already evident that the prewar European technology can be greatly improved, and it seems probable that gasoline can be made from cheap natural gas in the more remote fields at costs similar to present costs of making gasoline from crude. While the gasoline tends to be rather low in octane number, modern catalytic-refining processes will make it quite acceptable. The process will also yield high-quality diesel fuel and wax.

Although the conversion of natural gas by the Fischer process, like the hydrogenation of heavy petroleum residues, is important from the standpoint of augmenting our raw materials for liquid-fuel manufacture at costs not far from present costs, it cannot be considered an ultimate solution of the problem. The total known domestic reserves of natural gas on a heat-content basis are not quite so large as those of crude petroleum. Also, many of the larger reserves are already earmarked for public utilities, and the efficiency of conversion of liquid fuels is not so great as in the case of crude. Presently attainable gasoline yields from methane (allowing for fuel used in the process) are around 50 per cent on a B.t.u. basis, as compared with around 85 per cent from crude by catalytic cracking plus hydrogenation. On the other hand, the trend in recent years has been to find more gas per barrel of oil discovered, and this ratio will probably continue to increase as improvements in drilling technique permit the exploration of deeper sands. In the light of present knowledge, however, it does not appear that the over-all recovery of liquid fuels from present known natural-gas reserves will exceed a few billion barrels. Thus, this process, using present and future gas reserves, will serve more to help stretch our crude reserves over an extra decade or so than to take their place.

Other Possible Intermediate Technologies.—During the period (of uncertain length—possibly several decades) between the beginning of some commercial use of the foregoing processes and the next major step of substantial utilization of oil shale and/or coal for the production of liquid fuel, there will be an interesting race among various competitive processes. It seems probable that under local conditions of unusual supply or demand, or large transportation differentials, numerous processes may come into local use long before they are commercially feasible on a nation-wide scale. Consider for example the single problem of the supply of household fuel, for which the customer is glad to pay some premium to avoid the use of coal. The original type of home-heating fuel—namely, light gas oil distilled from crude—will presumably have been very largely diverted to diesel fuel or charging stock for cracking, but among the known possibilities which will be competing for this major market will be:

1. Distillate heating oil made as a by-product from catalytic or thermal cracking.
2. Imported heating oil.
3. Natural gas from distant points.
4. Artificial gas made from coal in local plants.
5. Artificial gas made from coal gasified at the mine mouth and transported by pipe line.

To show some of the complicated interrelationships among these alternatives, consider the following examples:

Heating oil from catalytic or thermal cracking can fairly readily (by hydrogenation, plus catalytic cracking) be converted to the extent of around 80 per cent into gasoline. The value of such oils will accordingly tend to approach (but not equal) the value of gasoline when and if crude becomes short and hydrogenation facilities are generally available. This will make it easier for natural or artificial gas to compete in areas which they can economically reach. On the other hand, the availability of processes for the conversion of natural gas into gasoline will tend to increase its value at the well, even in remote areas, and thus tend to make it less competitive for household fuel, though the cost at the well is not a large factor in eastern markets. At the same time, higher gasoline and fuel-oil prices will tend to increase the value of benzene and other by-products obtained in making artificial gas from coal and hence reduce the net cost of artificial gas, though the oil required to enrich coal and water gas to meet present B.t.u. standards will become more expensive. The use of natural gas to enrich coal and water gas may well increase and become an important factor in conserving oil.

In this group of intermediate competitive processes, transportation costs are a particularly important factor. Some interesting points in this connection are:

1. The 24-in. pipe line will transport about nine times as many B.t.u. per day in the form of crude or heating oil as in the form of natural gas. Thus gas transportation by pipe line can compete with oil transportation by the same means only when the price of gas in the field is much lower per B.t.u. and/or the price of gas at the point of consumption is much higher per B.t.u. than that of oil. Historically, both conditions have generally prevailed and will probably continue to do so, but with narrowing margins of difference. On the other hand, tankers are competitive with even the largest pipe lines for the transportation of liquids, so gas transportation might be the logical use for the large war-emergency lines.

2. The pipe-line transportation of unenriched gas from the complete gasification of coal costs around four times as much per B.t.u. as does that of natural gas, on account of the low heat content per cubic foot of the former. If oil for enrichment near the point of consumption is as cheap as, or cheaper than at the mine mouth, it is generally cheaper to ship coal by rail than to pipe unenriched gas for any considerable distance. Availability of natural gas near the mines for enrichment purposes might change this picture.

3. Pipe-line transportation costs for either oil or gas increase rapidly as the load factor decreases. Since the heating load has a large seasonal fluctuation, transportation and storage of liquid or solid fuel have a substantial advantage for any volume above that assured as a fairly steady, year-round load.

4. From the Southwest to most New England points, ocean transportation of oil is far cheaper per B.t.u. than any other method in sight for the transportation of fuel.

As the result of the interworking of these and other factors, it would appear that under a reasonably possible future set of conditions, the most economical household fuel (other than coal) for points in western Pennsylvania would be artificial gas, while a natural gas line passing through western Pennsylvania (and not competitive in that area) would (on account of lower transportation costs) be the cheapest source of household fuel in eastern Pennsylvania, and at the same time furnace oil (made either from crude or from natural gas in Texas) shipped by tanker would be the cheapest source of household fuel in New England.

It is obvious that in the intermediate period a whole series of technologies, not predictable in detail, will be developed by the competition (and it is to be hoped, the technical cooperation) of the fuel industries. All these developments will tend to stretch further the period when liquid fuels from petroleum will be our main reliance, and before prices rise enough to make the production of liquid fuels from coal or oil shale commercially profitable.

Agricultural Sources.—There are some technical literature and considerable propaganda to indicate that the fermentation of agricultural wastes or other products to make alcohol would be an important source of motor fuel at costs lower than those for oil shale or coal. However, with the possible exception of a few points where an unusually favorable waste material may have had its gathering costs already paid by some other main product, the cost of making alcohol from such sources is far above its value for motor fuel, taking into account that a pound of alcohol has only two-thirds the heating value of a pound of the usual hydrocarbon fuels. Alcohol does have the advantage of a good blending-octane value, but it is relatively insoluble in ordinary motor fuel, and the more dilute blends have a tendency to separate into two phases under ordinary storage conditions in the presence of water or high humidity.

It must also be kept in mind that the demand for industrial alcohol in synthetic organic chemistry is continually increasing, and that any alcohol made from available agricultural wastes at costs permitting its use in motor fuel would be worth more for other purposes. Also, the total volume obtainable from collected agricultural wastes in question is very small in comparison with the volume of motor fuels required. To make alcohol from starch or grain or other food products would, of course, put it into a still higher cost bracket, and hence alcohol from such sources is an even more remote possibility as a substitute fuel.

Recent reports of converting waste agricultural products by destructive distillation into petroleumlike materials have not been supported by adequate data to permit reaching any conclusion as to probable costs or yields.

MANUFACTURE OF LIQUID FUELS FROM BITUMINOUS SOLIDS

The probable ultimate source of raw materials for liquid-fuel manufacture lies in those solid substances which will have to be mined, such as oil shales, tar sands, and coal. The sum-total reserves of bituminous matter contained in these substances is tremendous, and they could supply our probable needs of liquid fuels for more than a thousand years.

It is difficult to be certain from presently available information which substance will come into predominant use first. However, the important fact is that at the present state of process development all of them will, under favorable conditions, give gasoline at costs not over 10 cents above present prices, and none of them can as yet be relied upon to make it for less than 5 cents above present prices. Mining costs will constitute a substantial part of the total cost, particularly in the case of oil shale, and probably geographical considerations will be a large factor. Also, the deposits of oil shale and tar sands vary a great deal in richness, so that the richest of such deposits might well come in ahead of coal, whereas the poorer deposits might never be called upon.

In view of the uncertainty mentioned above, the following discussions are presented without any implication as to the probable order in which the respective sources will be developed.

Oil Shales.—The wide variety of figures in literature as to the cost of making gasoline and other petroleum products from oil shale largely reflect major differences in the assumed figures as to the richness of the deposits and the costs of mining and of shale disposal, which are the principal factors in the cost of making liquid fuels from oil shale. The importance of mining costs increases rapidly as the richness of the shale decreases. Accordingly, one of the most important things to be studied in order to determine more accurately just how soon, and to what extent, oil shale can be used as a source of substitute liquid fuels, is to conduct some really thorough exploration of our oil-shale reserves with determinations of the oil content throughout the body of the better deposits, rather than that of the mere outcroppings. Where major deposits of good-quality material are located, consideration should also be given to the important problems of available space for cheaply disposing of the shale residues, adequate water supply, rail facilities, etc. Once the most promising major deposits are located and blocked out, an imaginative investigation should be undertaken in an effort to develop better mining methods in the hope of reducing this very large element of cost and, in any case, establishing it more definitely than it has been to date. Government agencies are particularly well adapted to carrying out such investigations, and if they do not do it, it is not likely to be done in the reasonably near future.

Retorting oil shale for the purpose of distilling out the oil is subject to further improvement and might well justify one or two semicommercial units, once some of the above-mentioned factors are developed. The oil thus produced should be made available for processing in hydrogenation and catalytic-cracking pilot plants already available in several industrial laboratories, the results to be reported back.

Although the reserves of oil shale in this country are very large, it should be emphasized that only a small proportion of the presently known reserves appear to possess the desirable characteristics necessary to permit their commercial use on a basis competitive with coal. Although very little research or development has been carried out on shale oil during the past 15 years on account of the general feeling in the industry that the prospect of using it is rather remote, it is known that hydrogenation will greatly improve the quality of the product, and it is probable that after moderate development work, gasoline could be made from some of the richest shales for around 5 cents per gallon above present prices.

Tar Sands.—There has been a great deal of interest in the very large reserves of tar sands along the Athabaska River in west-central Canada. However, the situation with regard to these sands is similar to that of oil shales in that the deposits differ greatly in their oil content and in the ease of mining. Except for factors of geography, the richer tar sands appear to be a somewhat more economical source of the heavier hydrocarbons than the richer oil shales, but the remote location of the principal tar sands may well outweigh this advantage. In any case, the amount of tar sands definitely known to be rich, and which can be cheaply mined, is small compared to the figures generally quoted as representing the total reserves. Again, a more thorough exploration of the location and quality of the reserves and the study of commercial mining or displacement methods would seem to be desirable in order to permit a better evaluation of the real magnitude and relative promise of this possible source of liquid fuel, particularly the heavier fuel oils. Some study should also be made of the scattered deposits of oil sands and similar bituminous materials in the United States, about which comparatively little is known.

Coal.—The one substitute source of liquid fuel about which there can be no doubt as to either the quality and quantity of the reserves is coal. In this case, mining costs are less important because the oil yields per ton are substantially higher, and coal-mining costs, under different conditions, are already fairly well established. The major problems in this field are in connection with working out the best combination of processes for converting the coal into liquid fuels. Presently known processing methods are undoubtedly capable of marked improvement.

There are two general methods by which coal can be converted into liquid fuels. The first process to be developed, known as the hydrogenation process, involved treating powdered coal in an oil slurry with hydrogen under high pressure, in the presence of catalysts, to make a heavy liquid which can be further hydrogenated under still higher pressures to make gasoline and other products. This process and the related process for the hydrogenation of coal tar were the principal reliance of the Germans for the production of aviation gasoline during the war. Very large investments and steel tonnage are required, and in its present state of development the process is believed to be considerably more expensive than the alternative Fischer synthesis for the production of gasoline. The hydrogenation process does, however, have the advantage of giving somewhat better quality gasoline, and it can also be adapted to producing heavy fuel oil by carrying the process only part way, and under more moderate pressures.

A more recent process, also developed and widely used in Germany, is the Fischer process previously referred to, whereby carbon monoxide and hydrogen (water gas) made from coke and steam are converted into gasoline and other petroleum products. Only a few years ago this process was considered definitely inferior to hydrogenation because of the relatively high cost of the coke with which the process started, and the poor quality of the gasoline produced.

Within recent years both these objections have been overcome. In the first place, catalytic-refining methods have made it possible to produce high-quality gasoline from the Fischer

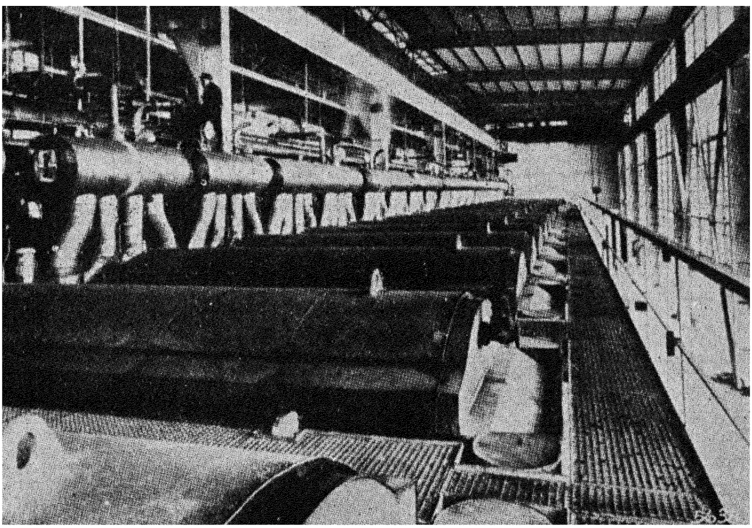

FIG. 3.—Top of synthesis chambers and cooling liquid manifolds at Ruhrchemie Fischer-Tropsch plant. (*Courtesy of U.S. Bureau of Mines.*)

product. In the second place, it has been found that it is not necessary to start with high-grade coke made from relatively scarce coking coals, but that the necessary mixture of carbon monoxide and hydrogen can be made advantageously from the many large deposits of subbituminous coal and lignite, for which there is relatively little other demand. The high water content of lignite makes it somewhat less attractive than subbituminous coal except where mining costs are very low, but large deposits of both materials are available for economical strip mining in various parts of the country. Starting with these materials, there are a variety of low-temperature carbonization processes or continuous gasification processes from which it is possible to make the necessary synthesis gases at moderate costs. Some of these processes bring into play the above-mentioned types of intermediate processes for converting gaseous hydrocarbons into carbon monixide and hydrogen. The by-product liquids produced by the cheaper low-temperature carbonization processes have always been hard to market in the past, but there is evidence that hydrogenation alone, or combined with other processes, will overcome these difficulties as well.

In the light of these developments the technical and commercial possibilities of the Fischer-Tropsch processes, particularly as applied to low-grade coals, have advanced very rapidly in the past few years, quite apart from developments which have doubtless occurred in Germany. Although it will require much more research and pilot-plant testing to determine the best combination of steps for converting a given type of coal into gasoline, it is the opinion of the best-informed technologists that the Fischer process, probably starting from subbituminous coal, is now the most promising major source of liquid fuel for the long-range future. Although the investment required will probably be three or four times that required in refining petroleum and the ratio of labor required something like double, it appears that given a few more years of research and development, gasoline can be made from coal by one of the above-mentioned combination processes for not more than 5 cents per gallon above present costs from crude petroleum.

Some of the above combination processes have the further advantage of producing large quantities of ammonia, benzene, phenol, and other by-products. The type of process ultimately used may depend considerably on the extent of the demand for these by-products and for by-product gas. As previously mentioned, the Fischer process can also be used to produce high-grade diesel fuel, wax, and even lubricating oil.

RECOMMENDATIONS REGARDING GOVERNMENT RESEARCH

Although some in the petroleum industry have been critical of the proposed government financing of large-scale demonstration units for making liquid fuel from coal or oil shale, much of this criticism has been based on the mistaken assumption that it was planned to build large plants prematurely, based on presently known technology. The industry has seen too much of the value of research to oppose any well-planned program by any agency which will add to the sum total of useful knowledge relative to the industry. There are, however, certain basic characteristics of, and problems connected with, all tax-supported research, which indicate the desirability of close examination and proper guidance of any government research program.

Tax-supported research has the following general advantages and disadvantages:

1. On account of the absence of the profit motive it is possible to study certain types of problems of general national interest which no private concern would feel justified in undertaking. Problems involved in meeting possible future wartime shortages or other contingencies of many sorts are cases in point.

2. On the other hand, this same absence of the profit motive plus the comfortable permanence of the employment and the proper interest of the personnel in any subject under study, makes it very difficult to terminate or redirect lines of research, even after they have lost any real promise of practical value.

3. Unless there is a definite mechanism set up and regularly used to keep the research in close contact with practical developments in a given field, work is likely to be continued long after a given problem has ceased to be of importance because of new developments within an industry.

4. Research by governmental agencies is always likely to be subject to political pressure to direct it into one channel or another favored by some particular group, rather than to be determined entirely by sound technical considerations.

5. In addition to the unfairness of taxing business in order to compete with it, government research in fields of immediate industrial importance is likely to defeat its own ends by discouraging a much larger volume of research which would otherwise be undertaken by private industry. Also, if the government undertakes research in a highly competitive field, it is naturally difficult to secure the needed industry cooperation and advice.

6. In the relatively few cases of really important commercial discoveries by government laboratories, it is frequently difficult to bring about prompt commercial use, first, because there is no pride of discovery to cause any one company to push the develop-

ment along, and second, because in the absence of a patent or an exclusive license there is little incentive for a company to assume the heavy expense of developing and marketing a new product, for if it is successful it will quickly be copied by others who have avoided the initial expense and hazard.

7. Government research is particularly well adapted to fields like agriculture and forestry, where the over-all public interest is large, and yet no appropriate private concerns exist to carry out more than a small fraction of the needed research.

8. Government research is also peculiarly adapted to making surveys of available raw-material resources and methods of recovering same, especially where they are in the public domain.

9. The government is again the appropriate agency for much of the research in standardization and testing methods, where it is important to have an impartial arbiter between different producers, or between producers and consumers.

10. Government agencies may also well undertake fundamental research into the basic reactions and characteristics of our raw materials, which is of value to industry generally but which no individual company is likely to undertake on a broad scale. An excellent example is the careful study by the Bureau of Standards, largely financed and guided by industry, of the composition of the individual hydrocarbons present in petroleum. This work proved to have unexpectedly prompt and large value in connection with the 100-octane gasoline program.

11. Government financing of research in university and foundation laboratories would have many advantages in making possible effectual employment of the time and abilities of large groups of professors and advanced students completing their training. The little publicized but enormously valuable work of the National Defense Research Council during the Second World War is illustrative of the possibilities. One difficulty during peacetime would be to have the work directed by a sufficiently eminent and nonpolitical group of scientists to resist the many pressures to assign the financial support on some basis other than the ability and facilities of the respective institutions, a large number of which would desire such funds to supplement their educational budgets.

In the light of these general considerations *in re* government research, and the status of the substitute-fuel outlook previously discussed, the logical first objectives of government research in these fields would appear to be as follows:

1. In the field of oil shale, the information most needed to permit accurate appraisal of its commercial possibilities is, first, better information regarding the size, location, and average oil content of the more promising shale deposits, and, second, better information as to the cost of mining such deposits, using modern machine methods. The government should undertake investigation along both of these lines, including some full-scale tests on the use of modern mining machinery in representative types of deposits. Any extensive effort to develop improved retorting methods should probably await preliminary determination of whether oil shale can reasonably compete with the coal processes as a substitute source of liquid fuel, but some pilot-plant retorting would probably have to be carried out in order to reach this preliminary conclusion. The industry will gladly cooperate in determining the applicability of modern methods of hydrogenation and catalytic cracking to the crude shale oil obtained in such investigations.

2. In the field of coal utilization, mining costs are better established and are of less importance in determining final costs. Much research and pilot-plant testing need to be conducted on various combinations of the available processes as applied to different types of coal, particularly subbituminous coals and lignites. There should be particular emphasis on the development of better methods for the continuous gasification of low-grade coals to make Fischer-synthesis gas. An effort should be made now that the European war is over to learn the latest developments of German technology as the result of their intensive practical experience, and compare these developments with those which have been made in this country. Not until this information is studied should there be construction of commercial-sized demonstration plants which might be obsolete before they could be completed.

3. In this connection it should be emphasized that while there are many processes which cannot be readily demonstrated on a laboratory scale, recent developments in the design and operation of pilot plants and the interpretation of pilot plant results make it possible to get at moderate cost and on a small scale results which can be applied with accuracy to commercial-sized units. Such

small pilot plants are not only far cheaper to build, but they permit operation under a wide variety of conditions and charging stocks and give many times as much information per dollar expended in their operation as it is possible to get from commercial-size units, where changes can only be made with a great expenditure of money and time, and where a single test run requires carloads instead of barrels of raw materials and finished products.

4. As to research on tar sands, the known sands within the United States are relatively unimportant, though some work should probably be undertaken to determine more definitely their size and quality. However, the really large deposits are in Canada, and it is hoped that the Canadian government, possibly with the advice and help of the United States government, will continue and expand its research on the mining and utilization of these deposits to determine whether they will come into the picture ahead of oil shale or coal, or behind them.

5. If the Navy is authorized to make its requested study of the production of Navy fuel from oil shale, the technical investigations should preferably be carried out by the Bureau of Mines as a part of the above-described program.

6. One major line of investigation which will be costly and time-consuming, but which should not be overlooked in view of its possible major importance, is that of gasification, distillation, or extraction, in the ground, of the solid bituminous materials discussed above. Radically new techniques would have to be developed, but the magnitude of the savings, particularly of labor, by avoiding mining operations, is great enough to justify a comprehensive and imaginative study of the possibilities, particularly of the controlled gasification of coal in the ground to make Fischer-synthesis gas.

If the Bureau of Mines is in general accord with the principles and the program outlined above, the writer is of the opinion that the petroleum industry would be willing, if the government so requested, to set up an advisory committee of technologists well-versed in these fields to bring together and analyze existing data from various sources. On the basis of this correlation of information they could advise and cooperate in recommending detailed research programs, designing pilot plants, and keeping the investigations guided along the most useful and practical lines.

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CHAPTER VIII

OIL IN PUBLIC DOMAIN, NAVAL RESERVES, AND FEDERAL AND STATE MARGINAL LANDS

Part 1. The Public Domain and Naval Reserves

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While there are scattered tracts of land belonging to the United States in many states, including various parcels recently acquired through purchase for resettlement, submarginal-land administration, or other purposes, or by foreclosure of loans made by governmental agencies, the so-called "public domain" is commonly understood to embrace the lands and mineral deposits owned by the United States in the Rocky Mountain states (Montana, Wyoming, Colorado, New Mexico, Idaho, Utah, Arizona, and Nevada), the Pacific coast states (California, Wash-

	Acres
Reservation of all minerals:	
Under Stock raising Act..	33,532,155
Under other acts.	2,209,269
Total...	35,741,424
Vacant and unreserved:	
Outside Federal grazing districts	394,000,000
Inside Federal grazing districts	131,000,000
Total	525,000,000
Alaska	225,000,000
Total United States and Alaska	750,000,000
Total open to oil and gas leasing in United States and Alaska	785,741,424
Oil and gas:	
Producing..	689,654
Prospective, included in permits, leases, or lease applications	2,014,575
Total	2,704,230
Total on defined "known geological structures"	1,691,617

ington, and Oregon), and Alaska. The United States also asserts claim to certain tide lands on the Pacific and Gulf coasts.

In the annual report of the Secretary of the Interior for the fiscal year ended June 30, 1943, the lands of the United States, so far as is pertinent to this inquiry, are classified as shown on page 230.

As of June 30, 1943, the Secretary estimated that the federally supervised oil and gas lands, which include Indian lands, contain about 7 per cent of the known petroleum reserves of the United States and produce annually about 5 per cent of the total crude-

PRODUCTION FROM PUBLIC, NAVAL-RESERVE, AND INDIAN LANDS IN 1942

State	Crude oil, bbl.	Gas, 1,000 cu. ft.	Gasoline, butane, gal.
	Public Lands		
California	14,741,902	34,687,992	34,530,203
Colorado	1,430,597	3,507,122	226,025
Louisiana	95,015	1,823,283	394,602
Montana	541,853	3,599,204	11,350
New Mexico	9,328,304	28,477,649	19,834,226
Oklahoma	88,793	121,183	136,927
Utah	14,624	3,672,059	
Wyoming	19,013,964	14,704,582	27,361,212
Total public land	45,255,056	90,693,074	82,494,545
Total, 1920 to Dec. 31, 1942	678,937,782	1,073,093,121	1,291,702,697
California naval reserve	2,930,589.58	1,858,010	8,770,143
California, 1920 to Dec. 31, 1943	134,559,742.12	123,160,940	314,976,789
Wyoming naval reserve	Shut in	Shut in	Shut in
Wyoming, 1920 to Dec. 31, 1942	3,550,227.63	5,162,869	2,483,896
Current totals (all lands)	48,185,646	92,551,084	91,264,688
Grand totals (all lands)	817,047,752	1,201,416,930	1,609,163,382
	Indian Lands		
Montana	1,662,677		
New Mexico	169,915	1,655,898	4,680
Oklahoma	8,966,708	6,253,515	31,576,800
Wyoming	1,076,100		
Total (all Indian lands)	11,875,402	7,909,413	31,581,480

oil production of the United States. As of the same date 10,532 public-land wells were under Federal supervision, including 5,601 capable of oil and gas production. During the year 1942, which is the latest calendar year for which the production figures are available, the total production of crude oil from the public lands, exclusive of Indian lands, which the United States supervises but does not own, and including production from the naval reserves, was 48,185,646 bbl., or 132,000 bbl. daily. The production from the naval reserves alone during the year 1942 was 2,930,589 bbl. or about 8,000 bbl. daily.

There are four naval reserves. Numbers 1 and 2 are in California (Elk Hills). Number 3 is the so-called "Teapot Dome," adjacent to the Salt Creek field in Wyoming. This reserve is shut in and its estimated total recoverable content is not important. There is another reserve in the vicinity of Point Barrow, Alaska, and there has also been reserved for the navy a large acreage of oil-shale lands.

The foregoing, in a rough and general way, is what we are talking about when we discuss oil and gas production and reserves, both known and yet unknown, on the public domain.

Under the existing acts of Congress the Secretary of the Interior is authorized to lease the public lands or reserved oil and gas deposits (except the naval reserves, which are under the jurisdiction of the Secretary of the Navy), for oil and gas prospecting and development. The leases reserve a sliding-scale royalty to the United States ranging from 12½ to 32 per cent, depending upon the production per well and the price of oil. No one person or corporation is permitted to hold more than 2,560 acres of government land on any single structure or more than 7,680 acres in any one state. If, however, a unitization or cooperative-development agreement is entered into which the Secretary of the Interior deems in the public interest and is willing to approve, such unitized areas are exempt from the acreage limitations. The leases are subject to such rules and regulations as the Secretary of the Interior may from time to time promulgate. The lease provisions are rigidly in favor of the United States as lessor, but are not so unreasonable as to render compliance impossible. A very ample authority is reserved in the leases and under the rules and regulations to control and direct operations. The Secretary exercises his power in this respect through the United States Geological Survey, which is staffed by a reasonably competent and experienced body of men who, while at times overzealous in protecting what they conceive to be the interests of their client, the United States, have on the whole discharged their functions with reasonable fairness. Thirty-seven and one-half per cent of the proceeds of all bonuses, royalties, and rentals (except from naval reserves) are paid by the Secretary of the Treasury after the expiration of each fiscal year to the state within which the leased lands or deposits are located for the construction and maintenance of public roads or for the support of public schools or other public educational institutions. The act of Congress under which the leases are issued consents to the taxation of the operators' production and property by the states and local taxing bodies.

The so-called "Oil Land Leasing Act" of Feb. 25, 1920, with subsequent amendments (briefly outlined in the preceding paragraph), may be regarded as the present national oil policy in respect to oil and gas deposits on the public domain. Prior to the enactment of the Leasing Bill in 1920, oil and gas deposits on the public domain were disposed of under the placer-mining laws, which involved an outright sale to the entry-man making a discovery, with no reserved royalty or control to the United States. The Leasing Bill was under consideration by Congress for several sessions before its enactment in 1920. It involved an entirely new oil and gas policy for the public lands. The legislation was under debate while the First World War was in progress, and very few pieces of legislation have ever been subject to such prolonged and thorough consideration. The policy crystallized by Congress in the Leasing Bill contemplates the discovery and development, through private capital and initiative, of the oil deposits underlying lands of the United States, but under leases favorable to the United States as a proprietor. While the royalties are high and the terms of the leases and rules and regulations rigid and restrictive, a significant amount of prospecting and development on the public domain has gone forward since the enactment of the bill in 1920. The production developed has resulted in very large revenues to the United States and the public-land states. Enormous amounts of private capital have been expended not only in the discovery and development of producing fields, but in the drilling of thousands of unsuccessful wildcats. If a sound public policy looks to the development of the natural resources of the United States, it cannot be said that Congress acted without prudence and foresight when it enacted the Oil Land Leasing Act in 1920. Quite recently, by an act of Dec. 24, 1942 (the O'Mahoney bill), Congress provided that during the period of the national emergency, when the Secretary of the Interior determines that a new oil or gas field or deposit has been discovered by virtue of a well or wells drilled within the boundary of any lease issued under the provisions of the act of Feb. 25, 1920, as amended, the royalty obligation to the United States of the lessee who drills such well or wells as to such new deposit shall be limited for 10 years following the date of such discovery to a flat rate of 12½ per cent. If the discovery lease is included within a unitized area, the benefit of the 12½ per cent flat royalty applies to all of the lands within such unit. This may be regarded as a very recent reaffirmation upon the part of Congress of the policy of encouraging the discovery and development of the oil and gas deposits on the public domain by private capital and private initiative. In my opinion this legislation, which has been limited to discoveries made during the period of national emergency, should be continued indefinitely and made applicable to any future discoveries of new oil and gas fields on the public domain.

If the present national policy in respect to the public domain, as reflected in the existing acts of Congress, is now to be reconsidered, the discussion will probably re-examine the following possibilities:

1. Withdraw all public lands and oil and gas deposits in which no private property rights have yet been vested as one large military reserve to be either shut in for future use or to be prospected and developed by the United States itself, or through a variety of contracts without uniformity which the Secretary of the Interior, the Secretary of the Navy, or the Secretary of War may negotiate.

Such a proposal, upon examination, is unthinkable, and it is quite unlikely that Congress could be induced even to consider it. The public domain is not one solid block of lands. On any producing structure which might be found it is quite likely that there would be privately owned and state lands. Consequently the United States could not drill a discovery well and proceed to shut in the production. It would be the Elk Hills situation all over again in almost every case. Furthermore, a single discovery well would only prove the small tract of acreage upon which the well is drilled. To determine the extent of the reserve and to make it immediately available for military necessities in the future it would be necessary to drill up the field. This would immediately lead to pipe-line and transportation problems, without which the reserve would be unavailable, and in considering a pipe-line outlet, how would the other terminus of the line be selected? For the United States itself to do the necessary prospecting and development of the public domain would involve the expenditure of continuing large appropriations for geological work and wildcatting, and it is hard to believe that Congress would year after year make such appropriations. It would quickly have its eyes opened to the enormous expense of geological exploration and dry holes in the pursuit of a single oil field. If contracts were negotiated for the drilling or development of such areas by private capital, there would be no advantage as against the present system of leaving to private capital and initiative all of the risk. All of the oil and other natural resources of the United States, whether on the public domain or elsewhere, are always available to the Federal government for the prosecution of a war. The states would be deprived of their tax revenue from the operations of the Federal government and also, presumably, of the 37½ per cent of oil royalties and rentals which they now receive from production on the public domain. The present total production from all Federally supervised lands, including Indian lands, is only 5 per cent of the total production of the United States. Whether the public domain contains a greater proportion of yet undiscovered oil fields than other parts of the country is something nobody knows, but it is reasonable to suppose that the aggregate of any discoveries made would not for many years create a reserve equivalent to the present producing fields. The effect of such a proposal upon the civilian economy would be far-reaching, even without considering the social, political, and economic aspects.

2. Withdraw additional areas to serve as naval or military reserves, or condemn additional areas on the public domain which are now proven.

I may not be familiar with all of the arguments which originally resulted in the creation of the present naval reserves, but I cannot see that they serve any useful purpose. Naval reserves 1 and 2 in California (Elk Hills) are the only ones that contain any considerable reserve, and the maximum daily production that could be developed from such reserves in time of war would be an inconsiderable fraction of the total naval and military requirements. Here again it may be pointed out that oil from the naval reserves is no more available in time of war to the Navy than any other oil produced at any point in the United States. If the United States should undertake by condemnation to acquire and shut in proved oil fields on the public domain, there would be endless litigation, and the total reserves that would thus have to be set aside would have to be enormous in order to afford a current military supply of any consequence in time of war. Furthermore, there is no difference between condemning oil fields in the public domain and oil fields in Texas or any other place. It is true that the United States would start in such condemnation proceedings by being the principal royalty holder, but there are very few producing tracts of government land without numerous overriding royalties. The fallacies and impracticalities underlying the withdrawal of the entire public domain as a military reserve are all present in the withdrawal of particular limited areas.

3. Continue the present policy of leasing the public domain for oil and gas exploration with some liberalizing of the statutes and rules and regulations, having due regard for the interest of the United States as a proprietor but designed to encourage rather than to retard or hamper development.

The existing statutes of the United States and most of the rules and regulations promulgated by the Secretary of the Interior have not unduly retarded an extensive exploration of the public domain for oil and gas. During the last 10 or 15 years, however, the attitude of the Department of the Interior, which has gradually seeped down into the United States Geological Survey, has been one of creating unnecessary resistances, impediments, and restrictions. It has seemed to many operators on the public domain that the policy of the Federal government was to discourage rather than to encourage development. In saying this we should not be unmindful of the honesty, devotion to duty, and competence of many of the older civil service employees in the Geological Survey, the General Land Office, and the Department of the Interior. They all seem to be afraid that a scandal of some sort is likely to jump out of the box at any time. If a sound national oil policy should, as I believe, look to the most intensive and extensive development of the public domain for oil and gas, and if Congress and the Interior Department should stand firmly behind such a policy, the statutes, rules and regulations, and lease forms could quickly and without many major changes be brought into line with such a reorientation of viewpoint.

There are large deposits of coal and oil shales in the public domain, and I can see no objection to the United States' spending whatever money might be necessary to keep in the very forefront of any technical advances in the mining and extracting of petroleum products from these raw materials. Without constructing large plants or going into competition with the oil business it seems to me that we should be as far advanced as any country in the world in utilizing these resources for petroleum products, if and when the necessity arises. This is essentially a government activity because no profit at the present time could be expected by private capital from an investment in this research.

Furthermore, nothing in this paper is intended to oppose the accumulation in times of peace of ample and properly protected stocks of petroleum products at all of our naval, air, and military bases. Such stocks should be purchased outright by the government in such a way as not to disturb unduly the civilian economy, and the quantity should not be so excessive as to invite undue loss or inconsistent with the possibility that the quality of such desirable stocks will undergo a radical change due to technological developments in the refining industry and in the types of military equipment.

Part 2. Lands of the United States

By A. C. Mattei

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Introduction.—This war has demanded unprecedented amounts of petroleum for military and essential civilian needs. The military requirements have been so large that it has been necessary to ration strictly petroleum products for civilian consumption.

The proved oil reserves are being drawn upon heavily and in some instances at a rate in excess of the maximum efficient rate, with attendant injury to ultimate recovery. Substantially all these requirements come not from the petroleum resources of foreign lands or from military, naval, or other reserves long ago established as a war stock pile, but from our privately owned domestic oil fields, because here we have in existence the integration of production, transportation, and refining so essential to the utilization of petroleum when and where needed. The existence of a vigorous competitive industry, guided by private initiative, enabled these unprecedented demands to be met—not too little and not too late.

The principles of conservation require that yearly withdrawals from a typical oil field be restricted to but a fraction of the total recoverable oil in the field; consequently, to maintain an adequate supply of petroleum there should be available proved reserves at all times equal to many times the annual demand. For the purpose of safeguarding our petroleum resources and assuring the nation of an adequate supply in the future, the Petroleum Industry War Council in the fall of 1943 appointed a committee of its members to formulate a national oil policy. After detailed studies, which are being continued, that committee submitted to the council on Feb. 28, 1944, a brief preliminary report of those principles believed essential to the determination of a sound national oil policy. One of the basic principles is referred to as government attitude. "Government should encourage the petroleum industry to assume risks inherent in oil finding and production by minimizing such risks as far as possible"; and "Government should not invade the province of industry either by participating with industry in operations or by itself entering into any phase of the business." It suggested that one of the elements of policy should be to continue "the present policy of leasing the public domain for oil and gas exploration . . . with some liberalizing of the statutes, rules, and regulations, having due regard for the interest of the United States as a proprietor but designed to encourage rather than to retard or hamper developments." It is the purpose of this paper to examine this suggested policy with relation to the lands of the United States and to endeavor to suggest how this policy may be reconciled with the foregoing basic principles.

Lands of the United States.—The lands owned by the Federal government today comprise more than 24 per cent of the total land area of continental United States and more than 36 per cent of the total land area of the United States and its territories. In the last decade Federal land holdings have increased by more than 150 million acres as a result of acquisitions by various governmental departments and agencies. These lands have been and are being acquired by purchase, gift, or condemnation under the Weeks Act (36 Stat. 961), the National Industrial Recovery Act (48 Stat. 200), the Emergency Relief Appropriation Act of Apr. 8, 1935 (49 Stat. 115), Section 55 of Title I of the act of Aug. 24, 1935 (49 Stat. 750), the Bankhead-Jones Farm Tenant Act of July 2, 1937 (50 Stat. 525), the Second War Powers Act of Mar. 2, 1942 (57 Stat. 176), and by other acts of Congress, and in some instances without any statutory authority whatsoever.[1]

Numerous departments, agencies, and bureaus of the Federal government (estimated at from 17 to 25) administer these lands, and it is not surprising that there is no uniform policy with respect to them. In a letter addressed by the Comptroller General of the United States to the Speaker of the House of Representatives, dated Oct. 5, 1943, it is stated that

> There is at the present time no satisfactory uniform control, administrative or otherwise, over the performance of the operational steps in the acquisition and disposition of real property for the uses and purposes of the United States and its various agencies, nor has any satisfactory procedure been established for the compilation of records whereby adequate administrative control could be effected. . . . The fact that current and dependable real-property data, needed by the Congress and others concerned, are not available through existing channels has been developed in recent hearings before congressional committees.

Estimates on land ownership by the Federal government have been prepared after great effort by congressional committees investigating this subject and they serve as the only evidence available and at best can be considered only as rough estimates, generally out of date by the time they are compiled.

In September, 1944, it was estimated that the Federal government owned some 455 million acres of land in continental United States and some 821 million acres of land in the United States

[1] Interim Report 1884, 78th Cong. 2d Sess., pursuant to H. R. 281, p. 17.

and its territories. In some of the states the percentage of land owned by the Federal government is startling: California—46 per cent, Nevada—87 per cent, Oregon—53 per cent, Idaho—64 per cent, New Mexico—44 per cent, Arizona—73 per cent, Wyoming—51 per cent, Utah—72 per cent, Colorado—35 per cent, Montana—35 per cent, Washington—35 per cent. In the territories the Federal government owns some 99 per cent of the land in Alaska, 10 per cent in Hawaii, and 12 per cent in the Virgin Islands.

The ownership by the United States of these extensive areas within the various states has created and is still creating a serious problem for those states in which the proportion is high. Report 1884 of the committee appointed by the House of Representatives (78th Congress, Second Session) pursuant to House Resolution 281, states that "The problem is extremely varied and complex. It is well settled in law that property owned by the United States is not subject to state or local taxation without the approval of Congress. . . ." That report points out that in some localities the local government has been virtually pauperized by the removal from the tax rolls of extensive areas of land, and that the tax requirements for public services such as roads, schools, hospitals, etc. have become a serious problem. It is no wonder therefore that the states and local communities are resisting every effort of the Federal government to acquire more lands within their borders and are seeking some means of requiring the Federal government to compensate them for their lost tax revenues. This agitation has given considerable impetus to the theory that the Federal government should pay state and local taxes the same as any other landowner, and in some instances legislation has been enacted providing for *in-lieu* payments by the Federal government. Neither course is satisfactory, and results in simply robbing Peter to pay Paul by shifting the burden of taxation to the entire people of the nation. The real solution is to have the Federal government dispose of all lands no longer used or useful and needed for the purpose originally acquired and to limit drastically future acquisitions of lands by the Federal government.

Our present proved oil reserves are only a part of the answer to our future oil supply. Much of our future production will come from fields not today discovered. This is historically the story of the development of oil. Today we are producing in excess of 400,000 bbl. daily from fields not discovered in December, 1941. New areas must be explored, and much time, money, and effort expended by the oil industry in the search for new fields in the United States as well as in foreign lands.

The enormous landholdings of the Federal government, comprising as they do some 24 per cent of the land area of continental United States and 36 per cent of the land area of the United States and its territories, should be a fertile field for oil exploration; and to this end the Federal policies and laws with respect to these enormous landholdings must be reviewed in light of all facts.

The lands owned by the Federal government fall roughly into two classes—those which for lack of a better term may be called acquired lands and those which we commonly refer to as the public domain.

Acquired Lands.—Some 150 million acres of land within continental United States, or almost one-third of the present landholdings of the Federal government, are lands which have been acquired by purchase, gift, or condemnation under various acts of Congress. They were acquired for special purposes under various acts, but more recently, during the war period, the War and Navy Departments have acquired large tracts of land for military purposes under the Second War Powers Act. Unfortunately in too many cases these lands should have been leased, but they were purchased outright, and although not acquired for their mineral content, no mineral reservation was retained by the owners. No attempt should be made by the Federal government to retain the minerals or any part thereof when these lands are no longer used or useful for the purpose acquired.

In addition to the lands acquired by the Federal government, additional lands have been acquired as a result of foreclosure by government lending agencies and by the Federal Land Banks. Although these banks are private institutions they operate with Federal funds, and a consistent policy, which is now entirely lacking, should be adopted with respect to the sale or other disposition of these lands and their mineral content.

In most congressional acts authorizing the acquisition of land, no provision is made for its disposition when the land has served the purpose for which acquired. There is no uniform policy with respect to the administration of these lands. There is no single agency whose responsibility it is to know what and where the landholdings of the United States exist. The Comptroller General, in the letter of Oct. 5, 1943, referred to above, states: "At present there are over 60 departments, agencies, and independent establishments from which the Congress and the Executive must obtain information upon which to base decisions and executive plans and policies regarding the real-property requirements of the government."

The only statutory authority for the disposition of the lands acquired for war purposes is to be found in the Surplus Property Act of 1944. This act is woefully lacking in any realistic approach to the tremendous problem of the disposition of government land to private ownership. It is doubtful whether or not merchantable title can be conveyed under the act because of the existence of the many mandatory priorities with respect to when and how each parcel of such land shall be sold. Furthermore, only land which is declared to be surplus by the Federal agency having jurisdiction of it comes within the provisions of this act.

Some of the government departments and agencies having jurisdiction of acquired lands are following the practice of leasing them for oil and gas exploration without any defined statutory authority and certainly without any well-defined or uniform policy. In February, 1943, Senator O'Mahoney stated on the floor of the Senate that Senate Bill 736, introduced by him, "is worth mentioning, even at this hour, because it tends to correct a recent tendency which has been manifest in some of the executive departments to expand their jurisdiction and activities without the benefit of statute. . . . Whenever any executive bureau of its own volition, without consultation with Congress, undertakes to set up machinery for administering lands of the United States acquired for another purpose, for purposes for which Congress has created the Department of the Interior, its policy is obviously a mistaken one. . . . "

The alarming rate of government acquisition of land is apparent in the Gulf coast area where oil operators, in an effort to expand and supplement the oil reserves of the nation by exploring remote areas, have run head on into a series of complications resulting from those acquisitions and the lack of any uniform policy of administration. Acquired lands, however, do not exist only in the Gulf coast area but in every state of the Union, and from time to time as exploration is expanded, similar complications will result in other areas from these acquisitions. The development of these lands for their mineral resources will be retarded unless a uniform and sound policy of administering them is adopted.

The first step is a statutory requirement that the administration of the sale or other disposition of acquired lands be centralized in one office; with more than two-thirds of the lands of the United States already being administered by the General Land Office of the Department of the Interior, that office is the only logical agency to undertake the administration of the acquired lands. It has demonstrated its competency by its broad experience in surveying and mapping the public domain and by its proposals for establishing and maintaining improved real-estate records, and has at the present time, both in Washington and in the field, the necessary personnel experienced in various phases of real-estate acquisition, disposition, and title work. Legislation should be enacted immediately requiring each department or agency of the Federal government having control over any land to furnish to the General Land Office a complete description of such land, a record of all sales or other dispositions theretofore made, a certification as to whether or not the land is used or useful and necessary for the purpose for which acquired, and such other information as may be necessary in order to complete the records of landownership by the United States.

The Department of the Interior, through the General Land Office with its years of experience in dealing with the public domain, has in existence all necessary machinery to administer the disposition of the acquired lands and it should be the only government agency operating in that field.

The acquired lands were never acquired for their mineral content, and they should be disposed of without any reservation of minerals to the United States unless they are proven to be valuable for minerals or unless they are still used or useful and needed for the purpose for which originally acquired; as to the latter, to the extent that the mineral development thereof is not inconsistent with a paramount public use, the mineral deposit should be leased or otherwise disposed of by the United States in the same manner and upon the same terms and conditions as the mineral deposits of the public domain. Such legislation should declare it to be the policy of the United States to sell and dispose of all acquired land when and as soon as it is no longer used or useful and needed for the purpose for which acquired, and where the use of the surface of acquired land for the public purpose to which it is devoted is not inconsistent with its mineral development, to dispose of the minerals under the general land laws of the United States. The mineral deposits in acquired lands previously disposed of with a reservation of minerals should be granted to the owners of such lands on the effective date of the legislation, provided such lands are not then either subject to a valid mining location or proven to be valuable for minerals; and all dispositions of acquired lands after the effective date of such legislation should be of the entire title, if at the time of disposition the lands are not proven to be valuable for minerals. Those lands proven to be valuable for minerals and those still used or useful and needed for the purpose originally acquired should be subject to mineral development in the same manner as the public domain.

Subjecting the acquired lands to the general land laws is but the first step in accomplishing the suggested element of national oil policy relating to the lands of the United States. That policy also contemplates "some liberalizing of the statutes, rules, and regulations, having due regard for the interest of the United States as a proprietor, but designed to encourage rather than to retard or hamper developments."

The Public Domain.—The public domain consists of lands owned by the Federal government, generally from the time of territorial acquisition, which are not reserved for any special governmental or public purpose. The public domain is subject to disposition under the general land laws, including the Oil-Land Leasing Act of Feb. 25, 1920. Originally more than 76 per cent of the entire land area of the United States comprised the public domain. Roughly speaking, the public domain today consists of some 300 million acres (16 per cent) in the United States and some 650 million acres (29 per cent) in the United States and its territories.

Historically, only lands valuable for minerals were reserved from sale under the act of July 5, 1866 (30 U.S.C.A. 21). That act in effect made lands more valuable for mineral content subject to one type of disposition—location and discovery under the mining laws—and lands more valuable for agriculture subject to disposition under the homestead laws. It was not until the Separation Act of July 17, 1914, that a policy of reserving minerals in all lands became established, and the surface made available for homestead entry regardless of the value of the minerals. Prior to the enactment of the Oil Land Leasing Act of Feb. 25, 1920, the public domain was subject to oil location under the placer-mining laws; and upon proof of discovery and payment by the locator of a nominal consideration, a patent to the fee title was granted by the United States free from any future claim or interest of the United States. In 1908 the government became alarmed at the oil shortage and an endeavor was made to withdraw the entire public domain from oil location under the mining laws and to retain it as a reserve for the future.[1] However, nothing was done, and the prospecting on the public domain, which was going on at an unprecedented rate, apparently bore fruit because on Sept. 17, 1909, the director of the Geological Survey called attention to the overproduction of oil and recommended that the public domain be withdrawn from oil location under the mining laws not as a reserve for the future, but "to prevent waste."[2] This agitation produced results—the famous Taft withdrawal orders, subsequently confirmed by the passage by Congress of the Pickett Act (36 Stat. 847). With overproduction continuing, there was no necessity for exploration of the public domain for oil, and years went by with Congress considering but not enacting legislation relating to the oil and gas deposits of the public domain. The mass production of the automobile after 1910, coupled with the extensive use of petroleum for naval and military needs during the First World War, resulted in an extreme shortage of oil throughout the world and particularly in the United States. Congress, activated by that acute shortage, finally enacted the Oil Land Leasing Act of Feb. 25, 1920 (41 Stat. 437)—"An Act to Promote the Mining of . . . Oil, Oil Shale, Gas . . . on the Public Domain." Under that act, applicants were granted a permit to prospect for 2 years upon limited areas of the public domain, with the assurance that if they discovered oil or gas

[1] *U.S. Geol. Survey Bull.* 623, p. 104.
[2] *U.S. Geol. Survey Bull.* 623, p. 133.

they would receive a lease for 20 years with certain preferential rights of renewal, and as a reward for discovery one-fourth of the area covered by the permit was leased at a royalty of 5 per cent and the balance at a sliding-scale royalty of from 12½ per cent to 33⅓ per cent. This act had a tendency to promote the exploration for oil on the public domain, and from 1920 to 1929 a significant amount of prospecting and development took place, stimulated not only by the provisions of the act but also by high prices generally prevailing for crude oil during this period. And the industry, stimulated by higher prices, entered upon a program of extensive exploration—exploration which produced by 1944 some 20 billion barrels of oil out of a total production of 28 billion barrels since the first discovery in 1859, and a proved reserve of some 20 billion additional barrels. Improved technology coupled with this extensive exploration resulted in the discovery of immense new fields in California, Oklahoma, and Texas during the twenties, and by 1929 the development of oil lands in the United States had reached a state of extreme overproduction. Then again, with the thought of arresting further development of oil on the public domain, a general withdrawal order was issued which stayed the granting of prospecting permits under the Leasing Act.[1] The effect of this order was but to create an inequity by holding back prospecting on the public domain while prospecting on private lands continued at the accelerated rate. Conservation became predominant in all thought of oil exploration, and voluntary unitization or cooperative development of single oil fields was then and has been ever since recognized as a great aid to conservation. In 1930 and 1931, Congress amended the Leasing Act to provide for voluntary unitization or cooperative development of the public domain. However, although these acts bore every evidence of conferring but discretionary authority on the Secretary of the Interior, he adopted a policy of requiring permittees and lessees to agree by contract to compulsory unitization upon terms to be determined by him as a condition precedent to an extension of time for the performance of development work or the issuance of leases upon discovery; thereby to a large extent he destroyed the value of these statutory provisions in areas where privately or state-owned lands existed along with the public

[1] Order 338, Secretary of the Interior, Mar. 20, 1929.

domain. In August, 1935, Congress authorized compulsory unitization, terminated the permit system, and substituted one of exploratory and development leases, the provisions of which are left largely to the discretion of the Secretary of the Interior.[1]

In the years since 1929, the ever-expanding regulations imposing restrictions upon, and close supervision over, the operations on the public domain have materially hindered development and deterred the unitization or cooperative development of the public domain with private lands or state lands, culminating in an almost complete revolt of the oil industry, as expressed at the hearings held by the Interior Department in Denver, Colo., on Nov. 18 and 19, 1943, to consider proposed general regulations relating to unit operation. These ever-expanding regulations and restrictions have resulted in but few wildcat wells being drilled on the public domain, particularly during the war period, when increased costs, material shortages, and lack of man power added economic burdens upon the oil operator disproportionate to the benefit to be derived under the present leases and regulations affecting the public domain. The present shortage in developed reserves on the public domain is but the logical consequence of ten years of the policy expressed in the act of Aug. 21, 1935.

It is probably too late to question the wisdom of the Oil-Land Leasing Act of Feb. 25, 1920. By setting up the leasing system the government set itself up as a proprietor of lands, leasing them for revenue, and it is not surprising that as a landlord the government strives to drive a hard bargain—one which tends to discourage rather than encourage the mineral development of those lands. With the vast majority of the public domain located in the western states—in areas of likely oil development—one would suspect that with the wartime oil shortage the Federal government would formulate a policy to increase the exploration of this vast domain for its oil content; and yet only 689,654 acres of the public domain are producing oil or gas, some 2 million acres are leased for oil and gas exploration, and the United States, as proprietor of more than 24 per cent of all lands, is contributing less than 5 per cent of the total oil production of the country.[2] In a communication recently

[1] Act of Aug. 21, 1935 (49 Stat. 676).

[2] *Annual Report*, Secretary of the Interior, 1943.

addressed to the President, the Congress, and the Secretary of the Interior by the Public Lands Committee of the Interstate Oil Compact Commission, it is pointed out that from Jan. 1, 1936 to Jan. 1, 1943, only 37 wildcat wells were started on the public domain, not including horizontal extensions—26 of these in Wyoming, 4 in Colorado, 4 in Utah, and 3 in Montana—and that during this same period not less than 21,000 wildcat wells were drilled in the United States. The only logical conclusion is that the present Oil-Land Leasing Act and the resulting regulations have discouraged development of the public domain in pace with that of private lands.

An historical examination of the disposition of the oil and gas deposits in the public domain discloses that at times of overproduction there has been a tendency on the part of the Federal government to control the development of the public domain by stringent laws and regulations—often under the guise of conservation when conservation had no necessary relationship whatsoever to exploration—and in times of shortage a tendency on the part of the Federal government to liberalize its laws and regulations to encourage exploration and development.

Assuming the continued existence of the leasing system, the United States as lessor should not go into the oil business by endeavoring to tell its lessees when, where, how deep, and how many wells shall be drilled, and by substituting its judgment (but the lessee's money) in the determination of operating practices which have no necessary relation to sound conservation principles. Years of experience have developed a system of leasing by private landowners of their subsoil rights to aggregations of capital financially able to spread the risk of wildcat drilling and develop the technology necessary to find, produce, and utilize our oil and gas resources. These years of experience have produced a simple lease form with rather uniform language and short, simple provisions, most of which have been adjudicated by the courts and found to be fair both to the operator and the landowner. On the other hand, the present lease used by the Secretary of the Interior, and the oil and gas regulations which are incorporated by reference, purport to deal with virtually every phase of exploration, development and operation.[1] On

[1] The lease covers some 9 pages of *General Land Office Inf. Bull.* 6; the

examination the lease and regulations in effect require the lessee to perform all acts and things required by the Secretary. Such expressions as "approved by the Secretary," "as the Secretary may determine," "when the Secretary may direct"—sometimes the word "lessor" being used in place of the word "Secretary"—appear some 23 or 24 times in the lease. These provisions virtually place the Secretary of the Interior in possession of the capital of the lessee, requiring it to be expended as he sees fit. Together with an extremely high rate of royalty they have for all practical purposes removed the public domain from exploratory development. The fact that these onerous provisions, although contained in the lease and regulations, are almost never taken advantage of by the administrative officials, is not an answer, as they are a part of the lease and regulations and are enforceable. The fact that they are rarely if ever enforced is but further justification for their removal. Any sound policy dealing with lands of the United States must make the leasing of those lands conform to terms and conditions acceptable to the industry and similar to those in general use in the leasing of private lands. In a business in which the risks are as great as those in oil finding and production, stability of contractual obligations is a prime requisite to the investment of capital. The lease terms should therefore be prescribed by law and not by regulations which may be changed from time to time as determined by the Secretary. Probably the greatest single deterrent to exploration and the greatest stimulant to premature abandonment of producing wells is a high royalty rate. And here again, the experience of years has demonstrated that a one-eighth royalty is the proper rate both for the lessor and the lessee.[1] Protection against monopoly should rest in the antitrust laws and not in any statutory acreage limitation such as is found in the Oil-Land Leasing Act. Competition of the oil companies in the leasing of private lands has demonstrated beyond doubt that an acreage limitation is unnecessary to prevent monopoly. New discoveries are becoming increasingly difficult, requiring large expenditures for subsurface geology

regulations are set forth in a pamphlet containing some 21 additional pages. Also, see 7 F.R., pp. 4132–4141.

[1] It has been estimated that more than 95 per cent of all wildcat leases of private lands are at a one-eighth royalty.

and drilling of deep wells, both unknown in 1920. Subsurface geology alone requires initial control of immense areas to protect the required capital investment. And when areas already substantially depleted are included in an acreage limitation, this only removes an active participant of the industry from the field of exploration for the discovery of new deposits. It is therefore suggested that the acreage limitation of the Leasing Act be eliminated entirely or at least enlarged, that the structure limitation be eliminated, and that those leases which have been on production for 5 years or more be exempt in any event. Members of the oil industry already producing on lands of the United States will thus be permitted to enter the field of exploration for new deposits again. The state of New Mexico has been a leader in the field of leasing state-owned lands, which are additional vast unexplored areas of potential oil lands, and no better evidence of the soundness of the policy of that state is needed than the fact that it has under lease for oil development some 5 million acres of land from which it derives rental, lease bonuses, and royalties amounting to some 4 million dollars per year. The Mineral Leasing Act of New Mexico provides a satisfactory form of lease at a one-eighth royalty and contains no limitation upon the area which may be leased by any one operator. A mere comparison of the number of acres of land leased by New Mexico for oil development with those leased by the United States is ample evidence of the deterrence which the present leasing act and regulations place on oil finding and production on the public domain.

Tide and Submerged Lands.—The tide and submerged lands, particularly on the Pacific coast, the Gulf coast, and the Atlantic seaboard, are likely areas of oil exploration. Although the title of the respective states to their tide and submerged lands has been formally established for approximately 100 years by numerous decisions of the highest courts, the United States nevertheless has recently asserted a claim of title through various departments and agencies. In California especially, applications for Federal oil and gas leases under the Oil Land Leasing Act have been filed under tide and submerged lands, contending that they are a part of the public domain. Until the last few years such applications were promptly rejected by the Interior Department on the ground that the United States had no title to such lands. However, since 1938 such applications have not been rejected but have been held on file in the department, and thereby individuals asserting such claims have been led to believe that their applications were being seriously considered. Considerable traffic in the sale of interests in such applications has developed notwithstanding local "blue-sky laws" and the Federal Securities Act; numerous individuals have been led to invest money therein upon the assertion that the retention of the applications on file in the Department of the Interior without rejection indicates that they have merit. Such slanders of title of the states to their tide and submerged lands have retarded the development by the states of these lands.

Naval Reserves.—No discussion of the public domain would be complete without some consideration being given to the four areas which are presently included in the naval reserves. The war demonstrated beyond doubt that the naval reserves are inadequate (whether developed or undeveloped) to supply this nation with any considerable proportion of the required petroleum products in time of war. As undeveloped reserves they are useless, because a war could be won or lost in the time it takes to develop them. As developed reserves they are but a drop in the bucket of the total petroleum requirements. Only by maintaining a nation-wide, healthy oil industry, with constant exploration resulting in new discoveries and added reserves, can the nation protect itself against an oil shortage in time of war; and it is only by such exploration and development in time of peace that the oil can be made available where needed in time of war. Undeveloped reserves and developed reserves which are not integrated to the entire industry by being a part of its daily life are liabilities, requiring large emergency expenditures to make them available for use in time of war, and even then they may be too little and too late. Petroleum reserves to serve in time of war must be part and parcel of the transportation and refining systems which are maintained ever modern by constant daily use. The present naval reserves, if abolished, would add to the store of available prospective oil lands for development and integration into the oil industry and thus become a part of the entire industry, the only true reserve for time of war.

Conclusion.—In conclusion, there can be no doubt but that the suggested policy of the National Oil Policy Committee of the Petroleum Industry War Council ("The present policy of leasing the public domain for oil and gas exploration should be continued with some liberalizing of the statutes, rules, and regulations, having due regard for the interest of the United States as a proprietor but designed to encourage rather than to retard or hamper development.") is sound and should extend not only to the public domain but also to all lands of the United States, and should be accomplished by legislation recognizing the basic principles that "Government should encourage the petroleum industry to assume risks inherent in oil finding and production by minimizing such risks so far as possible. . . Government should not invade the province of industry either by participating with industry in operations or by itself entering into any phase of the business." To this end legislation should be enacted by the Congress

1. Declaring it to be the policy of the United States to sell and dispose of acquired lands when and as soon as they are no longer used or useful and needed for the purpose for which acquired; and

a. the entire title of the United States should be disposed of if at the time of disposition the lands are not proved to be valuable for minerals;

b. the mineral deposits, if any, in acquired lands previously disposed of, with a reservation to the United States of minerals, should be granted to the owners of such lands on the effective date of the legislation if such lands are not then either subject to a valid mining location or proved to be valuable for minerals; and

c. acquired lands proved to be valuable for minerals and those still used or useful and needed for the purpose for which acquired should be subject to disposition pursuant to the general mining laws and mineral leasing laws applicable to like deposits in the public domain.

2. Designating the General Land Office of the Department of the Interior as the one central agency of the Federal government for the recordation of its landholdings, including the acquired lands, and to administer the disposition of all lands of the United States pursuant to the general land laws, including the general mining laws and mineral leasing laws.

3. Amending the Surplus Property Act of 1944 to remove therefrom all reference to real property, and providing that all acquired lands be disposed of under the general law referred to in paragraph 1 above.

4. Liberalizing the Oil-Land Leasing Act of Feb. 25, 1920, as amended, in many respects, and particularly by

a. setting forth *in extenso* a statutory form of oil and gas lease containing terms and provisions consistent with those found in the usual exploratory oil and gas leases of privately owned lands, and such as will encourage the petroleum industry to assume risks inherent in oil finding and production by minimizing such risks as far as possible;

b. recognizing that the interest of the United States is that of a proprietor of lands only, and eliminating the participation of the government in the details of operation inherent in oil finding and production;

c. providing for a royalty payable to the United States as proprietor consistent with the rates generally prevailing in commercial leases of privately owned lands, thereby encouraging oil finding and production and preventing premature abandonment of producing wells;

d. enlarging the acreage of lands of the United States available for exploration by each lessee, thereby encouraging oil finding and production with the technology of modern subsurface geology, and removing the existing penalty upon successful exploration of lands of the United States; and

e. providing for discretionary unit or cooperative development of lands of the United States with other lands upon terms and conditions determined by freedom of contract.

No additional areas of lands of the United States should be set aside as a military or naval reserve, whether developed or undeveloped, and consideration should be given to integrating the present reserves with the production, transportation, and refining industries as a current part thereof, thereby recognizing that the oil industry as a whole is the only true petroleum reserve for time of war.

The states should be encouraged to have developed by the oil industry their tide and submerged lands by removal once and for all of the slander of title by the United States; this can best be accomplished by the adoption by Congress of a joint resolution quitclaiming to the respective states the tide and submerged lands in confirmation of the judicial decisions of the past 100 years.

Part 3. Status of Federal Lands

(With particular reference to the Gulf coast states)

By L. T. BARROW

Vice-president Humble Oil & Refining Co.

Attention has been called recently to the large Federal ownership of real estate by a report of the Senate Committee on Reduction of Nonessential Federal Expenditures (Byrd Committee). A report entitled "Federal Ownership of Real Estate," published Nov. 18, 1943, estimated that as of June 30, 1943, the Federal government owned 384,519,556 acres, or 20.20 per cent of the land area of the United States. This does not include 50,592,542 acres of Indian reservations nor about 48 million acres of mineral rights under patented lands. Holdings of the Federal Land Banks are also excluded, although data on a few states show that these banks own mineral rights equal to 2 per cent of the land area of these states. The Byrd Committee report makes it clear that there is no complete record of the real estate owned by the Federal government. It must be borne in mind therefore that the following figures based on the report of the Byrd Committee are conservative, as they are incomplete.

THE SITUATION FOR THE UNITED STATES

World Almanac figures, which do not agree exactly with the Byrd report, show that the original public domain consisted of 1,442,200,320 acres of land equal to 75.78 per cent of the total area in the United States. The public domain included Alabama, Florida, Mississippi, and every state north of the Ohio River and west of the Mississippi River except Texas. By 1935, 75.23 per cent of this land had been disposed of, while 356 million acres were still owned by the government. The analysis of these two categories is as follows:

Disposition by 1935	Acres	Remaining land held, 1935	Acres
Cash sales and other dispositions	420,000,000	National forests	148,000,000
		Grazing districts	136,000,000
Homesteads	286,000,000	National parks and monuments	13,000,000
Grants to states	230,000,000	Military reservations	11,000,000
Grants to railroads	94,000,000	Miscellaneous	48,000,000
Indian reservations	55,000,000		
Total	1,085,000,000	Total	356,000,000

The United States followed a policy of disposing of its public lands until 1935, when President Roosevelt withdrew all remaining public lands from use on Feb. 8. This order affected about 1,200,000 acres and put the final touch on withdrawal from settlement, location, sale, or entry of the entire public domain. Under the present administration a policy has been adopted of purchasing privately owned lands for forest conservation or reforestation, national parks, conservation of fish and bird life, soil conservation, national defense, flood control, water commerce, land reclamation, and 51 other uses listed by the Byrd report. The largest purchases were originally for reforestation, but during the past few years the War and Navy Departments have bought the largest amounts of land.

The Byrd Committee report shows that land area under Federal ownership increased about 40 million acres, or 11 per cent, in the 6-year period ending June 30, 1943, as shown in the following tabulation:

Date	Federal ownership, acres	Indian ownership, acres	Total, acres
June 30, 1937	344,065,179	50,592,542	394,657,721
June 30, 1940	368,861,289	50,592,542	419,408,831
June 30, 1943	384,519,556	50,592,542	435,112,098

Table 1 shows an estimate of Federal lands owned in each state, based on a statement of June 30, 1940 prepared by the Federal Works Agency, plus the purchases and proposed purchases from Jan. 1, 1942 to June 30, 1944 listed by the Byrd Committee. It does not include 6,818,177 acres purchased between July 1, 1940 and Dec. 31, 1941, for which the Byrd report does not show distribution by states.[4] Due to these and other purchases the total Federal ownership shown by states is several million acres less than the total reported by the Byrd Committee on June 30, 1943.

It will be noted from Table 1 that 339,887,489 acres, or over 90 per cent, of the total owned by the Federal government, are in 11 western states. In these states the Federal government owns over 50 per cent of the land if consideration is given to Indian reservations, mineral rights, and holdings of the Federal Land Bank. The government is still acquiring acreage in these states, the actual and proposed purchases from Jan. 1, 1942 to July 1, 1944 amounting to 1,817,510 acres, or 0.24 per cent of the area. In the balance of the United States, Federal lands represent 3.05 per cent of the area, but purchases are being made at a rapid rate. Actual and proposed purchases of land by the Federal government for the period Jan. 1, 1942 to June 30, 1944 in the eastern states amounted to 4,554,135 acres, or 0.4 per cent, of the land area.

THE SITUATION IN SIX GULF COAST STATES

Federal ownership of lands in Alabama, Florida, Georgia, Louisiana, Mississippi, and Texas amounts to 8,722,653 acres, or 2.63 per cent of the area. In addition, some of the 6,818,177 acres purchased between June 30, 1940 and Jan. 1, 1942, for which distribution by states is not available, were doubtless in this area and therefore increased Federal holdings. Between Jan. 1, 1942 and June 30, 1944, purchases and proposed purchases by the Federal government in these states amounted to 1,645,420 acres, or 0.5 per cent of the land area. The estimate of Federal ownership of lands in the six Gulf coast states is shown below:

State	Total land area, acres	Federal lands, acres	Percentage of Federal lands
Florida	35,111,040	2,082,828	5 93
Mississippi	29,671,680	1,446,927	4.88
Louisiana	29,061,760	1,292,656	4.44
Georgia	37,584,000	1,350,000	3.59
Alabama	32,818,560	1,020,743	3.11
Texas	167,934,720	1,529,499	0.91
Total	332,181,760	8,722,653	2.63

Complete data are not available on the number of acres of Indian reservations, mineral rights under patented lands, or owned by Federal Land Banks in these states. The first two classifications are probably not important, but from reliable sources it is estimated that Federal Land Banks own one-half mineral rights under 4.5 per cent of the land in southern Mississippi and 4.1 per cent in southern Alabama.

The principal Federal landholdings in the Gulf coast states are held by the Department of Agriculture as national forests, by the Department of the Interior as national parks, by the War and Navy Departments as military reservations, and by the Federal Land Banks. The proportion of land owned by the government in these states has not been considered serious heretofore, but the growth in Federal ownership of land in recent years provides some cause for concern. One reason that the oil industry has not been seriously affected is that most of the land purchased for national forests was through deeds which left the mineral rights to the landowners for 10 years in most cases, or even 20 to 40 years in some instances. The mineral rights on tracts sold under the 10-year provision are just beginning to revert to the Federal government due to the fact that a large amount of the land has been acquired during the last 10 years. The situation in each of the states may be summarized briefly as follows:

TEXAS

The largest single Federal land project in Texas is the Big Bend National Park in Brewster County consisting of 788,000 acres, soon to be deeded to the Federal government. Part was public-school land and part was purchased from private owners. The park is a gift from the state of Texas to the Department of the Interior and includes mineral rights. There are four national forests in Texas in which the Federal government has acquired 660,500 acres. The outlines of these forests embrace 1,714,000 acres, presumably indicating plans to acquire the remaining 1,053,500 acres. The four national forests are shown in the table on page 258.

All this land has been acquired since the legislature of Texas in 1934 "invited the United States government to establish one or more national forests in Texas as a part of the Federal Conservation and Employment Program." The War and Navy

Departments have acquired considerable acreage in Texas during the past few years. This is estimated to involve several hundred thousand acres, although no data have been released on the size of the purchase.

Name	Acres	Counties
Sam Houston	161,500	Montgomery, Walker, and San Jacinto
Davey Crockett......	161,500	Houston and Trinity
Angelina.......	153,500	Angelina, San Augustine, and Jasper
Sabine.......	184,500	Sabine, Shelby, and San Augustine

As of Apr. 1, 1944, the Federal Land Bank owned in Texas 1,117 acres in fee and had mineral reservations on about 786,000 acres. The Federal Farm Mortgage Corporation owned 1,368 acres and had mineral reservations on 144,000 acres. In general these mineral reservations are one-sixteenth nonparticipating royalties.

LOUISIANA

The major portion of Federal-owned lands in Louisiana is in national forests, mineral reservations, and river and flood control projects. Federal Land Banks hold reservations to one-half the minerals on about 2 per cent of the acreage in general.

MISSISSIPPI

National forests account for the largest ownership of Federal lands in Mississippi, although there are several large military camps and one national park. Over 54 per cent of Franklin County is in a national forest. The Federal Land Bank has mineral reservations of one-half interest on about 4.5 per cent of southern Mississippi.

ALABAMA

Federal holdings are principally recent purchases for national forests and by the War Department. The Federal Land Banks have one-half the minerals reserved in an estimated 4.1 per cent of the state's area.

FLORIDA AND GEORGIA

The situation in these two states is similar to that in Mississippi and Alabama.

REGULATIONS GOVERNING MINERAL LEASES

War and Navy Department.—So far as can be determined, there is no provision for leasing War and Navy Department land. An act of Congress would be required to change this situation, either to confer authority for leasing on the department or to transfer the lands to the Department of Interior, where authority for leasing is vested in the Secretary of the Interior.

Department of Interior.—In the event Department of Interior lands are sold, all minerals are reserved. There are specific provisions for leasing Department of Interior lands except for certain reserved areas. Lands lying on a known geologic structure which the U.S. Geologic Survey determines to be productive of oil or gas, may be leased by advertising and receiving sealed bids or by sale at public auction. The form of the lease is fairly well defined, but it may be modified by the Secretary of Interior. In so-called productive areas, leases are for a term of 10 years and the minimum annual rental is $1.00 per acre. In areas classified as nonproductive of oil or gas, lands are leased without advertisement and without receiving competitive bids, the preference right for leasing being given the first applicant. The primary term of the lease is for 5 years, the advance rental of 50 cents per acre being paid for the first 3-year period, and 25 cents annually in advance for the fourth and fifth years. In either nonproductive or productive areas, no applicant may acquire more than 2,560 acres on any structure nor more than 7,680 acres in any one state. This limitation is modified to some extent where unit-operating agreements approved by the Secretary of Interior are put into effect.

The form of lease used contains many objectionable features. One of these features is the sliding-scale royalty, which ranges from 12.5 per cent to 32 per cent on oil, depending on the size of the well, and from 12.5 per cent to 16.67 per cent on gas, depending on the volume of production. Where discoveries were made on Federal land during the Second World War the operator was granted a period of 10 years at 12.5 per cent royalty. This provision affects the lease on which the discovery well is drilled, or all the land in a unit project in case a unit operation is approved by the Secretary prior to the discovery. Some provisions of the approved unit agreements are objectionable, particularly as regards submitting a plan of development. There have been instances where drilling according to such plan resulted in unnecessary dry holes.

Supervision of Department of Interior leases extends to and includes the marketing of products. The lease may not be surrendered without the consent of the Secretary. The discretionary powers of the Secretary are, to say the least, very broad in determining whether or not operations are conducted properly in compliance with numerous departmental regulations. Where a lease is forfeited the lessee must deliver the premises and surrender all improvements.

Department of Agriculture.—These lands are handled by numerous agencies of the Department of Agriculture. There are provisions for the sale of these lands and also for leasing lands where the minerals are owned in whole or in part by the department. There does not appear to be a comprehensive report on the rules governing leasing by the various agencies of the department. The Farm Security Administration is at present selling lands for farming purposes and reserving three-fourths of the minerals. In general, the Department of Agriculture appears to follow very closely the procedure of the Department of Interior in leasing lands. This includes the restrictions governing the amount of acreage which may be acquired by any individual or corporation. In some respects, leases by the Department of Agriculture are less objectionable, and in others more objectionable, than by the Department of Interior. Those provisions which appear to be more objectionable are as follows:

1. Disputes concerning questions of fact are decided by the officer in charge, subject to the right of appeal within 30 days to the Secretary, whose decision shall be final. This provision is objectionable since delays beyond the control of lessee are considered questions of fact, and since the lease remains in effect only so long as oil or gas is produced in paying quantities, "in the opinion of the Secretary."

2. The lease provides that lessee will subscribe to, and operate under, such reasonable cooperative unit or plan as may be required by the Secretary. Although the plan is referred to as reasonable, there is no statement, such as is contained in the Department of Interior lease, to the effect that such plan will adequately protect the rights of all parties.

3. The lease provides that lessee will pay the United States for damage to all surface interests occasioned on the land, even where the only interest of the United States is the minerals under the land. This would leave an additional liability to the owner of the surface interest.

Federal Land Bank.—Land owned by the Federal Land Bank may be sold with or without reservations of minerals, or leased. Sales and leases are subject to the general rules of the Farm Credit Administration, which does not have any general rule providing for the reservation of minerals or prescribing the lease form to be used. In Louisiana the Federal Land Bank generally reserves one-half of the minerals. The Federal Land Bank of Houston, on the other hand, seldom reserves minerals, usually confining such reservations as are made to nonparticipating royalty interests. Both the trade and the lease form are almost entirely up to the local management of the bank handling the property. The form of lease used by the Federal Land Bank of Houston is satisfactory and follows closely the type of lease most commonly in use in this area. The bank handling Mississippi and Alabama lands generally reserves at least one-half the minerals and is somewhat more difficult in the matter of lease forms, probably because of the lower value of the land.

WHAT SHOULD BE DONE

In considering what should be done about Federal ownership of land it is necessary to distinguish between the different types of holdings. National forests in the Gulf states, for example, consist largely of cut-over land that neither the states nor the owners were willing or could afford to reforest. Whether these forests are justified or not, they are probably popular with the people in view of the stated major objectives, which include reforestation, development of recreational areas, and protection of watersheds. The size of national forests has created serious problems to some counties because of the drastic reduction in tax revenues involved.

National parks have generally been acquired as a gift from the state or its citizens. So far the Gulf states have not had a case similar to Jackson Hole, Wyo., where the department condemned a large body of land without a hearing. The creation of national forests, at least up to the present extent, appears to be looked upon with favor by the public.

It is difficult to discuss the lands owned by the War and Navy Departments because accurate data are not available and because during the war these departments have needed considerable land for their training activities. The Byrd Committee quotes figures to show that in the period 1939–1943, inclusive, the War Department bought 2,847,651 acres of land at a cost of $166,670,523.00 or $58.53 per acre, and 5,940 parcels of land at a cost of $122,582,664.00. The total cost is over $100.00 per acre, but this includes 12 hotels costing over 6 million dollars. It is impossible on the basis of existing information to decide how much of the land should be held for future use and how much should be sold.

Holdings of the Federal Land Banks are in a different category from the land owned by other government agencies. They do not present a serious problem in Texas, where they consist principally of one-sixteenth nonparticipating royalty. They do constitute a more serious problem in the other Gulf states, where the banks' holdings are usually in the form of one-half of the minerals and cover a greater percentage of the land area. The banks should sell mineral and surface rights together, since it should not be their purpose to acquire minerals or build up cash funds from mineral leases.

The Byrd Committee views with apprehension the alarming increase in Federal land during the last few years. Even allowing for acquisitions connected with the national emergency, it nevertheless finds that excessive amounts of land have been purchased by the government since 1938. It notes that the states are concerned over this problem because of the reduction in tax revenues and the possible postwar effect on real estate values if large tracts or parcels of land are dumped on the market. The committee recommends that Federal agencies contemplating acquisition of land should curtail such plans as far as possible. The recommendations of the Byrd Committee are quoted below:

1. That the government agencies begin immediately to liquidate surplus holdings in land and real estate which are not needed for Federal activities.

2. That consideration be given to the feasibility of assigning the operational functions of appraising, acquiring, abstracting, recording, and disposing of all real estate owned and controlled by the Federal

government to a central unit in an already existing government agency to reduce inequity, lack of uniformity, duplication, and waste of funds in connection with government acquisitions and disposition of real property.

3. That this unit shall be a part of already existing government machinery.

CONCLUSIONS

This report attempts to summarize the limited data available on Federal ownership of lands, particularly with regard to the situation in the six Gulf states. It is impossible in a limited review of such a complex and difficult problem to formulate a definite opinion regarding the solution of many phases. The following preliminary observations are set forth for consideration by those who may be interested in studying the matter further:

1. The recommendations of the Byrd Committee do not seem to offer a solution of the problem. The suggestion that all purchases be centralized in one agency probably will not prove practicable. Inasmuch as the separate agencies are not likely to liquidate their landholdings of their own accord, it will be necessary to establish standards by law or regulation instructing such agencies what policies should be pursued in selling Federal lands.

2. Public lands suitable for private development and use should be sold to private individuals, for it is not a proper purpose of government to maintain a large ownership of land. As a general rule, sales of land should be made in fee with no mineral reservations unless the minerals thereon have already been developed.

3. A large amount of land held by the Federal government is patented land which has been acquired from private individuals in various ways and for sundry purposes. There appears to be no good reason why such lands secured through Federal Land Banks, the Farm Credit Administration, and by other Federal agencies should not be sold as promptly as possible. Land acquired for military purposes by the War and Navy Departments should be sold to the extent that it is not required for national security in the future.

4. On lands that continue to be held by the Federal government, uniform rules for the execution of mineral leases should be adopted. Present lease forms employed are far from uniform and are very unsatisfactory. A serious attempt should be made

TABLE 1.—FEDERAL OWNERSHIP OF LANDS
(Exclusive of 6,818,177 acres purchased between Aug. 1, 1940 and Jan. 1, 1942

State	Total area, acres	Proposed purchases Jan. 1, 1942 to June 30, 1944	Per cent purchases to area	Estimated Federal ownership	
				Acres	Per cent of total
Nevada	70,285,440	43,161	0.06	55,123,176	78.43
Utah	52,597,760	104,249	0.20	35,869,613	68.20
Idaho	53,346,560	276,122	0.52	32,683,160	61.27
Wyoming	62,430,720	123,610	0.20	28,663,304	45.91
Oregon	61,188,480	173,656	0.28	27,598,869	45.10
Arizona	72,838,400	74,142	0.10	31,016,299	42.58
California	99,617,280	541,458	0.54	41,500,952	41.66
Colorado	66,341,120	149,242	0.22	22,967,030	34.61
New Mexico	78,401,920	149,510	0.19	26,508,636	33.81
Montana	93,523,840	102,359	0.11	26,790,470	28.65
Washington	42,775,040	80,001	0.19	11,165,980	26.11
Total western states	753,346,560	1,817,510	0.24	339,887,489	45.12
District of Columbia	44,320	295	0.07	11,441	25.81
New Hampshire	5,779,840	4,766	0.08	473,068	8.19
Arkansas	33,616,000	186,438	0.55	2,701,574	8.03
Virginia	25,767,680	118,791	0.46	1,733,918	6.73
Michigan	36,787,200	67,045	0.18	2,359,732	6.41
Minnesota	51,749,120	79,357	0.15	3,182,862	6.15
West Virginia	15,374,080	11,122	0.07	916,901	5.96
Florida	35,111,040	308,535	0.88	2,082,828	5.93
Tennessee	26,679,680	450,670	1.69	1,547,615	5.81
North Carolina	31,193,000	258,543	0.83	1,728,211	5.54
South Dakota	49,195,520	305,085	0.62	2,613,617	5.31
Mississippi	29,671,680	202,102	0.68	1,446,927	4.88
Louisiana	29,061,760	239,879	0.83	1,292,656	4.45
Wisconsin	35,363,840	63,250	0.18	1,560,309	4.41
South Carolina	19,516,800	33,264	0.17	752,431	3.85
Georgia	37,584,000	189,113	0.50	1,350,000	3.59
Missouri	43,985,280	131,584	0.30	1,483,202	3.37
Alabama	32,818,560	90,203	0.28	1,020,743	3.12
Vermont	5,839,560	2,681	0.05	171,385	2.94
Kentucky	25,715,840	139,418	0.54	724,081	2.81
Delaware	1,257,600	3,011	0.24	30,157	2.40
North Dakota	44,917,120	73,046	0.16	1,037,033	2.31
Rhode Island	682,800	5,493	0.80	15,588	2.28
Maryland	6,362,240	19,738	0.31	144,556	2.27
Pennsylvania	28,692,480	57,298	0.20	579,779	2.02
Oklahoma	44,917,120	324,219	0.72	741,445	1.66
Nebraska	49,157,120	93,380	0.19	550,605	1.12
New Jersey	4,808,960	21,176	0.44	48,473	1.01
Illinois	35,867,520	45,179	0.13	336,980	0.94
Texas	167,934,720	615,588	0.36	1,529,499	0.90
Indiana	23,068,800	125,333	0.54	188,589	0.81
Ohio	26,073,600	104,837	0.40	197,499	0.76
Maine	19,132,800	10,295	0.05	109,789	0.57
New York	30,498,560	30,662	0.10	123,337	0.40
Kansas	52,335,360	108,376	0.21	203,138	0.39
Massachusetts	5,144,960	16,464	0.32	32,083	0.62
Iowa	35,575,040	15,572	0.04	74,541	0.21
Connecticut	3,084,800	2,327	0.08	3,061	0.10
Total eastern states	1,150,366,400	4,554,135	0.40	35,102,653	3.05
Total United States	1,903,712,960	6,371,645	0.33	374,990,142	19.70

to develop a standard form of lease for all Federal lands. The terms of such leases should be clearly expressed, and the rental, royalty, and other important requirements should be uniform. Such procedure would make it possible to follow the established practice of leasing lands for cash to the highest bidder by public auction or under sealed bids.

5. Ownership of land for national parks and national monuments should be confined to a reasonable extent. Such land held in national parks and national monuments should be for recreational purposes.

CHAPTER IX

CAPITAL EMPLOYED IN THE PETROLEUM INDUSTRY

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For a number of years the Department of Petroleum Economics of the Chase National Bank has been conducting a study of the capital employed in the petroleum industry. The technique followed is that of combining and summarizing the available financial and operating data for a group of 30 representative oil companies doing about two-thirds of the domestic business of the entire industry.

This paper presents the result of the findings for the year 1943, and supplements the survey, "Sources, Disposition, and Characteristics of the Capital Employed by Thirty Oil Companies During the Nine-Year Period, 1934–1942," presented before the Petroleum Division of the American Institute of Mining and Metallurgical Engineers on Feb. 24, 1944, and also published as a pamphlet by the Chase National Bank.

The companies included in the study are of three types, as follows: Type *A*, 9 companies engaged principally in crude-oil production (Amerada Petroleum Corp., Barnsdall Oil Co., Houston Oil Co., Louisiana Land and Exploration Co., Pacific Western Oil Corp., Plymouth Oil Co., Seaboard Oil Co., Texas Gulf Producing Co., and Texas Pacific Coal and Oil Co.); Type *B*, 4 companies with production averaging in excess of requirements (Continental Oil Co., Ohio Oil Co., Phillips Petroleum Co., and Skelly Oil Co.); and Type *C*, 17 companies with refinery throughout in excess of production (Atlantic Refining Co., Gulf Oil Corp., Lion Oil Refining Co., Mid-Continent Petroleum Corp., Pure Oil Co., Richfield Oil Corp., Shell Union Oil Corp., Sinclair Oil Corp., Socony-Vacuum Oil Co., Standard Oil Co. (California), Standard Oil Co. (Indiana), Standard Oil Co. (New Jersey), Standard Oil Co. (Ohio), Sun Oil Co., Texas Co., Tide Water Associated Oil Co., and Union Oil Co. of California).

Combined Income.—The aggregate net income of the 30 oil companies amounted to 510 million dollars in 1943, an increase of 106 million dollars or 26.2 per cent over 1942 and 32.8 per cent over the yearly average for the 10-year period, 1934–1943. A comparative combined income statement of the group is summarized in Table 1.

Gross operating income for 1943 compared with 1942 increased

TABLE 1.—COMBINED INCOME STATEMENT OF 30 OIL COMPANIES, 1943 VS. 1942, AND THE AVERAGE FOR 1934–1943

	In million dollars			Per cent of change	
	Average 1934–1943	1942	1943	1943 vs. 1942	1943 vs. average 1934–1943
Gross operating income	4461	5,161	6,261	+21.3	+ 40 3
Costs and expenses	3441	3,954	4,760	+20.4	+ 38.3
Operating income	1020	1,207	1,501	+24.4	+ 47.2
Depreciation, depletion, etc.	511	542	610	+12 5	+ 19 4
Net operating income . .	509	665	891	+34.0	+ 75.0
Nonoperating income (net).	90	71	76	+ 7.0	− 15.6
Income before other deductions. . .	599	736	967	+31.4	+ 61.4
Less: interest and discount on debt.	36	35	37	+ 5.7	+ 2.8
extraordinary charges, etc...	33	41	58	+41.5	+ 75.8
income and excess profits taxes..	117	234	334	+42.7	+185.5
minority interest.	29	22	28	+27.3	− 3.4
Net income accruing to companies. . .	384	404	510	+26.2	+ 32.8
Less: preferred dividends paid	13	10	9	−10.0	− 30.8
common dividends paid...... .	195	212	233	+ 9.9	+ 19.5
Net income retained in business............. .	176	182	268	+47.3	+ 52.3

21.3 per cent, while costs, operating, and general expenses increased only 20.4 per cent, thus permitting an expansion in operating income of 24.4 per cent.

Distribution of the average sales dollar for the periods under review is shown in Table 2. In 1943, for each dollar of income 75.1 cents was absorbed by costs and expenses; 9.6 cents covered charges for capital extinguishments; 5.3 cents went for income and excess profits taxes; 2.0 cents was accounted for by other deductions; and 8.0 cents accrued to the companies as net income. This figure of 8.0 cents compares with 7.7 cents for 1942, and 8.4 cents for the 10-year period, 1934–1943.

TABLE 2.—DISTRIBUTION OF DOLLAR INCOME OF 30 OIL COMPANIES, 1943 VS. 1942, AND THE AVERAGE FOR 1934–1943
(In cents)

	Average 1934–1943	1942	1943	Per cent of change	
				1943 vs. 1942	1943 vs. 1934–1943
Total income	100.0	100 0	100.0		
Costs and expenses	75.6	75 5	75.1	−0 4	−0.5
Depreciation, depletion, etc.	11.2	10.4	9.6	−0.8	−1.6
Income and excess profits taxes	2.6	4.5	5.3	+0.8	+2.7
Other deductions	2.2	1.9	2.0	+0.1	−0.2
Net income accruing to companies	8 4	7.7	8.0	+0.3	−0.4
Preferred and common dividends paid	4.6	4.2	3.8	−0.4	−0.8
Net income retained in business	3.8	3.5	4.2	+0.7	+0.4

Combined Balance Sheet.—A combined balance sheet of the 30 oil companies, Dec. 31, 1943, compared with the like date of 1942, is given in condensed form in Table 3.

The total assets of the group on Dec. 31, 1943, amounted to 9,606 million dollars, an increase of 613 million dollars or 6.8 per cent over the previous year-end. During the year, current assets increased 480 million dollars and properties, plant, and equipment increased 221 million dollars; whereas current liabilities increased 338 million dollars, other reserves increased 36 million dollars, and investments and advances decreased 49 million dollars. The net result of these changes is reflected in an increase in net worth of 256 million dollars.

TABLE 3.—COMBINED BALANCE SHEET OF 30 OIL COMPANIES, DEC. 31, 1943 VS. DEC. 31, 1942

Assets and other debits	Dec. 31, 1942	Dec. 31, 1943	Change, Dec. 31, 1943 vs. Dec. 31, 1942	
	In million dollars			Per cent
Current assets...	2,790	3,270	+480	+17 2
Investments and advances	954	905	− 49	− 5 1
Long-term receivables	75	61	− 14	−18.7
Special funds and deposits.	60	38	− 22	−36 7
Properties, plant, and equipment (net)[1].......	4,981	5,202	+221	+44 4
Intangible assets (net)...	52	49	− 3	− 5.8
Prepaid and deferred charges	81	81		
Total assets and other debits	8,993	9,606	+613	+ 6 8
Liabilities, capital stock, and surplus				
Current liabilities..	870	1,208	+338	+38.9
Long-term debt	1,110	1,088	− 22	− 2.0
Deferred liabilities and credits	81	85	+ 4	+ 4.9
Other reserves.	438	474	+ 36	+ 8.2
Minority interest.	271	272	+ 1	+ 0.3
Preferred stock.	173	168	− 5	− 2.9
Common stock..	3,441	3,474	+ 33	+ 9.6
Earned and capital surplus	2,609	2,837	+228	+ 8.7
Total liabilities, capital stock, and surplus..	8,993	9,606	+613	+ 6.8

[1] Gross investment· Dec. 31, 1942—10,384 million dollars.
Dec. 31, 1943—10,838 million dollars

An analysis of the combined total net assets of 6,311 million dollars on Dec. 31, 1943 of the 30 oil companies reveals that 5,598 million dollars or 88.7 per cent is located in the United States, and 713 million dollars or 11.3 per cent applies to investments in foreign countries.

Sources and Disposition of Capital.—In 1943, the companies were provided with 1,216 million dollars in new capital from the following sources: 510 million dollars from net income, 610 million dollars from capital extinguishments, 86 million dollars from other noncash items, and 37 million dollars from the issuance of common stock, less 22 million dollars representing the liquidation of long-term debt and 5 million dollars covering the retirement of preferred stock.

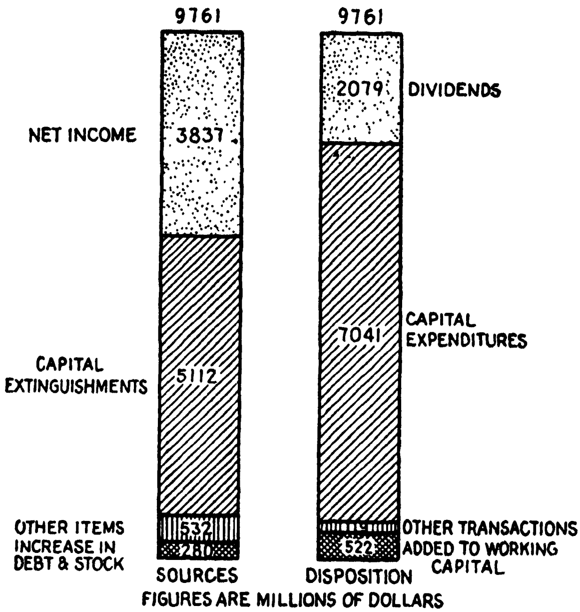

FIG. 1.—Sources and disposition of funds for 30 oil companies for the 10-year period, 1934–1943.

These funds were disposed of as follows: 925 million dollars for fixed capital assets and 242 million dollars for common and preferred stockholders, partly offset by other transactions contributing 93 million dollars. The balance of 142 million dollars was added to working capital. With the exception of certain moneys advanced by United States government agencies for war-plant facilities, the industry financed its expansion in 1943—again exemplifying its self-sufficient nature.

During the 10-year period, 1934–1943, net working capital increased 522 million dollars for the group of companies. A graphic view of the elements accounting for this growth of liquid funds is given in Fig. 1.

The total borrowed and invested capital of the companies increased 235 million dollars in 1943, amounting at the year-end to 7,839 million dollars. Borrowings declined 22 million dollars during the period, ending the year at 1,088 million dollars. An analysis of the changes in sources of borrowed capital during 1943 is shown in Table 4.

TABLE 4.—ANALYSIS OF BORROWED CAPITAL OF 30 OIL COMPANIES, DEC. 31, 1943 VS. DEC. 31, 1942

Lending agency	In million dollars			Distribution, per cent of total	
	Dec. 31, 1942	Dec. 31, 1943	Change, Dec. 31, 1942 vs. Dec. 31, 1943	Dec. 31, 1942	Dec. 31, 1943
Public	575	540	−35	51 8	49.6
Banks	149	156	+ 7	13.4	14.3
Insurance companies	208	189	−19	18.7	17.4
United States government agencies	41	79	+38	3 7	7 3
All other	137	124	−13	12.4	11.4
Total	1,110	1,088	−22	100.0	100.0

Capital Expenditures.—Total expenditures of the 30 oil companies for properties, plant, and equipment amounted to 925 million dollars in 1943, an increase of 139 million dollars or 17.7 per cent over 1942, and 31.4 per cent over the yearly average for the 10-year period, 1934–1943. Allocation of these expenditures to the divisions of the business is summarized in Table 5.

The combined expenditures of the group aggregated 7,041 million dollars for the 10-year period, 1934–1943. The trend thereof by years is presented by divisions in Fig. 2, and the relative distribution thereof for the periods under review is depicted in Fig. 3.

The capital expenditures in the United States and in foreign countries since the inception of the Second World War are summarized in Table 6.

A survey made by the Petroleum Industry War Council as of Dec. 31, 1943, reveals that estimated expenditures of oil com-

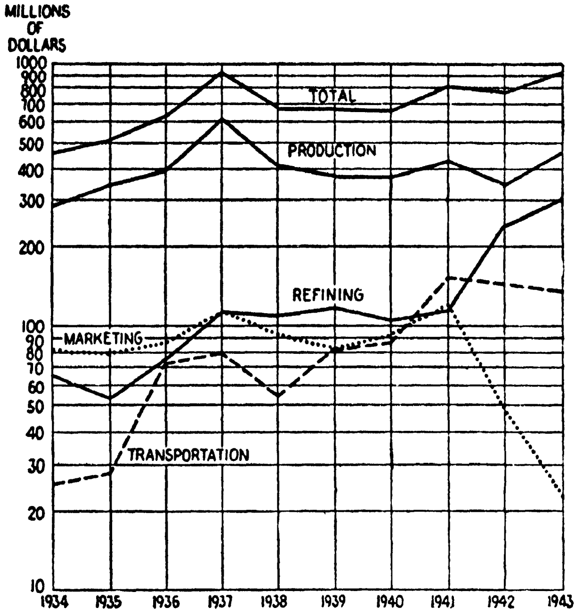

FIG. 2.—Trend of capital expenditures of 30 oil companies, subdivided into principal divisions of the business, by years, 1934–1943. Semilogarithmic scale.

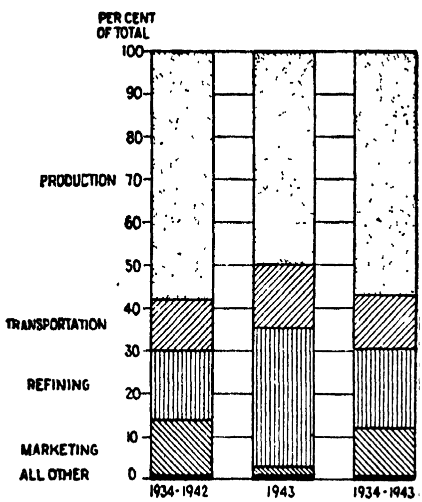

FIG. 3.—Distribution of expenditures for properties, plant, and equipment for the 10-year period, 1934–1943.

panies in the United States for war-plant facilities will amount to 970 million dollars during the 4-year period, 1941–1944. This outlay of funds excludes projects financed by United States government agencies, and also substantial amounts spent by the industry for stepped-up exploration, development, and wildcatting activities for increasing crude-oil production and reserves.

A breakdown of the total expenditures of 970 million dollars is as follows: refining, 750 million dollars; transportation. 197 million dollars; and marketing, 23 million dollars.

TABLE 5.—GROSS EXPENDITURES[1] BY 30 OIL COMPANIES FOR PROPERTIES, PLANT, AND EQUIPMENT, CLASSIFIED BY DIVISIONS, 1943 VS. 1942, AND THE AVERAGE FOR 1934–1943

Division	In million dollars			Per cent of change	
	Average 1934–1943	1942	1943	1943 vs. 1942	1943 vs. average 1934–1943
Production	403	343	462	+34.7	+ 14.6
Transportation	86	144	135	− 6.3	+ 57.0
Refining	129	242	299	+23.6	+131.8
Marketing	80	45	22	−51 1	− 72.5
All other	6	12	7	−41.7	+ 16.7
Total	704	786	925	+17 7	+ 31.4

[1] Expenditures represent gross additions to fixed asset accounts, and also include intangible development costs of producing wells and dry holes, and lease-purchase costs charged to income account, if data were furnished.

TABLE 6.—EXPENDITURES OF 30 OIL COMPANIES SEGREGATED BETWEEN DOMESTIC AND FOREIGN, BY YEARS, 1938–1943

Year	In million dollars			Foreign vs. total, per cent
	Domestic	Foreign	Total	
1938	567	100	667	15.0
1939	576	89	665	13.4
1940	601	56	657	8.5
1941	766	45	811	5.5
1942	721	65	786	8.3
1943	874	51	925	5.5
Total 1938–1943	4,105	406	4,511	9.0

Capital Reservoir.—During 1943, the combined current assets of the 30 oil companies increased 480 million dollars, while current liabilities expanded 338 million dollars. The difference was a gain of 142 million dollars in net working capital in spite of substantial amounts expended for fixed capital assets and dividends.

TABLE 7.—ANALYSIS OF NET WORKING CAPITAL OF 30 OIL COMPANIES, DEC. 31, 1943 VS. DEC. 31, 1942

Assets and liabilities	In million dollars			Distribution per cent of total	
	Dec. 31, 1942	Dec. 31, 1943	Change Dec. 31, 1943 vs. Dec. 31, 1942	Dec. 31, 1942	Dec. 31, 1943
Cash	593	769	+176	21 3	23.5
Marketable securities	400	587	+187	14 3	18.0
Receivables (net)[1]	778	896	+118	27 9	27.4
Inventories	999	992	− 7	35.8	30 3
All other	20	26	+ 6	0.7	0 8
Total current assets	2,790	3,270	+480	100 0	100.0
Accounts payable	396	547	+151	45.5	45 3
Notes and other borrowings	75	100	+ 25	8.6	8.3
Federal income and other taxes	323	468	+145	37.1	38 7
Accrued liabilities	53	82	+ 29	6.1	6 8
All other	23	11	− 12	2.7	0 9
Total current liabilities	870	1,208	+338	100.0	100 0
Net working capital	1,920	2,062	+142		
Ratio of current assets to current liabilities	3 21	2 71	−0.50		

[1] Includes receivables from United States government agencies: Dec. 31, 1942—337 million dollars; Dec. 31, 1943—402 million dollars.

An analysis of the combined working-capital position of the group on Dec. 31, 1943, compared with Dec. 31, 1942, is given in Table 7, together with the changes in the major items during the year.

The Securities and Exchange Commission recently prepared an analysis of the working capital position of over 1,000 registered corporations for each of the years ending Dec. 31, 1939–1943. A comparison of the ratio of current assets to current liabilities of the 30 oil companies with this group for the period under review is presented in Table 8.

TABLE 8.—RATIO OF CURRENT ASSETS TO CURRENT LIABILITIES, 30 OIL COMPANIES VS. 1,007 REGISTERED COMPANIES, BY YEARS, 1939–1943

Year ending	30 oil companies	1,007 registered companies	Difference
Dec. 31, 1939	4.36	3.12	+1 24
Dec. 31, 1940	4.20	2.71	+1 49
Dec. 31, 1941	3.19	2 24	+0 95
Dec. 31, 1942	3 21	2 05	+1 16
Dec. 31, 1943	2.71	1 99	+0.72

TABLE 9.—TREND OF REPORTED NET INCOME OF 30 OIL COMPANIES BY YEARS, 1934–1943, AND ITS RELATION TO DIVIDENDS AND INVESTED CAPITAL

Year	Reported net income, in million dollars	Change from previous year, per cent	Common and preferred dividends, in million dollars	Dividends per cent of net income	Per cent of return on invested capital	
					Net income	Dividends
1934	157		128	82	2 9	2.3
1935	253	+61	120	47	4 8	2.3
1936	412	+63	233	57	7.6	4.3
1937	573	+39	288	50	10.0	5.0
1938	300	−48	199	66	5.1	3.4
1939	321	+ 7	188	59	5.4	3.1
1940	377	+17	209	55	6 3	3.5
1941	530	+41	251	47	8.8	4.2
1942	404	−24	221	55	6.6	3.6
1943	510	+24	242	47	8.0	3.8
Average	384	. .	208	54	6.6	3.6

Productivity of Capital.—The rate of return on invested capital of the 30 oil companies rose from 6.6 per cent in 1942 to 8.0 per cent in 1943, compared with an average of 6.6 per cent for the past 10 years. This return was smaller than the average rate of return for over 1,100 manufacturing companies (compiled by the National City Bank), which was 9.9 per cent in 1943, 10.1 per cent in 1942, and 8.8 per cent for the past 10 years. In

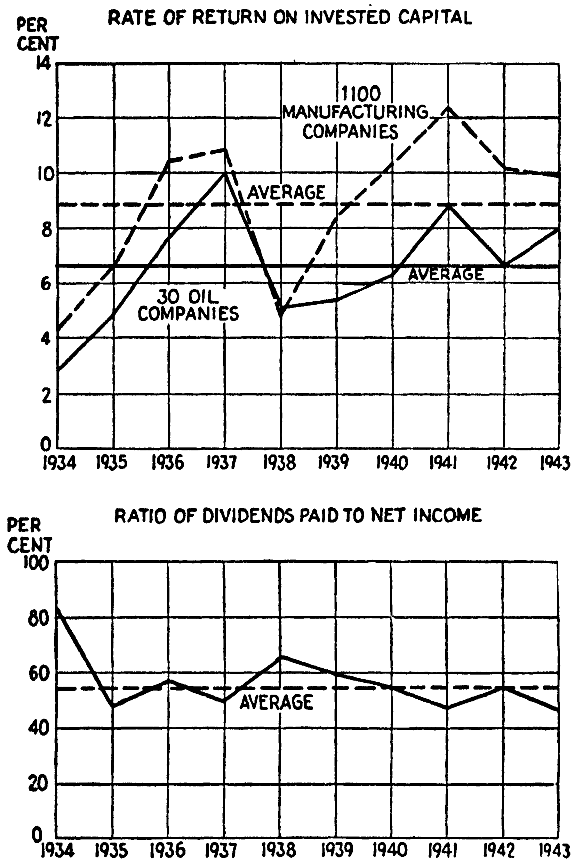

FIG. 4.—Trend of indexes showing the productivity of capital employed by 30 oil companies during the years 1934–1943.

1943, 9 producing companies realized a return of 13.3 per cent; 4 companies with production averaging in excess of refinery requirements, 10.3 per cent; and 17 companies with refinery requirements in excess of production, 7.7 per cent.

The reported net income, the dividends paid, the percentage of net income disbursed as dividends, and the ratios of both net income and dividend payments to invested capital for the 30 oil companies during the 10-year period, 1934–1943, are summarized in Table 9, and several of these features are shown in Fig. 4.

Growth of Capital.—The gross investment in properties, plant, and equipment of the 30 oil companies increased from 10,472 million dollars on Dec. 31, 1942, to 10,932 million dollars on Dec. 31, 1943; reserves, from 5,455 million dollars to 5,696 million dollars in the same period; and net investment increased from 5,017 million dollars to 5,236 million dollars.

Combined gross and net investment of the group on Dec. 31, 1943, is presented in Table 10, which shows the segregation into domestic and foreign categories and the allocation to the divisions of the business.

Operations.—In 1943, the companies produced 2,077,000 bbl. per day of crude oil or 57.6 per cent of the total produced in the United States, compared with 53.8 per cent in 1942 and 53.2 per cent as a 10-year average. The group ran to stills 3,195,000 bbl. per day of crude oil, or 81.6 per cent of the refinery throughput of the United States in 1943, compared with 78.8 per cent in 1942, and 80.6 per cent as a 10-year average. The second war year reveals a larger participation by these companies in the over-all operations of the industry, due primarily to utilizing unused productive capacities.

An analysis of the crude-oil production for 1943, by states, of the group of companies compared with the industry, is given in Table 11.

Capital Costs of Production and Refinery Throughput.—Capital expenditures made by the 30 oil companies in 1943 for crude-oil production facilities amounted to 51.4 cents per barrel of oil produced, compared with 43.3 cents in 1942 and the ten-year average of 53.4 cents.

In the same year the outlay of this group of companies for refining facilities was 22.7 cents per barrel of crude oil run to stills, compared with 20.7 cents in 1942 and the 10-year average of 11.6 cents.

Net fixed capital on Dec. 31, 1943, invested in the production of crude oil averaged $2.59 per barrel and in the refining of crude oil averaged 88 cents per barrel.

The estimated cost of replacing developed crude-oil reserves in the United States rose from 44.3 cents per barrel, the average for 1940–1942, to 56.3 cents per barrel in 1943.

TABLE 10.—GROSS AND NET INVESTMENT OF 30 OIL COMPANIES IN PROPERTIES, PLANT, AND EQUIPMENT ON DEC. 31, 1943
(Classified by divisions and segregated between domestic and foreign)

Division	In million dollars			Per cent	
	United States	Foreign countries	Total	Division vs. total	Domestic vs. total
Production	4,722	567	5,289	48 4	89 3
Transportation	1,455	87	1,542	14.1	94.4
Refining	2,163	182	2,345	21.5	92.2
Marketing	1,396	125	1,521	13.9	91.8
All other	223	12	235	2.1	94.9
Total gross investment[1]	9,959	973	10,932	100 0	91.1
Production	2,104	249	2,353	45.0	89.4
Transportation	698	29	727	13.9	96.0
Refining	1,078	75	1,153	22.0	93.5
Marketing	824	52	876	16.7	94.1
All other	125	2	127	2.4	98.4
Total net investment[1]	4,829	407	5,236	100.0	92.2

	In million dollars	
	Gross	Net
[1] Investment per balance sheet (see Table 3)	10,838	5,202
Add. leasehold costs carried at no value	27	5
crude-oil pipe lines (Shell P. L. Corp.)	54	21
product pipe lines (Sun Oil Co.)	10	5
sundry adjustments	3	3
Investment per above analysis	10,392	5,236

Conclusions.—Analysis of the combined statements covering the financial and operating data of the group of thirty oil companies for 1943 and for the ten-year period, 1934–1943, serves as a basis for the following broad conclusions:

1. The petroleum industry continued to generate the capital needed for its expansion in 1943 from its own operations, as

shown by the increase of 142 million dollars in net working capital during the year.

2. The long-term debt contained in the financial structure of the industry remained small in relation to the total capital employed on Dec. 31, 1943, having been reduced by 22 million dollars during the year.

TABLE 11.—DOMESTIC NET CRUDE-OIL PRODUCTION, 30 OIL COMPANIES VS. TOTAL UNITED STATES, YEAR 1943

State	In million barrels		30 companies vs. industry, per cent
	Whole industry[1]	30 companies	
California	249	154	61.8
Illinois	72	47	65.3
Kansas	93	37	39.8
Louisiana	108	65	60.2
Oklahoma	108	56	51 9
Texas	519	324	62 4
All other	166	75	45 2
Total	1,315	758	57.6

[1] Based on 87.5 per cent of gross production.

3. The capital expenditures of the group of 30 oil companies amounted to 7 billion dollars for the 10-year period, 57.2 per cent being allocated to the production division. In 1943, expenditures for refining facilities attained an all-time high, whereas expenditures for marketing facilities reached their lowest level.

4. Net income of 510 million dollars in 1943 for the group approximated the earnings reported for 1941, in spite of accelerated amortization charges for war-plant facilities and increased income taxes.

5. In 1943, for each dollar of income 8.0 cents was carried down to net income, compared with 7.7 cents in 1942. The increase is due primarily to reduction in unit-operating costs caused by the increased volume of crude-oil production and of refinery throughput.

6. In 1943, government funds continued to flow into the industry, as indicated by increased advances from various agencies of 38 million dollars for war-plant facilities.

7. The group in 1943 paid out 47 per cent of its net income in the form of dividends, compared with an average of 54 per cent that was thus distributed during the 10-year period.

8. The rate of return on invested capital in 1943 for the group averaged 8.0 per cent, compared with 6.6 per cent reported for 1942. Producing companies showed a return of 13.3 per cent in 1943, an all-time high for the 10-year period.

9. The group increased its 1943 crude production by 16 per cent and its refinery throughput by 12 per cent over 1942, compared with an expansion of only 4 per cent in gross fixed capital assets.

CHAPTER X

THE AMERICAN OIL INDUSTRY

By LEONARD M. FANNING

Author of "The Rise of American Oil"

Victory with Oil.—When the record of our participation in the Second World War is written, American industry will receive the accolade for its production job, the magnitude of which is today giving the United Nations overwhelming advantages that spell the final victory. In line for recognition is the American oil industry, which has supplied 90 per cent of all the petroleum products used by the United Nations.

As victory in war can only be achieved with oil and more oil—conversely, Germany's defeat seems to have been secured largely because of lack of oil for the Luftwaffe and the Wehrmacht. The contribution of this industry to ultimate victory has been a major one.

In the first 2½ years after we entered the war, a total of 44,881 new wells were drilled for oil and gas in the United States, 23,412 less than during a like period prior to the war, at a saving of 1½ millions tons of steel for other war purposes.

Yet in the face of this 34 per cent decrease after Pearl Harbor, the United States oil industry was able to expand its crude-oil production to an all-time high record of over 5 million barrels daily and to satisfy all military demands of the nation and her allies.

Augurs Well for Peace.—Behind the oil industry's success in meeting war demands for petroleum products is a long and unbroken record of success in finding enough oil and making enough gasoline, lubricating oils, fuel oils, and other products to satisfy the insatiable appetite of the industrial and motor age.

In the space of 25 years, gasoline and the automobile changed the face of the country, helped cover it with a network of highways, spread dwellings into areas once sparsely settled and inaccessible, revolutionized rural and city life, transformed land transportation. By virtue of gasoline we went from the horse to horsepower, from roadways to airways, from 30 miles a day to 300 miles an hour—and all within a quarter of a century, whereas centuries had elapsed between the first vehicle and the first steam wagon.

The standard of living of the American people reached the highest ever attained by any people since the beginning of history. In this the petroleum industry played its important part not only by furnishing fuel for engines but also by lubricating the motors of vacuum cleaners, washing machines, and refrigerators that reduced household drudgery; by supplying the fuel for automatic home heating; and by contributing other products which advanced social, economic, educational, and health standards.

Now that the last gun has been fired in the present war, this country's industries will be reconverting to peacetime manufacture, and as restrictions on use are relaxed, we expect to go back to this American standard of living and way of life. It augurs well for the American people that the oil industry will enter the postwar period with ample supplies of products so vital to the maintenance of these standards, and it might be well at this time briefly to review the history of the American oil industry at home in relation to our living standards.

Petroleum as an Illuminant.—When Col. Edwin L. Drake struck oil in western Pennsylvania in 1859 by using an engine and a drill pipe, he gave the world a method by which oil could be recovered from the bowels of the earth in plentiful quantity. The story of the Drake well has been told so many times it need not be repeated. The important fact is that in 1860 there were two relatively new, cheap, and efficient illuminants beginning to supplant the candle and the sperm-oil lamp—one processed from coal, the other from petroleum. The struggle for position between them hardly got started, for petroleum came on the market with a rush and in such quantities that it was possible to refine and market an illuminating oil made from it at a price much below that of coal oil. This more than any other factor determined the rapid and widespread use of kerosene.

Moreover, along with the development of oil came another source of light and heat—natural gas. Here no manufacturing process was involved. Nature's own product, straight from the earth, was utilized.

Supplementing the price advantage of kerosene were the improvements made in refining it, which removed most of its odor, reduced considerably its explosive danger, and made it almost water-white. In addition, lamps for burning it were produced in increasing quantities. As to its light, it was superior to any other illuminant. As time went on and production steadily increased, the price continued to decline.

It is one of kerosene's most significant contributions that it facilitated the spread of information by affording more and more people the opportunity to read. Reading circles, book clubs, and the like appeared, and many a community library sprang from such groups.

The improved and inexpensive artificial illumination of the kerosene lamp helped the creation of an increasingly more literate, better informed population. With the opportunity to utilize the hours after dark, millions of boys and girls as well as adults now found it possible to study at night. Many a poor boy was able to improve his chances of advancement by reason of the opportunity to study by the aid of a kerosene lamp, as Abe Lincoln had done by candle.

Kerosene produced from petroleum became the illuminant in the field of transportation both on land and sea, contributing to safety. It supplied the warning beam of lighthouses.

In the cities kerosene gave way to gas and electricity, but even today it is the chief illuminating and cooking agent in rural United States and in many countries of the world.

In the manufacture of gas for lighting and cooking, gas-oil, which is derived from petroleum, is used in great quantity and is indispensable for enriching purposes. In fact, petroleum enters indirectly both into electricity and gas, which largely supplanted kerosene.

Aid to Electricity.—In high-voltage transmission of electricity, by protection of lines and equipment oil came to play an important part. In the development of the switches known as oil-circuit breakers, which protect against short circuits and grounds, a special oil, switch oil, endowed with very high insulating properties, was made. To take care of the needs of transformers, a transformer oil of peculiar characteristics was supplied. In the making of the clay disks which are strung like beads on high-tension wires at the poles, petroleum solvents and insulating oils today are indispensable.

In fact, the great harnesser, electricity, is seen at work everywhere today and aiding and abetting it in almost every particular is petroleum. Not only is petroleum the lubricant employed in the motors and electrical machines in factories, mills, agriculture, and the home, but more times than not it waves its magic wand to aid in the insulation of the electric wires and cables without which the transmission of electricity and its use in the millions of machines and appliances of today would be impossible. Insulation of electric wiring and cabling owes its existence and efficacy very often to the petroleum chemists who have developed miraculous solvents and insulating compounds.

Oil for Power.—In relation to power, electricity is symbolic of a mechanical age, striking the note of modernity in our present-day industrial civilization; and similarly, oil came as a power fuel, arriving at the beginning of the century. Fuel oil began to be burned in power and industrial plants and in railroad locomotives to generate steam, increasing the efficiency and reducing the cost of the production of power. Fuel-oil power, except when used in the diesel engine, is indirect power. Gasoline power came as direct power. Both gasoline and fuel oil are derived at the same time in the refining of crude oil. As the automotive age arrived and progressed it required the making of a greater and greater volume of gasoline with a proportionate increase in production of fuel oil and the finding of a market for it in competition with coal.

As refiners adapted their processes in order to make fuel oil for various duties based on engineering research and practice, the use of fuel oil spread throughout industry. Whether used as a fuel under boilers, as a diesel fuel, or to increase the yield of gasoline in the refining process called cracking, fuel oil is today reckoned a major source of power. No mere by-product of refineries, it vies with gasoline in its importance to a civilization nurtured on power and speed, deriving comforts, conveniences, and even enlightenment from mechanical appurtenances.

To man today, power—electrical and mechanical—with its necessary concomitant of efficient and cheap fuel, means release from reliance upon muscle power and places within his reach food, clothing, shelter, and transportation.

Petroleum on the Seven Seas.—Even before the First World War the maritime powers were turning to oil as against coal for fueling steam-driven ships. Saving in useful space, labor cost, and fueling time, longer cruising radius, greater speed—all were factors in favor of oil, and oil-bunkering stations were established wherever ships put in. The war hastened this change; the wholesale conversion of naval and merchant ships to oil burners and accelerated shipbuilding programs called for oil-fueled ships throughout the world.

The navies of the great powers became oil-burning almost overnight. Even coal-producing countries such as Germany, France, and England built only oil-burning ships for use in international trade. Petroleum revitalized maritime commerce, performed a miracle almost comparable to steam's victory over sail.

As early as 1903 the German Navy launched the first diesel-engined submarine, and in the following year Diesel secretly developed a two-cycle engine for it. But Diesel did not live to see the real success of his engine, which came with its wide adoption in naval and merchant vessels after the First World War.

In the peacetime world of the twenties and thirties the great ocean liners were all diesel-driven. Diesel engines displaced steam plants in passenger vessels and fast freighters. Many of the great American tank vessels carrying petroleum and petroleum products use diesel power. So the revolution that began with the adoption of oil fuels for power has found its ultimate expression in an engine directly oil-fired—what has been termed the greatest prime mover, the diesel engine.

Petroleum Aids Farmer and Nation's Health.—On the farm, mechanical power was first used for threshing and then for cultivating and harvesting crops, thus enabling farmers to produce more food and reducing not only the time required but much of the drudgery of farm work as well. Today the gasoline engine, the oil-fueled diesel engine, or the kerosene engine furnish the power for all farm machinery. Of all the machines used on the farm for actual operations, none is more important than the gasoline- or kerosene-fueled tractor.

Crops must be protected against insects and plant growths. This is particularly true of the production of fruits. Here, petroleum, kerosene, and oil emulsions perform a peculiarly important service as insecticidal sprays.

With the advent of the automobile came improvement and development of roads and highways, liberating the farmer from absolute dependency on the railroad so that he could reach the market himself by truck. This benefited the farmer while also dwellers in urban areas are assured a supply of fresh farm goods through their own retail markets, from itinerant farm peddlers, or by going directly to the country for their goods.

Quite as important as the ability to increase the production of foodstuffs were the developments in canning or preserving them and in the introduction of packaged food. Like canning, packaging is done by machinery. Not only does petroleum enter this field as a lubricant for the processing machinery, but also a petroleum wax is usually used to make the package moisture-proof and guard it against decomposition. As a result of the mechanical developments in the field of preserving food, we were able to build up a continual reserve of food against need. Waxed paper made with petroleum wax is an important agent in keeping bread and cakes fresh, for it protects them from air and moisture. Cardboard containers impregnated with wax are already being used for milk, while everyone is familiar with the waxed drinking cup.

There are certain types of food which must retain their quality during export and long periods of storage. A good example of such are California fruits. In order to guard against shrinkage and mold formation, these are coated with a thin film of wax preparatory to shipment. Such protection may be used with vegetables such as potatoes. It has also proved valuable for coating certain types of cheese. By dipping in molten wax they may be protected against loss of weight and are able to retain moisture.

It will be apparent that in almost every step of modern food growing, preparation, marketing, and preservation, petroleum has contributed to modern food methods that have improved the health of the American people.

Oil in the Home.—Mechanical appurtenances have created a new conception of the home. The spiritual hold of the home has prevailed since early colonial days, but inescapable nevertheless were the chores and the drudgery, the work that wracked women in maintaining the home. The dawn of a new concept came with the inventions of a youthful machine age which greatly lightened woman's work. As the twentieth century opened there came in rapid succession the vacuum cleaner, the power washing machine, the electric iron—stout allies of an awakened womanhood struggling for emancipation.

American homes—of the rich and well-to-do, the rank and file, and often the poor—became equipped with these labor-saving devices. True, they entail some handling, some work, but they are the essence of a standard of living higher than the human race has ever reached before. And there was still a greater boon to come—automatic heat. Automatic heat converts the central furnace into a wholly efficient machine. It has a social significance as important as man's original discovery of fire, and it arrived by way of the use of oil—the oil burner.

In this automatic process not a finger has to be lifted, not a thought to be exercised. Only as the mind becomes adjusted to the change does it grasp the significance related to the comforts and conveniences derived, the saving in physical and mental wear and tear, the freedom for more leisure and other occupations, and the possibilities that may lead to vast improvement in the family's physical health. In the automatic control of the room temperatures in which we have to live, science has joined invention in opening up an entirely new concept of the home which, in essence, is truly the difference between "home a shelter" and "home a habitation."

Lubricating the Industrial Age.—Until the later years of the last century, most machines of the swiftly moving industrial age were being slowed down by inefficient animal and vegetable fats for lubrication, until petroleum refiners began to introduce mineral oils with increasing success.

As the mass-production phase of industry was intensified, the burden on the oil and grease maker increased. As engines in industry and transportation attained higher speeds and assumed greater loads, the petroleum-refining industry went about solving the lubricating problems involved and made many new designs possible.

To meet and anticipate new machine and engine design, industry began to make lubricating oils and greases of infinite variety. For the gas engine it made oils in a whole range of characteristics; for turbines, special oils. It solved, with new leaded compounds, lubrication problems brought to the steel mills by their adoption of tremendous rolling mills, electrically driven. It developed special-property oils for speeded-up spindles of electrically driven spinning frames. It gave the railroads lubricants that make the hotbox a rarity rather than a common occurrence. Scientific investigation of lubrication was stepped up. Numerous investigations were made embracing the study of physical properties of lubricants and of the action of lubricants and the performance of the bearing under service conditions.

Power and production machines—virtually all the wheels that turn today—are getting the oil or grease they must have from petroleum or petroleum compounds.

Gasoline and American Standards.—That the gasoline car survived infancy and thrived is attributable to the remarkable fuel that gave it power, and to the remarkable oil that gave it lubrication—to petroleum, the source of both. Gasoline gave direct power; no carrying of a weighty and cumbersome boiler was necessary to convert heat to power as in the case of steam; no carrying of storage batteries involving weight, restricted speed, and radius of travel, no battery recharging, as in the case of the electric.

Gasoline in peace and war is one of the most fundamentally necessary fuels of the modern world. The days when it was a new, experimental fuel for the new and experimental combustion engine, when gasoline was used to drive the hand-made automobile so costly only the well-to-do could own one, when the automobile was chiefly a pleasure car—those days were gone before the First World War began.[1] Since that time automobiles have been steadily made better and cheaper. Their production and sale have been not by thousands but millions. Their predominant ownership is no longer by the rich, but by the rank and file of the middle- and lower-income group. In the last two decades they have completely revolutionized passenger transportation. On May 1, 1941, Ralph Budd, President of the

[1] *What Is Gasoline and Who Pays the Gasoline Tax?*, from statement by LaFayette B. Dow, representative American Petroleum Industries Committee, National Petroleum Association, and Western Petroleum Refiners' Association, before House Ways and Means Committee, May 9, 1941.

Burlington Railroad and Transportation Commission, Advisory Commission to the Council of National Defense, before the American Mining Congress, said of all intercity passenger transportation: Ninety per cent is in private automobiles; 5 per cent on railways; about the same on busses; and one-half of one per cent in airplanes. In other words, in prewar America gasoline was the motor fuel which provided 95 per cent of all intercity passenger transportation. Within the cities, busses and taxicabs were narrowing the field of electric streetcars. The growing use of private automobiles from home to place of work was merely a matter of observation.

A study of automobile ownership by income groups for 1938, taken from Department of Commerce and Natural Resources Board sources, throws a clear light on this subject.

PASSENGER MOTOR CAR OWNERSHIP, 1938[1]

Income group	Percentage of total persons in each group who are car owners	Number of persons owning passenger vehicles	Percentage of total car owners	Number of vehicles owned	Percentage of total vehicles owned
$10 per week or less...	30.3	1,672,000	7.5	1,738,500	7.5
$10 to $20. ...	43.9	4,659,000	20.9	4,769,000	20 5
$20 to $30.....	60.5	5,350,000	24.0	5,497,000	23.7
$30 to $40......	70.3	3,946,000	17.7	4,073,500	17.6
$40 to $60....	78.7	3,901,000	17.5	4,071,000	17.5
$60 to $100....	86.9	1,806,000	8.1	1,945,000	8.4
$100 per week and over........	93 0	958,500	4.3	1,119,000	4.8
Total.	100.0	22,292,500	100.0	23,213,000	100.0

[1] This table shows that 51.7 per cent of the passenger vehicles in use in 1938 were owned by persons having an income of $40 a week or less. Only 12.4 per cent of the nation's car owners had weekly incomes of over $60.

Always a restless nation, the travel psychology born of the automobile and highway has satisfied a desire for travel and completely changed the entire aspect of American life. Touring has helped to break down the isolation of sections, narrow sectionalism. The increasing use of the automobile has been responsible for migrations from crowded cities to the suburbs. In general, among the intangible results of motor transportation are a broadening of outlook, an improvement of society.

Jobs Created.—Moreover, the automobile and gasoline have developed numerous new sources of income, many of them small individually but collectively adding to the national income and the distribution of goods and services: for example—service stations, garages and repair shops, tourist facilities, and roadside stands.

In peacetime, gasoline service stations alone provided employment for 307,000 workers, full- or part-time. Workers at garages, hot-dog, barbecue, and lunch stands, at parking lots, at stores engaged partly in the sale of petroleum products, numbered 180,000. Wholesale oil marketing provided work for about 148,000, and retail oil marketing for about 87,000. These include bulk-plant distributors, truck drivers, marine employees, and other handlers of oil products. All told this made an estimated 722,000 workers receiving annual compensation of about 800 million dollars.[1]

Oil Industry a Symbol of American Enterprise.—No industry has shown itself more characteristically American than the oil industry. If at any one stage this industry had fallen down in meeting a crying demand for any of its main products, certainly American industrial, economic, and social progress would have been retarded. The miracle is that it has never failed, and the answer to the miracle is free private enterprise. From the very start, private enterprise and initiative have found full play.

Never in the history of mankind were men faced with greater problems than the oil pioneers. An abundant material, in itself valueless, was discovered in a then remote part of the world—an inflammable liquid that had to be transported like coal or grain, that had to be refined by processes still in the laboratory stage, a product for which the world was crying but with no technical or commercial machinery yet invented for its development.

With incredible rapidity that machinery was developed. Reservoirs were excavated in the earth, and lined with logs and cement and boxlike structures of planks or logs. These gave way to huge wooden receptacles or tanks holding hundreds of barrels,

[1] *American Petroleum Industry*, 1935, American Petroleum Inst., N.Y.

invented by a young school teacher. After rail and barge lines had extended into the Pennsylvania oil regions, came great trains of oil-barrel-laden wagons on almost impassable roads. Then the teamster era gave way to the short iron pipe line, a unique invention for oil transportation. On the railroads the flatcar laden with oil barrels gave way to the boxcar equipped with wooden tanks, which in turn stepped aside for the iron tank car. Vessels in foreign trade turned over part of their holds for permanent tanks for the carriage of oil.

Batteries of stills, erected in the oil regions, in Pittsburgh, and in several eastern cities for distilling crude oil into illuminating oil, took on the aspect of sizable chemical manufacturing plants. Within a half dozen years of the drilling of the Drake well these factories were making three grades of illuminating oil, prime white, standard white, and straw white, and selling not only to American markets but also for export. A few were making lubricating oils.

Ten years after the Drake well was drilled, American oil was going to almost every country in the world, including the Far East, and the United States became as famous abroad for its oil as for its cotton. American kerosene and the kerosene lamp have penetrated into every corner of the civilized world. The New England whaler struck her flag, and the world turned from the tallow candles and sperm-oil lamp to petroleum.

In almost a day, it seems—within a dozen years in reality—civilization was out of the darkness. No greater tribute can be paid to the energy, resourcefulness, and courage of the men who founded the American oil industry.

Meeting the Challenge of Gasoline.—Problems there were when the automobile arrived—problems of fuel quality and of having the fuel on the spot where needed to supply a tank on wheels. But the oil industry was alert, aware of the possibilities of this new market. It saw an outlet for a by-product—gasoline. It began to put gasoline where it was needed by inventing the filling station. Had the coming of the gasoline engine been delayed for 20 years, aroused automotive genius no doubt would have held to steam and electricity and automobiles might have been steam-driven or electrically driven.

The only fuel available for the internal-combustion engine was the regular kind in straight distillation. As the number of

Distillation products	Redistillation products	Acid treating cracking, rerunning, solvent extraction, dewaxing products	Alkylation, isomerization, polymerization and other treating method products	End products and uses
Gases	Noncondensable	Hydrogen		Metal cutting, glass manufacturing, fuel carbon black
	Liquefied gases			Cooking illuminating gas
		Olefins, diolefins	Butadiene, styrene	Synthetic rubbers
			Polymers (Vistanex)	Lube oil additives
			Antiknock agents	Aviation gasoline blending agents
			Alcohols, esters, ketones	Antifreeze, fat, lacquer and drug solvents
			Synthetic plastic waxes	Inks, paints
			Resins	
Light oil	Gasoline	Light naphthas		Gas machine gasoline
		Intermediate naphthas	Aviation gasoline	Airplane fuels
			Motor gasoline	Automobile fuels
			Commercial solvents	Rubber and fatty oil solvent, lacquer diluent
			Toluene, xylene	Explosives
		Heavy naphthas		Varnish makers, painters, dyers and cleaners, naphthas and turpentine substitutes
	Kerosene	Refined kerosene		Stove, lamp and tractor fuels, railroad signals, lighthouse oil, ship illuminants, gas absorption oils
Medium oil	Gas oil	Naphthenic acids	Soaps	Lube oil additives, paint driers, fungicides
				Water-gas carburetion oils, metallurgical fuels, heating fuels, diesel fuels
	Absorber oil			Gasoline recovery oils, benzol recovery oils
Heavy oil	Lubricating oils	Wihte oils (technical)		Insecticide sprays, tree sprays, bakers, fruit packers, candy makers, egg packers, and slab oils, recoil oils, hydraulic oils
		White oils (medicinal)		Internal lubricants, salves, creams, and ointments
		Saturating oils, Emulsifying oils, Flotation oils		Wool, leather and twine oils, coal-spray oils, dust-laying oils, cutting, textile, paper and leather oils, metal-recovery oils, quenching oils
		Paraffin wax		Candy makers, chewing gum, candle, laundry, sealing, etchers, saturating, insulating, match cardboard, paper, medical and canning waxes
			Paraflow	Lube oil pour depressant
			Fatty acids	Grease and soap lubricant
			Fatty alcohols and sulphates	Rubber compounding, detergents, and wetting agents
		Light lubricating oils		Turbine, light spindle, transformer, household lubricating, compressor, ice machine, meter, dust and tempering oils
		Medium lubricating oils		Journal, motor, diesel, engine, aircraft, and railroad oils
		Heavy lubricating oils		Steam cylinder, valve, transmission, printing, black oils and lubricating greases, tempering oils
	Lubricating-oil residuum	Medicinal petrolatums		Salves, creams, ointments and petroleum jelly
		Technical petrolatums		Rust-preventing compounds, rubber softeners, lubricants, and cable-coating compounds
Residues	Residual fuel oils			Wood preservative, boiler fuel, gas-manufacture oils, and metallurgial oils
	Asphalts	Liquid asphalts, Binders, Fluxes		Roofing and shoe material, shingle saturants, roofing saturants, road oils, and emulsion bases
		Steam reduced asphalts		Briquetting and paving asphalts, paint bases, flooring saturants
		Oxidizing asphalts		Roof coatings, waterproofings, rubber substitutes, and insulating asphalts
	Coke			Carbon electrodes, carbon brush, fuel coke, metallurgical coke
		Refinery sludges	Acid coke	Fuel
			Sulfonic acid	Saponification agents, fat-splitting agents, special oils, demulsifying agents, emulsifiers
			Heavy fuel oils	Refinery fuel

FIG. 1.—Petroleum is a source of many products.

TABLE 1.—PETROLEUM PRODUCTION[1]
(In thousand barrels)

Year	United States	World	United States per cent of total
1944	1,678,000[2]	2,633,000[2]	63
1943	1,503,176	2,273,089[2]	66
1942	1,386,645	2,191,290[2]	63
1941	1,402,228	2,224,882	63
1940	1,353,214	2,141,946	63
1939	1,264,962	2,085,444	61
1938	1,214,355	1,988,041	61
1937	1,279,160	2,039,231	62
1936	1,099,687	1,791,540	61
1935	996,596	1,654,488	60
1934	908,065	1,521,474	60
1933	905,656	1,441,007	63
1932	785,159	1,310,298	60
1931	851,081	1,373,656	62
1930	898,011	1,411,904	64
1929	1,007,323	1,485,867	68
1928	901,474	1,324,774	68
1927	901,129	1,262,582	71
1926	770,874	1,096,823	70
1925	763,743	1,068,933	71
1924	713,940	1,014,318	70
1923	732,407	1,015,736	72
1922	557,531	858,898	65
1921	472,183	766,002	62
1920	442,929	688,884	64
1919	378,367	555,875	68
1918	355,928	503,515	71
1917	335,316	502,891	67
1916	300,767	457,500	66
1915	281,104	432,033	65
1914	265,763	407,544	65
1913	248,446	385,345	64
1912	222,935	352,443	63
1911	220,449	344,361	64
1910	209,557	327,763	64

[1] Authority: U.S. Bureau of Mines; American Petroleum Institute.
[2] Preliminary figures subject to revision.

TABLE 2.—GROWTH OF UNITED STATES MOTOR-FUEL DEMAND PARALLELS RISE IN AUTOMOBILE REGISTRATIONS[1]

Year	Gasoline demand, thousands of barrels of 42 United States gal.	Automobile registrations
1944	Figures not available	30,136,500[2]
1943	Figures not available	30,888,134[2]
1942	Figures not available	33,002,600[2]
1941	Figures not available	34,764,996[2]
1940	589,490	32,452,861
1939	555,509	31,009,870
1938	523,003	29,852,910
1937	519,352	30,041,292
1936	481,606	28,464,818
1935	434,810	26,514,791
1934	410,339	24,933,403
1933	380,494	23,843,591
1932	377,791	24,115,129
1931	407,843	25,832,884
1930	397,770	26,545,281
1929	382,878	26,501,443
1928	338,881	24,493,124
1927	305,367	23,133,243
1926	267,128	22,001,393
1925	232,745	19,937,274
1924	196,586	17,595,373
1923	175,088	15,092,177
1922	137,770	12,238,375
1921	116,840	10,463,295
1920	108,948	9,231,941
1919	88,648	7,565,446
1918	79,949	6,146,617

[1] Authority: U.S. Bureau of Mines, U.S. Bureau of Public Roads, and Automobile Manufacturers Association.
[2] Estimated.

cars increased with the introduction of the self-starter, the petroleum industry cut more deeply into the kerosene fraction of crude oil to meet the demand for gasoline, also developing another source of gasoline—natural gasoline from natural gas. However, straight-run and natural-gas gasoline alone were not enough. The oil producer, the wildcatter, feverishly developing new oil sources, opening up field after field in an effort to find the oil to meet the multiplying demand of the motor car, found the pace swift.

United States Production Record.—The production record of the American petroleum industry bespeaks the successful results of exploitation and production methods to meet the challenge of the automobile. Annual production increased from 209 million barrels in 1910 to 443 million in 1920, 898 million in 1930, and 1,353 million in 1940 (Tables 1 and 2). This record has made the United States the largest oil-consuming nation in the world, with all this implies in high living standards (Fig. 1).

The Oil Industry before Pearl Harbor.—Few other industries have faced problems more difficult than those that have confronted the oil business at every stage in its development. The requirements of a dynamic market in fields that changed the nature of modern industrial civilization all had been satisfied. A brilliant body of technology had been constructed to meet the specialized requirements of every department of the undertaking of every demand.

The public is concerned with service, quality, and price. In service and convenience perhaps the petroleum industry overdid it with more filling stations than were needed and an excess of service. The quality of petroleum products showed the progressive improvement characteristic of all commodities whose technology has received the stimulus of keen competition. This improvement was in part due to the development of better gasoline by refiners and in part to improvements in engine design by automotive manufacturers. Between 1931 and 1941 the octane rating of regular-grade motor fuel went up from 60 to 74, and of premium-grade from 72 to 80.

The average retail price of gasoline (excluding sales tax) in 50 representative cities in the United States declined from 21.06 cents per gallon in 1923 to 12.75 cents per gallon in 1940. During the same period and for the same cities, the average sales tax, Federal and state, increased from 0.91 cents per gallon in 1923 to 5.66 cents per gallon in 1940 (Table 3). Compared with the retail price of other essentials and with the living-cost average, gasoline is one of our cheapest commodities (Table 4).

In 1939 the U.S. Bureau of Census reported 241,856 service stations in the country. It has also been estimated that there

TABLE 3.—AVERAGE RETAIL GASOLINE PRICES, BY YEARS[1]
(Simple averages of first-of-month prices in 50 representative United States cities, in dollars per gallon)

Year	Dealers' net,[2] excluding tax	Service station, excluding tax	Gasoline taxes				Service station, including tax
			State	Federal[3]	Local[4]	Total	
1940	0.0908	0.1275	0.0436	0.0125	0.0005	0.0566	0.1841
1939	0.0958	0.1331	0.0436	0.0100	0.0008	0.0544	0.1875
1938	0.1004	0.1407	0.0435	0 0100	0.0009	0.0544	0.1951
1937	0.1053	0.1459	0.0431	0.0100	0.0009	0.0540	0.1999
1936	0.1021	0.1410	0.0425	0.0100	0.0010	0.0535	0.1945
1935	0.0937	0.1355	0.0420	0.0100	0.0009	0.0529	0.1884
1934	0.0981	0.1364	0.0415	0.0100	0.0006	0.0521	0 1885
1933	0.0942	0.1241	0.0410	0 0125	0.0006	0.0541	0.1782
1932	0.1008	0.1330	0 0407	0.0050	0.0006	0.0463	0.1793
1931	0.0965	0.1300	0.0395	.	0.0005	0.0400	0.1700
1930	0.1248	0.1616	0.0374	.	0.0005	0.0379	0.1995
1929	0.1557[1]	0.1792	0.0347		0.0003	0.0350	0.2142
1928	0.1561	0 1790	0.0301		0 0003	0.0304	0.2094
1927	0.1581	0.1831	0.0278		0.0003	0.0281	0.2112
1926	0.1842	0.2097	0.0238		0.0003	0.0241	0.2338
1925	0.1746	0.2009	0.0208		0.0003	0.0211	0.2220
1924	0.1690	0.1946	0.0147		0.0001	0.0148	0.2094
1923	0.1866	0.2106	0.0091	.	0.0001	0.0092	0.2198
1922	0.2263	0.2482	0.0038	.	0.0001	0.0039	0.2521
1921	0.2409	0.2608	0.0020	.	0.0001	0.0021	0.2629
1920	0.2805	0.2973	0.0009		0.0001	0.0010	0.2983
1919	0.2411	0.2542	0.0006		..	0.0006	0.2548
1918	0.2392	0 2512	.		.. ..	.	0.2512

[1] Data gathered and compiled by the Texas Co.

[2] Dealers' net price available only since 1930. In 1929 and prior years, figures in this column are the average tank-wagon price, not comparable with dealers' net.

[3] Federal taxes levied as follows: 1 cent a gallon, effective June 21, 1932; 1½ cents a gallon, June 17, 1933; 1 cent a gallon, Jan. 1, 1934; 1½ cents a gallon, July 1, 1940.

[4] Local gasoline taxes levied in 3 of the 50 cities in 1940; from 1931 through 1939, in 4 cities; in 1930, in 3 cities; from 1925 through 1929, in 2 cities; in prior years, 1 city.

were in addition some 200,000 business places that carry gasoline and oil as a side line. The number of bulk-tank stations in the country in 1931 was 30,822 according to the U.S. Bureau of Census. From the bulk plant, gasoline is transported by tank trucks to service stations, other retail outlets, and large commercial customers.

United States Refineries and Transportation.—Before Pearl Harbor, petroleum refineries in the United States were located

TABLE 4.—INDEXES OF UNITED STATES RETAIL PRICES OF GASOLINE AND OTHER ESSENTIALS[1]
(1923 = 100)

Year	Gasoline service station, excluding tax	Cost of living[2]	Foods	Clothing	Housing	Fuel and light	Sundries
1940	60.5	85.3	77.7	73.1	86.9	85.4	97.4
1939	63.2	84.5	76.6	72.3	86.3	84.9	96.8
1938	66.8	85.7	78.7	74 3	87.0	85.2	97.3
1937	69.2	87.8	84.7	76.9	86 5	85.2	96.9
1936	67.0	84.1	81.6	73.8	77.9	86.0	94.6
1935	64.3	82.2	80.8	75.0	70.3	85.7	93 8
1934	64.7	79.4	75 3	77.5	64.8	86.9	93.2
1933	58.9	74 9	67 8	67.6	63.8	85.2	91.4
1932	63.2	77 9	69.7	66.5	72 4	86.9	93.6
1931	61.7	87.2	83.7	79 5	82.4	90.5	96.6

[1] Authority: Gasoline indexes computed from prices reported to the American Petroleum Inst.; all other indexes from National Industrial Conference Board.
[2] Combined index.

TABLE 5.—CENSUS OF UNITED STATES PETROLEUM REFINING, BY YEARS[1]

Census year	Number of establishments	Cost of materials	Value of products[2]	Value of products, all manufacturing industries	Petroleum refining, per cent of total
1939[3]	485	$1,933,264,243	$2,461,126,549	$56,828,807,223	4.33
1937	365	2,064,306,627	2,546,745,730	60,710,072,958	4.19
1935	395	1,478,224,853	1,838,621,913	44,993,698,573	4.09
1933	389	1,064,437,370	1,378,636,948	30,557,328,149	4.51
1931	376	1,210,517,000	1,524,284,997	41,350,464,564	3.69
1929	390	2,031,314,000	2,639,665,000	70,434,863,000	3.75

[1] Authority: Census of Manufactures, Bureau of the Census.
[2] Includes small income from products other than petroleum products, and receipts for contract work.
[3] Preliminary.

TABLE 6.—NUMBER AND CAPACITY OF UNITED STATES REFINERIES, BY STATES, JAN. 1, 1940[1]

State	Number of refineries				Capacity, barrels per day				
	Operating	Shut down	Building	Total	Operating	Shut down[2]	New plants building	Additions building	Total capacity
Alabama	1			1	4,000	....	....	....	4,000
Arkansas	6		.	6	32,950	8,000	....	...	40,950
California	73	11	1	85	799,110	136,300	. .	500	935,910
Colorado	7	3	1	11	11,550	1,730	125	...	13,405
Delaware	1	.		1	3,500	....	..	....	3,500
Georgia	1			1	4,000	....	....	....	4,000
Idaho	2			2	1,800	....	....	....	1,800
Illinois	24		1	25	188,450	9,800	600	53,000	251,850
Indiana	8		1	9	215,250	25,000	2,500	....	242,750
Kansas	19	6	1	26	150,500	16,470	3,000	....	169,970
Kentucky	9			9	36,750	3,000	..	1,050	40,800
Louisiana	14	3	1	18	188,600	17,450	4,000	....	210,050
Maryland	3			3	42,500	5,000	....	....	47,500
Massachusetts	2			2	50,600	....	....	....	50,600
Michigan	25	2	1	28	79,550	3,700	2,000	1,800	87,050
Minnesota	2			2	6,000	1,000	....	....	7,000
Mississippi		.	1	1	..	...	2,000	....	2,000
Missouri	3			3	25,000	2,550	....	....	27,550
Montana	27	10		37	28,514	9,226	....	....	37,740
Nebraska	5	2	.	7	1,560	775	....	....	2,335
New Jersey	6	1		7	226,700	25,500	....	3,750	255,950
New Mexico	9	4		13	7,775	2,900	....	....	10,675
New York	7		1	8	69,200	2,500	5,000	....	76,700
Ohio	12	1	.	13	151,500	15,500	....	....	167,000
Oklahoma	23	8		31	189,100	38,775	....	500	228,375
Pennsylvania	26	1		27	303,366	4,034	....	700	308,100
Rhode Island	2	.	..	2	12,500	....	....	....	12,500
South Carolina	1	.	..	1	3,500	1,500	....	....	5,000
South Dakota	3	..	..	3	480	....	....	.	480
Tennessee	1	..	.	1	150	....	....	....	150
Texas	101	27	.	128	1,289,925	89,470	....	10,200	1,389,595
Utah	2	1	..	3	9,200	200	....	....	9,400
Virginia	1	..	.	1	2,000	....	....	....	2,000
Washington	1		.	1	2,200	....	....	....	2,200
West Virginia	4	..	.	4	10,900	....	....	....	10,900
Wyoming	30	6	1	37	48,014	11,572	1,500	342	61,428
United States total	461	86	10	557	4,196,694	431,952	20,725	71,842	4,721,213

[1] Authority: U.S. Bureau of Mines.

TABLE 7.—PETROLEUM REFINING AND OTHER UNITED STATES MANUFACTURING, 1939[1]

Industry[2]	Rank of industry[3]	Number of establishments	Number of wage earners[4]	Total wages[4]	Number of salaried employees[4]	Total salaries[4]	Value of products[5]	Value added by manufacture
Motor vehicles[6]	1	1,054	397,537	$644,904,621	46,034	$114,840,544	$4,039,930,733	$1,319,369,575
Steel-works and rolling-mill products	2	253	368,904	569,724,280	34,527	88,554,227	2,720,019,564	1,147,548,010
Meat packing, wholesale	3	1,478	119,853	161,523,772	17,074	40,111,363	2,648,325,552	421,786,513
Petroleum refining	4	485	72,840	128,214,054	14,746	38,194,786	2,461,126,549	527,862,306
Bread and other bakery products	5	18,049	201,537	262,000,268	16,719	36,993,955	1,211,395,278	643,951,542
Cigarettes and cigars	6	633	78,323	60,247,188	3,783	8,804,857	1,198,501,941	308,184,539
Smelting nonferrous metals	7	63	27,630	38,411,086	3,717	9,056,365	956,572,486	137,414,096
Paper and paperboard mills	8	638	110,575	142,600,328	12,318	32,980,602	933,015,664	400,755,143
Cotton woven goods[7]	9	824	325,567	236,951,478	12,014	26,240,052	917,854,874	463,897,111
Newspaper publishing	10	7,310	97,251	164,719,199	68,399	149,891,942	910,188,611	677,696,650
Chemicals not elsewhere specified	11	543	60,268	94,883,557	14,076	38,221,310	839,750,366	471,114,783
Footwear (except rubber)	12	1,070	218,028	183,657,529	14,082	29,416,005	734,673,111	346,234,009
Woolen and worsted goods	13	659	146,103	139,549,193	9,239	24,269,896	698,468,246	274,021,644
Sawmills	14	7,391	265,185	214,920,436	14,983	30,568,482	692,944,624	412,935,370
Flour and other grain-mill products	15	2,143	24,771	28,369,796	5,548	12,517,968	649,943,088	143,881,569
Men's and boys' clothing[8]	16	2,449	137,518	139,728,411	7,851	20,334,433	598,273,267	263,716,394
Canning[9]	17	2,007	98,022	65,234,801	7,585	13,805,535	587,343,024	231,062,516
Tires and inner tubes	18	53	54,115	89,773,503	9,016	23,250,768	580,928,993	231,372,127
Blast-furnace products	19	81	19,537	28,312,336	1,911	5,387,999	550,802,313	87,082,842
Malt liquors	20	605	36,089	62,231,236	5,823	20,098,523	526,076,938	363,180,423
Job printing	21	9,595	96,039	132,957,236	20,298	48,795,502	515,435,609	323,401,882
All other industries	..	126,861	4,931,550	5,501,013,676	709,725	1,729,704,897	31,857,236,392	15,514,095,691
United States totals	..	184,244	7,887,242	9,089,927,984	1,049,468	2,542,040,011	56,828,807,223	24,710,564,735

[1] Authority: Census of Manufactures, Bureau of the Census.

[2] All industries with more than 500 million dollar value of products. Census reports separate many industries into smaller units which are difficult to recombine for purposes of interindustry comparison. Hence some large industries (like furniture and machine-shop products) are not included in this list, and other industries (like chemicals, clothing, foods, and textiles) are represented only by segments. However, it is believed that no additions would challenge the ranking of the first four industries listed.

[3] Ranked on basis of value of products.

[4] Number of employees includes both full-time and part-time workers, and wages and salaries are totals paid. Hence, particularly in industries with large part-time employment, average wages based on these data are not valid.

[5] Includes inseparable duplication (mostly between industries) where products of one manufacturer are bought by another manufacturer and incorporated in his product.

[6] Believed to include large duplication in value of product (see footnote 4).

[7] Cotton-broad woven goods and cotton-narrow fabrics.

[8] Suits, coats, and overcoats only.

[9] Fruits, vegetables, and soups only.

in 36 states, but about 90 per cent of the total refining capacity of the country is concentrated in 10 states: Texas, California, Pennsylvania, New Jersey, Illinois, Indiana, Oklahoma, Massachusetts, Kansas, and Ohio (Tables 5 and 6). In 1939 the petroleum refining industry ranked fourth among manufacturing industries (Table 7).

TABLE 8.—UNITED STATES EXPORTS OF PETROLEUM AND OTHER PRODUCTS, BY YEARS[1]

Year	Petroleum and products	All other products	Total domestic exports	Petroleum, per cent of total
1940[2]	$310,184,156	$3,624,500,617	$3,934,684,773	7.88
1939[2]	383,753,887	2,740,214,979	3,123,868,866	12.28
1938	388,606,000	2,668,563,000	3,057,169,000	12.71
1937	376,398,000	2,922,531,000	3,298,929,000	11.41
1936	263,450,000	2,155,519,000	2,418,969,000	10.89
1935	250,327,000	1,992,754,000	2,243,081,000	11.16

[1] Authority: Bureau of Foreign and Domestic Commerce.
[2] Preliminary estimates.

The petroleum industry under private enterprise had created its own unique transportation facilities. The crude-oil pipe lines of the United States constituted a far-flung system connecting the oil fields with the principal centers and water terminals. The aggregate length of lines in 1941 was approximately 126,000 miles—one-half the combined length of all our railroads. Oil pipe lines were located in 25 states.

The technique of pipe-line transportation had been successfully applied to gasoline and other refined products. The aggregate length of the refined-oil tank lines of the country in 1941 was around 9,500 miles.

Similarly, the oil industry provided its own facilities for the movement of oil by water. The industry in 1941 maintained a fleet of 441 tank ships with a gross tonnage of 2,722,481.

Foreign Trade in Oil.—The American petroleum industry supplied capital for the development of the oil business abroad and imported and exported crude oil and products in substantial volume. In its foreign trade in oil the United States had long had a favorable balance of trade on a dollar basis. In 1925, the net exports (exports minus imports) amounted to 390 million dollars; in 1940 to $240,035,000 not including reexports. Imports were confined virtually to crude oil and fuel oil, while exports also include gasoline, kerosene, lubricating oils, and other products (Tables 8 and 9).

TABLE 9.—VALUE OF UNITED STATES PETROLEUM EXPORTS, BY PRODUCTS[1]
(In thousand dollars)

Product	1940[2]	1939[2]	1938	1937	1936	1935
Crude petroleum	67,845	92,790	111,641	96,431	66,119	61,176
Natural gasoline	3,204	8,739	13,059	9,465	4,227	3,335
Gasoline:						
Aviation[3]	18,265	20,153				
Other[4]	48,013	81,833				
Total gasoline[4]	66,278	101,985	108,142	91,461	63,415	64,695
Kerosene	8,051	15,787	16,171	20,898	14,823	15,196
Gas oil and distillates	24,796	42,272	42,770	42,858	24,112	17,886
Residual fuel oil	9,870	12,133	13,586	11,709	11,244	9,582
Lubricants[5]	94,465	95,906	72,773	91,249	69,334	66,540
Other petroleum prod.[6]	35,675	14,042	10,464	12,327	10,177	11,916[5]
Total value	310,184	383,654	388,606	376,398	263,450	250,327

[1] Authority: Bureau of Foreign and Domestic Commerce.
[2] Preliminary.
[3] Separation not available prior to 1939.
[4] Includes mineral spirits, naphtha, solvents, and other finished light products; benzol not included.
[5] Includes lubricating oils: red and pale; black; cylinder bright stocks; cylinder steam-refined stocks; insulating and transformer oils; light lubricating oils in small packages; lubricating oils not elsewhere specified; and lubricating greases.
[6] Includes unrefined and refined paraffin wax; unmanufactured and manufactured petroleum asphalt; petroleum coke; and liquefied petroleum gases. Liquefied petroleum gases are included only in 1936 and subsequent years; not available in prior years.

Investment in the Oil Industry.—Before Pearl Harbor, gross investment in the oil industry was estimated as of 1937 at 13,725 million dollars. Estimated net plant investment totaled $6,243,750,000 (Table 10). Estimated rate of return on net worth averaged 5.91 per cent for 17 years, 1923–1939 (Table 9).

Earnings, 1934–1942.—According to an analysis of the earnings of 30 oil companies for the 9-year period, 1934–1942, the rate of return on invested capital averaged 6.4 per cent, while the ratio of dividends to invested capital averaged a modest 3.5 per cent[1] (Table 12).

[1] See this volume, p. 266.

Employment in Industry.—The total estimated number employed in the industry in 1939 was 1,124,000 (Tables 13 and 14).

TABLE 10.—NET INVESTMENT IN UNITED STATES PETROLEUM INDUSTRY,[1] 1937[2]
(In thousand dollars)

Division	Net plant investment	Per cent of total	Investment including other assets[3]	Per cent of total
Crude-oil production	$3,210,000	51.4	$3,740,000	47 4
Crude-oil pipe lines	458,400	7.3	506,500	6.4
Marine transportation	206,000	3.3	226,600	2.9
Refining	'848,500	13.6	1,400,000	17.7
Tank cars	105,000	1.7	112,500	1.4
Refining production pipe lines	48,850	0.8	54,000	0.7
Marketing	1,267,000	20.3	1,752,000	22.2
Segregated administration	100,000	1.6	100,000	1.3
Total	6,243,750	100.0	7,891,600[4]	100.0

[1] Depreciated value of physical facilities, inventories of crude oil and products, and net working capital employed. Does not include investment of United States oil companies in foreign countries, estimated by Department of Commerce at 1,100 million dollars. Gas producing properties included were inseparable from oil properties, but investments o natural-gas companies are not included. It was estimated that the gross investment represented by the above data amounted approximately to 13,725 million dollars.

[2] Authority: Estimated from large samples by John D. Gill before TNEC.

[3] Principally inventories of crude oil and products and net working capital.

[4] No complete later data are available, but from a smaller sample it was estimated that the total net investment increased to about 8,200 million dollars in 1939.

Industry's Taxes before Pearl Harbor.—The American Petroleum Industries' Committee estimated that the total amount of taxes collected from the petroleum industry, its products and customers, amounted in 1940 to approximately $1,520,291,044. Over three-quarters of the total represented state and local levies, while one-quarter was paid into the Federal treasury (Tables 15, 16, and 17).

Teamwork with Government in War.—On D day of the Allied invasion of France, William R. Boyd, Jr., Chairman of the Petroleum Industry War Council, pledged anew the determination of America's oil industry to achieve any goal set for it by the needs of Uncle Sam's fighting men. He noted that 3 years previously almost to the day, government and the petroleum

TABLE 11.—RATE OF RETURN ON NET WORTH[1]

Year	Petroleum industry[2]	Manufacturing industry[3]	All industry[3]
1939	5.0	8.7	6.2
1938	4.9	5.0	3.8
1937	10.0	10.6	7.2
1936	7.5	10.2	7.3
1935	5.2	6.6	5.0
1934	2.9	4.3	3.5
1933	1.46	2.7	2.6
1932	1.09	−0.3	0.3
1931	−1 07	2.5	2.4
1930	4.35	6.3	5 7
1929	9.67	12.6	10.7
1928	9.39	10.7	10.1
1927	5.01	8.8	8.5
1926	10.63	11.0	9.3
1925	10.81	10.7	9.1
1924	7.39	8.9	7.3
1923	6.28	10.0	7.7
Simple average, 17 years.......	5.91	7.61	6.28

[1] Authority: Testimony of John D. Gill before TNEC.
[2] Sample of 24 representative oil companies.
[3] Samples of National City Bank and Standard Statistics Co.

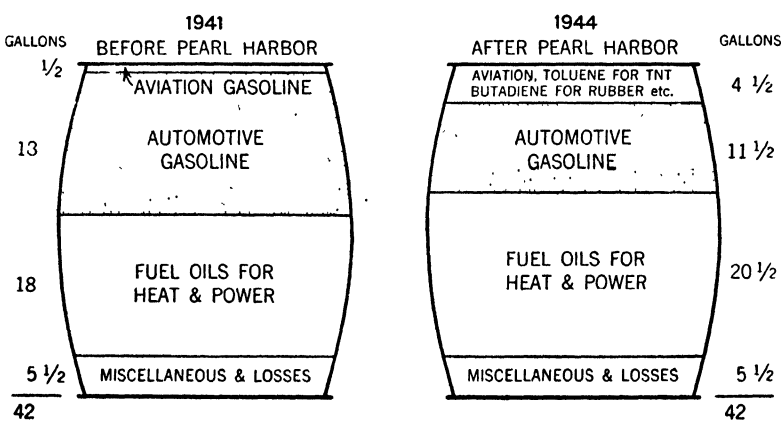

FIG. 2.—Gasoline goes to war. Automotive production reduced so that greater airplane demand can be met. Gallons produced per 42-gallon barrels of crude oil run by refineries. PAW chart.

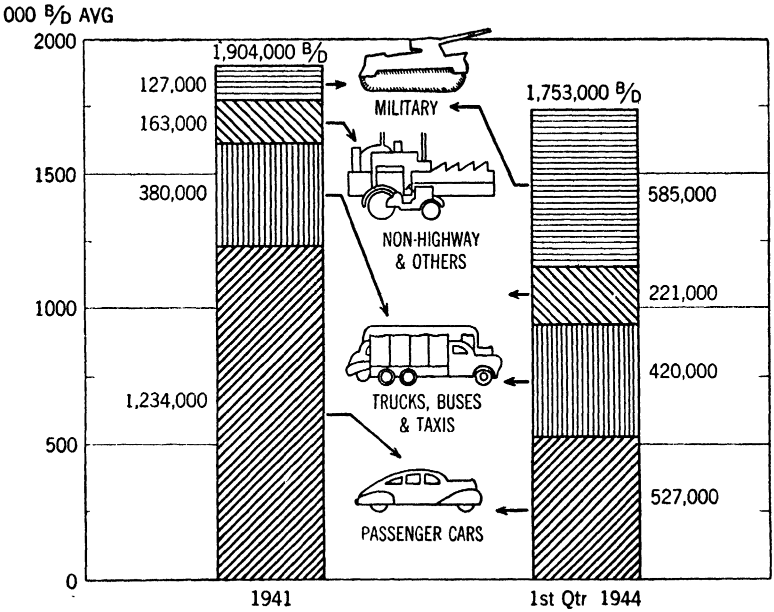

FIG. 3.—United States consumption of gasoline by uses. PAW chart.

TABLE 12.—TREND OF REPORTED NET INCOME FOR 30 OIL COMPANIES, BY YEARS, 1934–1942, AND ITS RELATION TO DIVIDENDS AND INVESTED CAPITAL[1]

Year	Reported net income, million dollars	Change from previous year, per cent	Common and preferred dividends, million dollars	Dividends in per cent of net income	Rate of return on invested capital, per cent	
					Net income	Dividends
1934	157	.	128	82	2.9	2.3
1935	253	+61	120	47	4.8	2 3
1936	412	+63	233	57	7.6	4.3
1937	573	+39	288	50	10.0	5.0
1938	300	−48	199	66	5.1	3.4
1939	321	+ 7	188	59	5.4	3.1
1940	377	+17	209	55	6.3	3.5
1941	530	+41	251	47	8.8	4.2
1942	404	−24	221	55	6.6	3.6
Average..	369		204	55	6.4	3.5

[1] Source: See this volume, p. 266.

TABLE 13.—EMPLOYMENT IN THE PETROLEUM INDUSTRY, 1939[1]

Division of industry	Source of data	Average number of employees
General administrative employees[2]	Estimated from WPA study[1]	65,000
Drilling and production:[3]		
Salaried employees	Estimated from WPA study[1]	155,000
Wage earners	Estimated from WPA study[1]	15,000
Total drilling and production		170,000
Petroleum pipe lines:		
Salaried employees	Estimated from 1939 I.C.C. pipe-line report	2,800
Wage earners	Estimated from 1939 I.C.C. pipe-line report	23,100
Total petroleum pipe lines		25,900
Marine transportation[4]	Estimated from inspected tank vessel register	15,000
Refining:[5]		
Salaried employees	1939 Census of Manufactures	14,745
Wage earners	1939 Census of Manufactures	72,840
Other refinery workers	Estimated	13,000
Total refining		100,585
Automotive transportation[6]		
Wholesale marketing:		
Proprietors	1939 Census of Business	23,978
Employees	1939 Census of Business	106,875
Total wholesale marketing		130,853
Retail marketing:		
Proprietors	1939 Census of Business	231,475
Employees	1939 Census of Business	235,527
Indirect employees[7]	Estimated	150,000
Total retail marketing		617,002
Total marketing		747,855
Total petroleum-industry employment		1,124,340

[1] Official or accurate employment data for the petroleum industry as a whole are not available. In some branches of the industry, reasonably adequate figures are reported; in other branches the data are deficient, are on widely varying bases, or are nonexistent. This table is an attempt to correlate the known data with estimates (some of which are only informed guesses) to show employment for the entire industry. Classifications cover only direct employment in the industry itself, and do not include employment in much work done for the industry, or employment in the further processing and distribution of many products made with petroleum as a raw-material base. Except for employment in drilling and pro-

industry teamed up to place the oil power behind the nation's war-production program (Fig. 2 and 3).

The petroleum industry of the United States produces almost 90 per cent of the total petroleum products in use by the Allied forces. "It has a tremendously important stake in the invasion of France and in all military plans and programs related thereto. It would seem that for one industry to have produced the gasoline and other motive oil to propel and lubricate the machines of war would have been a singular honor. But for one industry to have produced so many vital products, without which these machines of war could not have moved from the coast of Britain, constituted a momentous achievement for which every oil man in the country can rightfully take credit.

"I speak for the country's oil companies, both large and small, which have submerged their private aims and stood shoulder to shoulder with the government in the national emergency, which have pooled their patents and processes that the nation might be better served, and which have been able out of the enormous war production of all industrial America to contribute more than half of all tonnage of supplies sent abroad to serve the Allies."

Harold L. Ickes, Petroleum Administrator for War, in his book "Fightin' Oil,"[1] says:

The relationship now existing between the government and the petroleum industry demonstrates beyond dispute that government and

[1] Ickes, Harold L., "Fightin' Oil," 1944.

duction, no figures are given for the natural-gas industry. The most exhaustive study of employment in the industry is the WPA report, "Technology, Employment, and Output Per Man in Petroleum and Natural-Gas Production." Even this, however, is incomplete and extends only through 1937. Authority: See table and footnotes.

[2] Central-office employees not segregated by branches of the industry.

[3] Includes exploration, drilling, and production of crude oil, natural gas, and natural gasoline. Gathering of accurate data is complicated by the year-to-year changes in proportion of work done by producers themselves and by contractors, the difficulty of obtaining any reliable data on contract work, and by the nonuniformity of classifications used by the several agencies which compile these figures. Contract work (mostly drilling), it is estimated, employs roughly 30,000 to 35,000 of the 155,000 wage earners.

[4] Workers employed on all United States registered tank ships and barges, ocean-going and inland. Does not include marine employees of foreign subsidiaries of United States oil companies.

[5] Beginning with 1939, the Census of Manufactures is counting only strictly manufacturing employees of refineries; other refinery workers, estimated here, include maintenance and construction workers, and distribution employees (truck drivers), employed at refineries.

[6] Automotive-transportation workers (mostly truck drivers) are included with the industry division in which they work; quite probably well over 100,000 truck drivers are employed throughout the industry.

[7] Several hundred thousand outlets sell gasoline and oil at retail in addition to those covered as service stations by the Census of Business. This estimate of indirect employment is an approximation of the number of workers engaged in the sale of petroleum products at these secondary outlets.

industry can work together, although it has taken a war to prove it. In terms of human affairs the machinery (PAW-PIWC) that I am about to describe is unique. Nothing like it, I believe, has ever been attempted, much less achieved.

TABLE 14.—PETROLEUM-PRODUCTION EMPLOYMENT AND PRODUCTIVITY, BY STATES, 1938[1]

State	Crude oil		Natural gas[2]		Natural gasoline	
	Average number of workers	Productivity, bbl. per man-hour	Average number of workers	Productivity, cu. ft. per man-hour	Average number of workers	Productivity, gal. per man-hour
Arkansas	1,980	4.49	30	88.3	90	139 4
California	18,800	6.51	23	254.9	1,800	186.8
Colorado	130	5.08	7	136.5	10	17.5
Illinois	3,090	3.19	12	6.8	55	18.7
Indiana	240	2.19	86	9.3		
Kansas	8,520	3.52	480	51.4	210	127.5
Kentucky	1,530	1.73	375	59.0	55	60.7
Louisiana	7,890	6.12	200	712.3	280	164.3
Michigan	1,640	4.97	57	94.0	20	81.4
Montana	510	5.53	85	110.0	10	61.0
New Mexico	1,280	13.52	13	1,034.5	135	179.7
New York	1,600	1.23	625	35.4	.[3]	
Ohio	2,190	0.86	925	20.7	95	38 9
Oklahoma	21,250	4.19	420	89.2	2,520	90.3
Pennsylvania	7,050	1.17	1,955	19.3	180[3]	31 1
Texas	34,950	6.86	420	808.8	3,070	106.9
West Virginia	2,990	0.63	2,300	28.6	500	52.0
Wyoming	1,850	4.87	30	448.0	175[4]	88.6
Other states	18[5]	0.48	47[6]	269.6		
United States total	117,570	5.11	8,090	95.5	9,205	114.6

[1] No later data available; Authority: U.S. Bureau of Mines.

[2] Includes employment and production at dry-gas wells only; of 1938 gross production of 3,048,200 million cu. ft. of natural gas, 48.6 per cent was produced from oil wells.

[3] New York included with Pennsylvania.

[4] Includes Utah.

[5] Includes Mississippi, Missouri, Nebraska, Tennessee, and Utah.

[6] Includes Mississippi, Missouri, North Dakota, South Dakota, Tennessee, Utah, and Washington.

We have issued no fiat or ukase. No dictatorship exists or impends. We—the government and the petroleum industry—had been working in close harmony for many months, but on that memorable morning of

TABLE 15.—PETROLEUM TAX BILL[1]

Tax[2]	Total taxes collected		
	1940[3]	1939	1938
State gasoline taxes	$868,000,000	$816,433,000	$766,853,000
Federal gasoline tax	281,653,761	215,217,325	200,880,797
Real- and personal-property taxes	140,000,000	138,500,000	138,200,000
Income taxes: federal, state, local	100,000,000[4]	59,800,000	57,000,000
Severance taxes and drilling permits: state and local	42,000,000	41,600,000	40,000,000
Lubricating-oil taxes: federal, state	34,420,051	29,836,487	31,295,340
Federal pipe-line tax	12,017,232	10,971,177	11,599,693
Federal import taxes	8,000,000	8,295,000	6,557,501
Capital-stock taxes	7,200,000	7,200,000	7,140,000
State petroleum inspection fees	6,000,000	5,610,000	5,250,000
Registration fees for petroleum vehicles	5,880,000	5,620,000	5,590,000
Federal excises on automotive equipment used by petroleum industry	4,500,000	4,310,000	4,300,000
Local gasoline taxes	4,000,000	4,320,000	4,350,000
Corporation franchises and mercantile licenses	4,000,000	4,000,000	4,080,000
Sales, privilege, and occupational taxes: state and local	2,500,000	2,263,000	2,250,000
State sales taxes on automotive equipment used by petroleum industry	200,000	187,400	185,000
Federal tax on crude oil processed	....	2,944[5]	583,142[5]
Total petroleum taxes	1,520,291,044	1,354,166,333	1,286,114,473

[1] Authority: American Petroleum Industries Committee.
[2] Listed in order of 1940 tax collections.
[3] Many items preliminary rough estimates.
[4] Includes estimate of 1940 excess profits tax payments.
[5] Tax expired June 30, 1938; subsequent collections are late returns.

Dec. 8, 1941, we really became full-fledged partners in a total war on a common enemy, and the partnership will not be dissolved until the war is won. After Pearl Harbor we really took off our gloves, rolled up our sleeves, and started swinging from the cellar.

The Oil Industry's War Expenditures.—The American oil industry dug into its own pockets for nearly 1 billion dollars for

TABLE 16.—PETROLEUM TAXES COMPARED WITH PETROLEUM-INDUSTRY EARNINGS[1]

Year	Petroleum-industry net earnings[2]	Petroleum taxes	Taxes as percentage of earnings
1940[3]	$435,000,000	$1,520,291,044	349.49
1939	398,698,000	1,354,166,333	339.65
1938	372,615,000	1,286,114,473	345.16
1937	700,536,000	1,315,487,798	187 69
1936	500,664,000	1,183,147,498	235 86
1935	310,505,000	1,121,936,698	361.33
1934	199,304,000	1,046,149,575	524 90

[1] Authority: American Petroleum Industries Committee.
[2] Estimate for entire industry of net earnings after depreciation, taxes, interest, and other charges, but before dividends.
[3] Preliminary.

TABLE 17.—TREND IN STATE GASOLINE-TAX RATES, BY YEARS[1]
(Number of states, including District of Columbia, levying at each rate[2])

Year	Tax rate, cents per gal.							Number of states levying gasoline tax
	2	3	4	5	6	6½	7	
1940	2	9[3]	19[3]	10[4]	5	1	3	49
1939	2	9	19	10[4]	5	1	3	49
1938	2	10	18	10	5	1	3	49
1937	2	10	18	10	5	1	3	49
1936	3	11	17	9	5	1	3	49
1935	3	10	18	10	5	1	2	49
1934	4	12	15	10	5	1	2	49

[1] Authority: American Petroleum Industries Committee.
[2] In years when rate changed, highest rate levied during year was used.
[3] Minnesota rate lowered from 4 to 3 cents, effective Sept. 30, 1940; change will be reflected in 1941 tabulation.
[4] Includes one state (Idaho) in which rate was increased to 5.1 cents, effective Mar. 11, 1939.

construction and expansion of petroleum plants and facilities to expedite the defeat of the Axis by Allied armed forces, the Petroleum Industry War Council announced June 7, 1944.

Mr. Boyd stated that oil companies in the United States, as of Jan. 1, 1944, reported expending $970,058,739 exclusively as part of the war effort in acceleration of refining, marketing, and transportation in the war-geared petroleum industry. This total, he emphasized, reflects capital expenditures voluntarily made as an additional contribution to the successful progress of the war above and beyond any and all Federal government funds which were forthcoming in petroleum's part in the world conflict. Under normal circumstances, Mr. Boyd said, these companies doubtless could not have justified such vast expenditures for war-born improvements and expansions so necessary.

He further explained that the nearly billion-dollar war expenditure of the industry did not include the incalculable other millions of dollars spent by the companies for stepped-up exploration, development, and wildcatting activities that were undertaken to assure petroleum production at the prodigious pace and in the quantities exacted by military and essential civilian requirements. Neither, he said, did the sum involve still other capital financings by the natural-gas industry for such war projects as gathering and transmission lines and nautral-gas wells.

The $970,058,739 petroleum-company war outlay was reported by companies canvassed by the Petroleum Industry War Council in a comprehensive survey that was conducted to ascertain the petroleum industry's financial effort in the war. The reporting companies revealed that *in toto* they had to date voluntarily spent $749,977,761.39 for refining, $197,249,723.07 for transportation, and $22,831,254.60 for marketing petroleum and petroleum products—these sums comprising completed financial outlays and antitipated expenditures for completion of the projects.

The Miracle of 100-octane Aviation Fuel.—The United States petroleum industry provided the fighting fuel—100-octane gasoline—for our Army and Navy airmen from the South Pacific to the Straits of Dover. It produced 100-octane aviation fuel at a rate in excess of 400,000 bbl. daily, whereas a few years ago this was a laboratory product selling at $30 a gallon. For comparison, in December, 1941, the industry produced some 45,000 bbl. daily, and in a normal prewar year our needs were amply satisfied with only 5,000 bbl. a day.

The huge increase was achieved in the United States during the first 2 years of the war through new plants and facilities, under a program sponsored by the Petroleum Administration for War. The total cost of all new aviation-fuel facilities will run in the neighborhood of 900 million dollars—that program now being 85 per cent complete and 760 million dollars of that

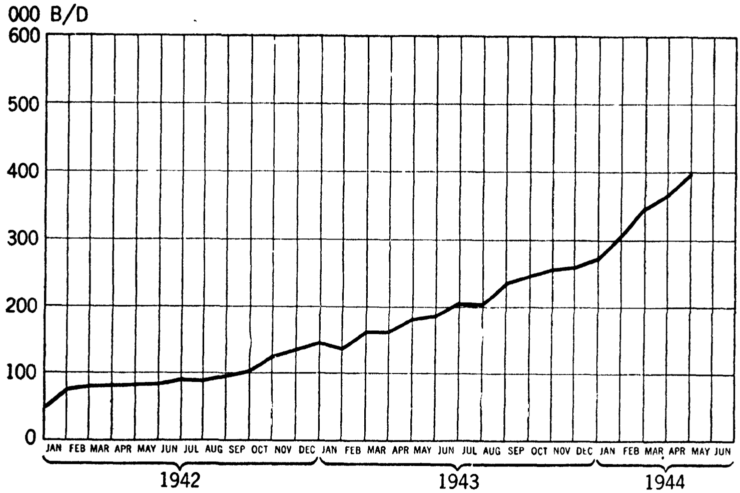

FIG. 4.—United Nations' production of 100-octane gasoline. PAW chart

program being spent for plants in this country. Also, it was accomplished through conversion of existing refinery units to production of aviation fuel, through new blending agents developed by American technical skill and ingenuity. More than 450 refineries and natural-gasoline plants over the United States are linked to some phase of the 100-octane program.

Probably no other major war industry will have had so small a proportion of government financial participation, according to Deputy Petroleum Administrator Ralph K. Davies.[1] Of the $760,000,000 domestic program, $550,000,000 was private capital, and the balance, through Defense Supplies Corporation, government investment, largely used to aid smaller refineries in the program.

[1] Before Oil Subcommittee of the House (Lea) Committee for Interstate and Foreign Commerce, May 17, 1944.

In the first quarter of 1942, due to previous intensive efforts to increase 100-octane facilities, the United States was already producing more high-octane gasoline than all of the refineries and synthetic plants of Axis Europe, according to the best available estimates (Fig. 4).

War Pipe Lines.—All told the total mileage of new pipe-line construction, reversals, and conversions completed up to Apr. 1, 1944, was 11,388 miles. The projects remaining will add another 600 miles. The war-emergency 24-in. pipe line—"Big Inch"—from Texas to the East coast was the most spectacular of many government-financed pipe-line projects. Today, 1,700,000 bbl. of oil daily are flowing to the eastern seaboard through pipe line, tank car, barge, and lake tanker, as against 1,359,000 bbl. daily a year ago.

The Oil Industry in the Synthetic Rubber Program.—In December, 1941, while Pearl Harbor was still smoking from the blasts of Japanese bombs, representatives of oil companies met with PAW in the Interior Building in Washington to explore the technology of petroleum butadiene for synthetic rubber manufacture. When the Rubber Administration was set up, the technicians of the oil industry were entrusted with the building and operation of butadiene plants financed by the government.

On Sept. 10, 1942, the President submitted the Baruch Committee's report to Congress recommending that no speed above 35 miles per hour be permitted for either passenger cars or trucks, calling for a voluntary tire conservation program and for compulsory periodic tire inspection.

The principal recommendations of the Baruch Committee were concerned with presenting a program for the production of synthetic rubber. It outlined plans for an overall production of 705,000 tons annually of Buna S synthetic rubber, which it termed the "mainstay of the present synthetic rubber program . . . well adapted as a material for tires," and the President appointed William M. Jeffers to the post of Rubber Director to carry out at once the recommendations of the committee. By May, 1943, Mr. Jeffers made his third progress report on synthetic rubber and pointed out that the construction of plants to produce synthetic rubber had proceeded very satisfactorily and fairly well in line with the recommendations of the Baruch Committee.

On July 25, 1944, Col. Bradley Dewey, who had succeeded Mr. Jeffers as Rubber Director, announcing accomplishment of the task to create a synthetic rubber industry of sufficient magnitude to make the United States independent of foreign oil imports, voluntarily surrendered the Office of Rubber Director emergency powers and urged its contraction into a routine division of the War Production Board.

He said he felt justified in this and in himself resigning because the production of synthetic rubber had been stepped up to the point where, for the three months ended June 30, output was running at the rate of 836,000 long tons annually, compared with prewar imports of crude rubber ranging from 550,000 to 650,000 long tons a year.

TNT for Block Busters.—The role petroleum products plays in the war is so universal and varied as to be burdensome in the recounting. However, the petroleum industry's place in making explosives can scarcely be ignored. After France had fallen, one of the most difficult military shortages—it can be told, now—was TNT, the pale-yellow stuff which serves as the principal high explosive in modern warfare.

Faced with a gigantic demand for TNT, the conventional method of production would have left us with a shortage which might well have meant that the German air force would be able to drop two bombs to the Allies' one. But what has saved us in this war has been an entirely new catalytic process by which synthetic nitration-grade toluene is being produced from petroleum cheaply and in enormous quantities.

Two thousand tons of bombs may total up to 2,750,000 lb. of TNT. During the 2 months beginning in mid-November, 1943, 14,000 tons of bombs were dropped on Berlin alone—perhaps 19,250,000 lb. or nearly 10,000 tons of TNT. And air bombardment is only one of the uses of TNT—it is also used in land and sea mines; it is used in the smaller calibers of shells, while the amatol in the heavier shells is a blend of from 20 to 50 per cent TNT with ammonium nitrate.[1] TNT has remained the major high explosive in this war as it was in the last for very simple reasons. It is a marvelous explosive. It is relatively easy to make, comparatively cheap, and safe to handle. And it is available thanks to the American petroleum industry.

[1] *The Lamp*, February, 1944.

Postwar Outlook.—The industrial advancement of the world depends more upon transportation than upon any other single factor. Given modern transport facilities we have the basis for a great expansion in production and trade. Just as the First World War created the automobile, so the Second World War has given a tremendous impetus to the airplane. The world will find in automotive transportation on land, on sea, and in the air the agent which will encourage expansion in industrial output and international trade and without which there can be no lasting peace.[1]

Because it is essential to modern transportation, petroleum becomes a key element in this postwar world. Development of oil must go hand in hand in the reconstruction and maintenance of a rising standard of living. If oil and automotive transport can be so directed and stimulated as to lead the way, then expansion with its widespread trade and employment is inevitable. To assure such a result, the return of the petroleum industry to the hands of private enterprise is a first essential, for only in the hands of private industry can the great demands be met and can oil continue as a great social and economic force in this country as it has in the past.

"When the war is over your American oil industry will find the way to continue to deliver all the oil that's necessary to serve the people of the United States," Chairman Boyd of the Petroleum Industry War Council recently said. "This last statement is pretty broad. It should be qualified. Because the United States had maintained an historic policy of allowing full opportunity for petroleum's development by men of business vision, investors, technologists, and scientists, because such men had full opportunity to operate under the competitive system, when war came the oil industry became at once a tower of strength to the war program.

"The proof of the pudding is in the eating and we think that both our prewar and our wartime records have proved that our industry can best serve peaceful pursuits when it is free from regimentation and controls which cripple our efficiency."

[1] Address by Joseph E. Pogue, *Oil in War and Peace*, Sept. 28, 1943.

FILMS AVAILABLE FROM THE OIL INDUSTRY

The following list of motion pictures can be used to supplement much of the material in this book. The films can be secured from the sources listed, or in some cases they can be secured from your local film library or local film distributor.

The running time (min) and whether it is black and white (B&W) or kodachrome (kd) are listed with each title. All of these are 16-mm. sound (sd) motion pictures.

The title in many cases adequately describes the material in the film. In doubtful cases, a brief description is given with the title.

U. S. BUREAU OF MINES
PITTSBURGH, PA.

Automobile Lubrication (11min sd B&W).
Evolution of the Oil Industry (34min sd B&W).
Lubrication (30min sd B&W).
Petroleum and Its Uses (42min sd B&W).
The Story of Gasoline (22min sd B&W).
The Story of Lubricating Oil (22min sd B&W).

INTERSTATE OIL COMPACT COMMISSION
OKLAHOMA CITY, OKLA.

Oil for Tomorrow (30min sd Kd). Story of America's oil resources.

PETROLEUM INDUSTRY WAR COUNCIL
WASHINGTON, D. C.

Victory's Oil (30min sd Kd). The importance of petroleum and its products in peace and war.

SHELL OIL COMPANY
PUBLIC RELATIONS DEPARTMENT
NEW YORK 20, N. Y.

Flight Log (23min sd B&W). Shows development of new fuels for aviation engines.

10,000 Feet Deep (20min sd B&W). Modern methods of exploration and drilling for oil.

Oil from the Earth (18min sd B&W). Locating, drilling, and transporting oil from the well to the refinery.

Oil for Aladdin's Lamp (28min sd B&W). Describes the development of the petroleum production in the research laboratory and the necessity for continued petroleum research.

Pipe Line (17min sd B&W). Construction of a modern pipe line.

STANDARD OIL COMPANY (CALIFORNIA)
PUBLIC RELATIONS DEPARTMENT
SAN FRANCISCO 20, CALIF.

Oil Fires—Their Prevention and Extinguishment (45min sd B&W).

The Amazing Legacy of Rudolph Diesel (45min sd B&W). Development of the diesel engine; how it differs from the gasoline engine.

Seeing Is Believing (28min sd B&W). Testing of different gasolines in an experimental engine.

A Switch in Time (32min sd B&W). A trip through an oil refinery.

STANDARD OIL COMPANY (NEW JERSEY)
ADVERTISING-SALES PROMOTION DEPARTMENT
NEW YORK 4, N. Y.

Power and Octane (33min sd B&W). Training film for pilots.

Esso at War (45min sd B&W). Esso's contribution to the war effort.

Bouncing Molecules (22min sd Kd). Explains chemical processes for making synthetic rubber.

Rubber Goes Synthetic (23min sd B&W). Research necessary for the production of synthetic rubber.

Oil for Victory (15min sd B&W). Construction of a pipe line.

Friction Fighters (40min sd Kd). Development of motor lubricants.

Design for Power (35min sd B&W). Development of modern gasoline.

Road of Tomorrow (20min sd B&W). Construction of the Pennsylvania Turnpike.

THE TEXAS COMPANY
NEW YORK, N. Y.

Deep Horizons (40min sd Kd). Shows how petroleum is found and refined.

Pipe Line (40min sd Kd). Construction and operation of pipe-line systems.

Masters of Molecules (40min sd Kd). Shows how petroleum is refined and used.

Tanker (20min sd Kd). Shows how tanker fleet operates, principally during the Second World War.

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