RESOURCES *for* FREEDOM

Volume III

THE OUTLOOK FOR ENERGY SOURCES

A Report to the President by

THE PRESIDENT'S MATERIALS POLICY COMMISSION

June 1952

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FROM

THE PRESIDENT OF THE UNITED STATES

TRANSMITTING

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Volume III

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IN FIVE VOLUMES

Volume I—Foundations for Growth and Security

Volume II—The Outlook for Key Commodities

Volume III—The Outlook for Energy Sources

Volume IV—The Promise of Technology

Volume V—Selected Reports to the Commission

LETTER OF TRANSMITTAL

THE WHITE HOUSE,
Washington, July 1, 1952.

HON. SAM RAYBURN,
Speaker of the House of Representatives,
Washington, D. C.

MY DEAR MR. SPEAKER: I am transmitting to the Congress the report of the President's Materials Policy Commission, "Resources for Freedom." Our knowledge and understanding of the materials position of the United States and of its allies throughout the free world will be considerably increased by the detailed review which has been prepared by the Commission. This is a document which deserves the most careful study by every member of the Congress, and I hope each one of them will take the time to familiarize himself with its contents.

This report, the fruit of months of intensive study by an independent citizen's group aided by experts drawn from Government, industry, and universities, shows that in the past decade the United States has changed from a net exporter to a net importer of materials, and projects an increasing dependence on imports for the future. The report indicates that our altered materials situation does not call for alarm but does call for adjustments in public policy and private activity.

In more than seventy specific recommendations, the Commission points out the actions which, in its judgment, will best assure the mounting supplies of materials and energy which our economic progress and security will require in the next quarter century.

I am requesting the various Government agencies to make a detailed study of these recommendations, and I am directing the National Security Resources Board to assume the responsibility of coordinating the findings and of maintaining a continuing review of materials policies and programs as a guide to public policy and private endeavor. As the need arises for legislation to solve materials problems affecting this Nation and other free nations, appropriate recommendations will be made to the Congress.

It is my hope that this report and the actions which may be taken as a result of it will contribute significantly to the improvement of this Nation's materials position and to the strengthening of the free world's economic security, both of which are the continuing objectives of United States policy.

Sincerely yours,

HARRY S. TRUMAN.

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RESOURCES for FREEDOM

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Volume III

The Outlook for Energy Sources

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RESOURCES for FREEDOM

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Volume III—The Outlook for Energy Sources

The Commission

William S. Paley,
Chairman

George R. Brown

Arthur H. Bunker

Eric Hodgins

Edward S. Mason

The Executive Staff

Philip H. Coombs
Executive Director

William C. Ackerman
Executive Secretary

Max Isenbergh
General Counsel

Norvell W. Page
Editorial Director

Foreword and Acknowledgment

In publishing separately the commodity studies that deal with the major sources of energy for the United States and the free world, the Commission seeks to emphasize the strong interrelationships among energy sources. Equally important, it wishes to stress the basic importance of ample, low-cost energy, along with technology, as the foundation on which industrial growth is built, and a prime essential in supporting national security.

The studies presented here—on oil, gas, coal, and electric energy—were prepared to assist the Commission's analysis of this important field. Recommendations are not made here; volume I of this Report gives the Commission's findings and views, and lays special emphasis upon the key point of the energy problem: the fact that all sources of energy must be considered not as separate entities but as the related parts of an essential whole.

Here, the Commission wishes to express its thanks to the staff members who prepared these studies, and to the many consultants, both in Government and industry who, during the preparation and later review, assisted the staff and the Commission. The original staff work on coal was done by Fred H. Sanderson; on electric power, by Herschel F. Jones; on natural gas, by E. Wayles Browne; and on oil, by Cornelius J. Dwyer. Mary E. McDermott assisted on the oil study, and John G. Godaire gave general assistance as statistical analyst. The staff was supervised by Robert Blum during the period of the original staff work and preliminary writing. In the preparation of the final reports, the major analytical and writing contributions were made by Sidney S. Alexander, with the assistance of David W. Lusher on the report on electric power. Samuel G. Lasky served as editor of the volume. The consultants who assisted in the preparation of these studies are Eugene Ayres, Walter E. Caine, Walker Cisler, David E. Cohn, E. L. DeGolyer, Edward Falck, Martin G. Glaeser, W. F. Hahman, Serge B. Jurenev, R. A. Kampmaier, George A. Lamb, A. I. Levorsen, Walter J. Levy, Louis C. McCabe, E. W. Morehouse, Philip Sporn, John R. Thomas, Jack L. Ziercher, and Hanina Zinder. They provided valuable data and suggestions, but did not necessarily support the conclusions of the Commission.

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Letter of Transmittal

JUNE 2, 1952.

DEAR MR. PRESIDENT:

As a part of the task which you assigned us, we present volume III of our Report, entitled "The Outlook for Energy Sources." It discusses the present and estimated future use and supply of energy as derived from the principal sources—oil, natural gas, coal, and waterpower—and the special problems for each of these sources.

Energy is an integral element with materials and technology in the continued economic growth of the United States and the rest of the free world. The studies that make up this volume, therefore, figured importantly in the Commission's appraisal of the materials position of the United States and formed the basis of the recommendations made in volume I concerning the expansion and efficient use of the Nation's energy resources.

In preparing these analyses, the Commission staff received the assistance of many individuals, both in Government service and in private industry, who are especially qualified in the energy field.

Respectfully submitted,

William S. Paley
George R. Brown
Arthur H. Bunker
Eric Hodgins
Edward S. Mason

THE PRESIDENT,
The White House.

Contents

The Outlook for Energy Sources

Introduction

Four Studies on Energy

In this third volume of its Report, the Commission presents the basic studies which helped its analysis of the outlook for energy sources and provided foundations for its recommendations in this field. The four studies interconnect at many points. The survey of the problems, and the approaches to solutions, of liquid fuels includes not only petroleum but the possibilities of extracting oil from shale. The discussion of coal and lignite necessarily includes the possibility of extracting liquid fuels, or gas, from these sources, as well as their use for thermal generation of electricity. Natural gas was considered not only as a fuel, but as a tool for helping to lift oil from underground pools. Hydropower is only a part of the electricity supply study because electricity generated by burning coal, gas, and oil is such an important part of total production.

Necessarily, the divisions between the studies have been somewhat arbitrary—the interrelations are much more important than the separations. As the brief discussions of volume I make clear, a supply of energy sufficient to meet the total demand of the United States can be achieved without prohibitive increases in real costs only if the Nation looks at its energy resources as a whole; only if it exploits fully the shifting interrelationships among various sources of energy; only if it takes the fullest economic and technical advantage of the flexibilities in end-use, in distribution, in drawing on each energy source for its best and most efficient contribution. Moreover, the energy position of this Nation must be judged and acted upon in the light of energy needs and resources of other free nations. These studies therefore complement the volume I discussions and in turn are supported by various studies in other volumes, particularly those in volume IV, "The Promise of Technology," which report on advances that engineering has made, or may be expected to make, in improving use, extraction, and distribution, as well as on the potentialities of synthetics and fuel byproducts.

The estimates of future demand herein follow the same pattern applied to key commodities in volume II—an approximation of the situation in the decade of the 1970's, with 1975 chosen as a typical year of that period. Projections of United States energy demands for 1975 were based on the Commission's assumptions on population growth and increases in the total national production of goods and services, and the premise that international tension will continue but that a third world war will be prevented. These projections are not offered as predicitions but only as possibilities neither optimistic nor pessimistic, which can form a prudent basis for analysis and recommendation. The chapter in volume II, "Projection of 1975 Materials Demand," discusses the application of the Commission's assumptions to the individual energy sources. Some of the projections in that chapter and in this volume vary slightly from the energy estimates in volume I, which were not based exclusively on demand assumptions. Estimates of reserves follow the findings of the chapter on "Reserves and Potential Resources" in volume II. Security considerations have been important in analysis of the adequacy of energy supply, particularly of petroleum.

The essence of the energy problem—the total energy problem which in this volume is dissected in individual studies—is that huge further expansion of supply must be accomplished in the face of limitations upon the free world resource base which threaten to force real costs upward and which might, in event of war, cause serious shortages.

It is pertinent to repeat here, as summarizing the total energy problem which industry and Government together must attempt to resolve, the four questions which the Commission attempts to answer in volume I, with the help of the analysis presented in basic studies printed here:

Does the United States have the natural resources—the petroleum and gas, the coal, the waterpower—to provide enough energy for the future?

Will the real costs of energy be forced upward, and will any resultant rise retard economic growth?

In the event of all-out war at any time in the next 25 years, will the United States and its allies have enough fuels and other forms of energy to support full economic mobilization and maximum fighting strength?

What opportunities are there for strengthening the long-term energy position of the United States and other free nations, and what will it take to develop these opportunities?

Chapter 1 Oil

The Situation in Brief

The free world's demand for oil products can be expected to continue to grow vigorously over the next quarter century. Consumption may be expected to double in the United States, triple in Europe, and possibly quadruple elsewhere. Free world oil demand, about 10 million barrels daily in 1950, may accordingly approach 27 million barrels in 1975.

The free world's liquid fuel resources can support this tremendous increase in demand. The geological basis for greatly increased crude petroleum production is clearly visible in the Middle East, and prospects in Venezuela, Canada, and elsewhere in the Western Hemisphere are favorable. In the United States, however, the outlook is somewhat uncertain. This country is presently producing about half the world's oil on the basis of less than 30 percent of the world's proved reserves and of probably a considerably smaller fraction of the world's undiscovered deposits.

Oil is still being discovered in this country more rapidly than it is being produced. The prevailing view in the petroleum industry is that there is no lack of places in which the search for oil may be successful, so that greater knowledge, improved technology, and increased exploratory work give promise of large supplies for the foreseeable future. There are, however, some signs that the cost of new discovery and development is rising, as measured in dollars of constant purchasing power, though these signs are as yet far from clear-cut. Ultimately the growth in United States crude production will have to taper off as it becomes increasingly difficult to make new discoveries. In any case, production prospects are better abroad, so that it will be economical for the United States to turn to imports to meet an increasing proportion of its growing demand for oil. At some point it will also pay to supplement supplies increasingly with liquid fuels derived from the Nation's abundant reserves of oil shale, coal, and lignite.

The gravest problem is the threat to the wartime security of the free world implicit in the pattern of world oil supply that is taking shape. The Eastern Hemisphere, and Europe in particular, is coming to depend on huge imports of oil from the Middle East, which must be considered more vulnerable to attack by a potential enemy than are Western Hemisphere sources.

Oil is even more urgently needed in war than in peace, and sources of supply and transportation routes may be vulnerable to enemy attack. There is accordingly required a continuously operative joint Government-industry program of preparedness to meet a wartime emergency. A balanced reserve capacity to produce oil in the Western Hemisphere, and to transport and refine it, must be kept in being along with an ability to expand this capacity further in wartime as required.

In the near future an emergency cushion can be maintained as part of the normal structure of the industry, but additional arrangements are necessary to preserve the basis of wartime expansion for the more distant future. As free world dependence on vulnerable sources grows, emergency expansibility of production in secure areas must also grow.

There are two principal methods by which this end may be achieved: first, proved reserves may be set aside to be used only in an emergency; second, peacetime oil production may be so conducted that output can be greatly increased in a reasonable time. The second method must eventually include the ability to increase output through rapid buildup of shale oil production capacity and possibly of synthetic production from coal. In the less distant future, however, it seems more economical to maintain an emergency capacity to increase production through the drilling of additional wells in known fields. Government (both Federal and State) and industry should therefore work toward the encouragement of exploration, and of so conducting operations as to preserve maximum expansibility consistent with economic operation of petroleum production. In particular, the development of the Continental Shelf should be so governed as to provide a basis for a large expansion of production in an emergency.

In addition, Government research should continue to be directed toward bringing the production of oil products from shale and from coal-based synthesis to a stage where it is commercially attractive. Moderate financial assistance should be given to private companies that are ready to go ahead with commercial production of shale oil or of oil from coal. Such developments can reasonably be expected to lead to improvements and cost reductions that promise to make our tremendous resources of oil shale and coal the basis of wartime oil security and long-run oil supply.

Great advances have been made in the oil producing States toward the conservation of oil through use of more efficient methods of production. The adoption of these methods has been closely associated with State regulation of production directed primarily at adjusting production to demand. The principal obstacle to the adoption of the most efficient known production practices at present is to be found in the difficulty of applying these practices while protecting the correlative rights of separate owners of a common oil reservoir. Further advances in conservation must be made not only to increase ultimate recovery of oil and to avoid the wastes of excessive drilling of wells, but also to support the increasing emergency expansibility of production that will be required for wartime security of the free world.

USE AND SUPPLY IN THE UNITED STATES

In the past 50 years, petroleum has changed from an insignificant to a major factor in the total energy supply of the United States. Together with natural gas, which is found largely as a byproduct of the search for oil, it accounts for well over half of the Nation's present energy supply, compared to less than one-tenth at the turn of the century.

The United States used more than 2⅓ billion barrels of petroleum in 1950 (6.5 million barrels a day), three times as much as in 1925. The rapid development of automobile, bus, and truck transportation created an enormous market, and the superiority of liquid fuel for rail and water transportation resulted in the extensive displacement of coal in those fields. In addition, liquid fuel has many advantages in residential and commercial heating and in many industrial uses, and along with natural gas has taken from coal large sectors of these markets.

Table I shows the total consumption of oil products in 1929 and 1950 and the portions going to various major uses.

TABLE I.—*Consumption of petroleum products in the United States, 1929 and 1950*

MILLIONS OF BARRELS

Item	1929	1950
Total domestic consumption:		
Annual	940	2,375
Daily	2.6	6.5
PERCENTAGE OF TOTAL		
Use		
Transportation:		
Highway	36	36
Railroad	9	5
Water	10	6
Air	(1)	2
Total transportation	55	49
Residential and commercial	6	19
Industry and agriculture:		
Manufacturing and mining	15	14
Generation of electricity	1	3
Manufacture of gas	2	2
Agriculture	3	4
Total industry and agriculture	21	23
Miscellaneous [2]	12	3
Nonfuel uses	6	6
Grand total	100	100

[1] 0.05 percent.
[2] Not allocable. The decline in this category from 1929 to 1950 undoubtedly reflects more complete statistical information for 1950.

SOURCES: 1929—Adapted from Bureau of Mines *Report of Investigations*, 4805, W. H. Lyon and D. S. Colby. 1950—Bureau of Mines, *Annual Petroleum Statement*, No. P 347; and *Mineral Market Report*, MMS 2003.

Although transportation has dominated the great increase of oil consumption since the beginning of the century, the share used by transportation has actually declined from 1929 to 1950, while that of residential and commercial use more than tripled. Fuel oils, which are derived as joint products with gasoline, kerosene, and lubricants, have come to find a substantial market. A wide variety of other products is also obtained from crude oil—such as wax, asphalt, road oil, coke, and chemicals.

The four major bulk petroleum products—gasoline, kerosene, distillate, and residual fuel oil—serve some uses in common, although each is used predominantly in one or two fields, as shown by table II.

Oil products used for stationary heat and power furnish energy in close competition with other fuels, while in transportation and in special uses, other fuels are not closely competitive. The principal concern for future oil supplies therefore centers upon transportation fuel and special products. An inadequate supply of liquid fuel to meet transportation demands would raise very serious problems, since a shift to nonliquid fuels for transportation would be difficult and expensive.

Fortunately such a shift need never be required. Should domestic supplies of crude petroleum become inadequate and foreign crude supplies unavailable, the problem could be met over the long run not only through recourse to synthetics from oil shale and coal, as described later herein, but also in part from a shift in the pattern of use. Coal, for example, could be used in many stationary heat and power applications, and more distillate could be used as diesel fuel. A whole series of readjustments would take place, the net effect of which would be to permit an increased proportion of oil products to go to uses where the liquid form has special advantages. Meanwhile synthetic liquid products from oil shale and coal might find substitution possibilities over a broad range of uses, both stationary and in transportation.

AN OUTSTANDING SUPPLY PERFORMANCE

Many materials are possible sources of liquid fuels: crude oil, natural gas and natural gas liquids, oil shale, coal, lignite, and tar sands. Crude oil, however, is now the overwhelmingly dominant source, as shown in table III.

Production and consumption of oil in the United States have grown vigorously since 1859, when Drake's well was brought in, the date conventionally regarded as the origin of the petroleum industry in this country. In the following year about half a million barrels were produced; in 1950 (90 years later), more than 4,000 times as much (table IV). In the early days of the industry, the principal demand was for kerosene for illumination, but after the First World War gasoline became the leading product in volume and value of production. In 1951, for the first time since 1929, consumption of distillate

TABLE II.—*Consumption of major petroleum products in the United States in 1950 and the portion going to each principal use*

Product	Consumption (millions of barrels)			Use (percent of total consumption of the product)				
	Annual	Daily	Percent of total consumption of all products	Transportation	Residential and commercial	Industry and agriculture	All other uses	Total
Gasoline	994	2.7	42	88		7	5	100
Kerosene	118	.3	5	7	87	6		100
Distillate and diesel oil	395	1.1	17	21	60	15	4	100
Residual fuel oil	554	1.5	23	33	13	53	1	100
Lubricants	39	.1	2	59		41		100
All other products	275	.8	11		17	38	45	100

SOURCES: Bureau of Mines, *Annual Petroleum Statement*, No. P 347, and *Mineral Market Report*, MMS 2003.

TABLE III.—*United States supply and demand, crude oil and petroleum products, 1950*

Item	Annual (millions of barrels)	Daily (thousands of barrels)	Percentage of total supply or demand
Supply			
Domestic production:			
Crude oil	1, 974	5, 407	79. 4
Natural gas liquids	182	499	7. 3
Total domestic production	2, 156	5, 906	86. 7
Imports:			
Crude oil	178	487	7. 2
Residual fuel oil	120	329	4. 8
Other products	12	34	. 5
Total imports	310	850	12. 5
Total new supply	2, 466	6, 756	99. 2
Stock withdrawal	20	56	. 8
Total supply	2, 486	6, 812	100. 0
Demand			
Domestic consumption	2, 375	6, 507	95. 5
Exports:			
Crude oil	35	95	1. 4
Residual fuel oil	16	44	. 6
Other products	60	166	2. 5
Total exports	111	305	4. 5
Total demand	2, 486	6, 812	100. 0
Net imports	199	545	[1] 8. 0

[1] 8.4 percent of domestic consumption.

SOURCE: Bureau of Mines, *Annual Petroleum Statement*, No. P 347, and Bureau of the Census.

and residual fuel oil together exceeded gasoline consumption by volume.

Along with this greatly increased volume of production, the quality of motor fuels, lubricants, and other products has been steadily improved and the real cost of refining greatly reduced, and all in all the technical performance of the petroleum industry has been outstanding. Prices of petroleum products, measured in dollars of constant purchasing power, were more than 16 percent lower in 1950 than in 1925, in spite of a 24 percent rise in the price of crude oil in constant dollars.

TABLE IV.—*Production and consumption of petroleum in the United States, selected years, 1900 to 1950*

[Millions of barrels]

Year	Production, crude oil and natural gas liquids	Consumption		
		Gasoline	Other products	Total
1900	64	(1)	(1)	(1)
1910	210	(1)	(1)	(1)
1920	454	101	355	456
1925	792	224	503	727
1929	1, 063	376	564	940
1940	1, 412	589	738	1, 327
1950	2, 156	994	1, 381	2, 375

[1] Not available.

SOURCE: Bureau of Mines.

Spectacular as the growth has been, however, it has not kept up with the enormous growth of consumption, and late in 1947 petroleum imports began to exceed exports. The United States has shifted from its former position as the world's largest exporter of petroleum to being one of the largest importers. In 1950, net imports were 545,000 barrels a day, or 8.4 percent of domestic consumption. (Table III.)

FUTURE USE AND SUPPLY

The consumption of petroleum products in the United States can be expected to grow vigorously though at a percentage rate considerably below that of the past 25 years. Total demand for petroleum products by 1975 has been projected for the Commission at slightly more than double the 1950 amount, as indicated in table V. The projected rise may be compared with a 4½-fold expansion of gasoline consumption, and a 2⅔-fold growth for other oil products in the preceding 25 years. The slackening rate of growth of gasoline consumption is expected principally as the result of a slowdown in the increase in the number of passenger cars, which are projected to consume in the aggregate only about 75 percent more motor fuel in 1975 than in 1950.

TABLE V.—*United States domestic demand for petroleum products, 1950 and projected 1975*

[Millions of barrels]

Product	1950		Projected 1975	
	Annual	Daily	Annual	Daily
Motor fuel [1]	994	2. 7	2, 085	5. 7
Kerosene and distillate fuel	513	1. 4	1, 180	3. 2
Residual fuel oil	554	1. 5	1, 110	3. 1
Lubricants	39	. 1	75	. 2
Other products and losses	275	. 8	550	1. 5
Total	2, 375	6. 5	5, 000	13. 7

[1] 1950, gasoline only; 1975, gasoline, highway diesel and LPG, and aviation fuel.

SOURCE: 1950—Bureau of Mines, *Annual Petroleum Statement*, No. P 347. 1975—See vol. II, Projection of 1975 Materials Demand.

These projections should be considered not as predictions but only as the most plausible assumption of future tendencies. Should there be long-run stringency in oil supply, the consumption of fuel oils might decrease significantly, inasmuch as competitive fuels, coal in particular, stand ready to invade the market. On the other hand, if future technological advances make possible an increased use of fuel oil for transportation and other special purposes, demand might increase by more than is projected. The principal question raised by a doubling in demand for oil, accordingly, is how the increased demand for transportation and other special uses is to be met, at what cost and with what safeguards for essential supplies in the event of war.

RESERVES AND DISCOVERIES

The future rate of oil production in the United States will depend primarily on the rate of discovery of additional reserves relative to demand. Proved reserves of crude oil and natural gas liquids at the end of 1951 are estimated at 32 billion barrels, 13 times 1951 production and 12.5 times 1951 domestic consumption [1]. This is a fairly normal relationship between reserves and annual production, since over the past 30 years proved crude oil reserves have characteristically averaged from 12 to 13 times annual production, as shown in table VI.

TABLE VI.—*United States petroleum reserves, new discoveries, and new developments compared with annual production*

[Annual averages]

Period	Millions of barrels			Ratio to annual production	
	Production	Proved reserves (Dec. 31)	New discoveries and new developments [1]	Proved reserves	New discoveries and new developments
CRUDE OIL					
1901–1910	137	3, 740	297	27. 3	2. 2
1911–20	305	5, 870	575	19. 2	1. 9
1921–30	772	9, 610	1, 412	12. 4	1. 8
1931–40	1, 068	14, 530	1, 608	13. 6	1. 5
1941–45	1, 542	20, 203	1, 902	13. 1	1. 2
1946–50	1, 868	23, 112	2, 934	12. 4	1. 6
1951	2, 214	27, 468	4, 414	12. 4	2. 0
LIQUID HYDROCARBONS					
1951 (total)	2, 481	32, 193	5, 138	13. 0	2. 1

[1] New discoveries and developments each year are composed of new discoveries, running about 16 percent of new reserves proved in recent years, and extensions and revisions of previous discoveries, running about 84 percent in recent years.

SOURCE: 1901 to 1949—*Petroleum Facts and Figures*, 9th ed., pp. 182 and 189. 1950–51—American Petroleum Institute press release, Mar. 12, 1952.

Public judgments of the prospects for future petroleum supplies have frequently been distorted because of popular misconceptions concerning the nature of proved reserves. Time after time the fact that proved reserves were equivalent to only about 12 to 15 years' production has come to the attention of publicists who have then sounded the alarm that the United States was about to run out of oil. Reserves must be considered not as the total reservoir from which all future production is to be drawn, but as the basis of operations, a sort of working inventory. Proved reserves are indeed like a reservoir, but a reservoir into which there is an inflow as well as an outflow. The fact that at any one time reserves are only a little more than a decade's outflow need not of itself be alarming if a steady inflow can be anticipated. The future position of United States oil production can accordingly be gaged not by the size of proved reserves but by the prospects for future discoveries relative to future demands on production.

If United States domestic production is to keep pace with the projected growth of consumption over the next 25 years it would have to increase at a rate of about 3 percent per year—to about 4½ billion barrels in 1975, allowing for a proportionate rise in imports. To support this growth, new reserves proved each year must on the average replace the production of that year plus a net addition of 3 percent of total reserves to permit the latter to increase in proportion to the 3 percent growth in annual production. Since reserves average about 13 years' annual production, 3 percent of total reserves equals about 40 percent of annual production. New discoveries and developments must accordingly run about 1.4 times annual production. Except during the Second World War when the steel shortage greatly limited exploration, and in the depression of the thirties when incentive for exploration was small, new discoveries and developments have exceeded this ratio by a considerable margin. In 1951, the year of greatest gross addition to reserves, new discoveries and new developments were more than double production, which also set a new high.

The petroleum industry is confident that, given a favorable economic and political environment, it can continue for a long time to meet the growing demands upon it. It is generally accepted, however, that at some time in the future the job will become considerably more difficult, but there is a broad difference of opinion as to when that time can be expected. Its approach will be indicated fairly well in advance by two closely related developments: (1) failure to provide new discoveries sufficient to support the growth of production and (2) increased cost of discovering and developing oil relative to the general price level.

IS COST OF DISCOVERY GOING UP?

As indicated in table VI there is as yet no evidence of failure to discover reserves adequate to support growing production. Any indication of future supply difficulties must therefore be sought in evidence of increased costs of crude oil. The total cost of crude oil is composed of three elements: the cost of finding new supplies, the cost of development, and the cost of lifting. In 1948, according to one estimate, finding and development each accounted for about 40 percent, and lifting for about 20 percent, of total cost [2]. Because of more widespread application of improved recovery methods, which should more than compensate for the additional difficulties of producing oil from ever greater depths, the average cost of lifting a barrel of oil is likely to decrease over the next 25 years. The principal factors therefore will be those affecting the costs of discovery and development. Experts consulted by the Commission agreed that these costs can be expected to rise in the United States in the future, but there is a considerable difference of opinion as to the magnitude of the cost increase.

Two sets of estimates are given in table VII, from which it appears that there was a rise of about one-third in the cost of finding and developing a barrel of proved reserves of crude oil between 1927–30 and 1936–41, and a further rise of the order of 15 percent to 1947–50. But for every barrel produced (as contrasted with discovered) the oil industry spends only very little more in constant dollars on finding and developing than in the past. These estimated expenditures are, however, subject to a wide range of error.

Except in the depression of the thirties, about 25 barrels of new oil reserves were proved for each foot of well drilled since 1925. See table VIII. At the same time the cost of each foot drilled is reported to have gone up, from $4.30 per foot in 1939 [3] to $9.44 [4] per foot in 1947, or $5.60 in 1939 dollars.

TABLE VII.—*Estimated expenditures for finding and developing oil in the United States per barrel of new reserves proved, and per barrel produced*

[Constant dollars 1950 purchasing power] [1]

Period	Expenditures per barrel proved [2]		Expenditures per barrel produced [3]	
	A [4]	B [5]	A [4]	B [5]
1927–30	0.37	...	0.85	...
1936–41	.51	0.56	.98	1.08
1947–50	...	[6] 0.64–0.56	...	[6] 1.02–0.92

[1] Original expenditures converted to 1950 purchasing power on basis of implicit price deflators for gross national product, 1929–50. Department of Commerce, *National Income Supplement to Survey of Current Business*, 1951, p. 146, table B. 1927 and 1928 implicit deflator estimated by P. M. P. C. staff.

[2] Total new crude oil reserves proved as estimated by the American Petroleum Institute.

[3] Crude oil produced, as reported by the Bureau of Mines.

[4] Petroleum Administration for War, Production Division, November 1943, "Survey of Expenditures for Finding, Developing and Producing Crude Oil in U. S., 1927–42."

[5] 1936–45—estimated expenditure from "Capital Requirements of Crude Oil Production" by Pogue and Coqueron, *Mining and Metallurgy*, October 1946, p. 503. 1946–50—Based on data compiled by Pogue and Coqueron for 30 oil companies and published annually by the Chase National Bank.

[6] Higher figure on basis of crude only; lower figure on basis of crude plus natural gas liquids (total liquid hydrocarbons).

TABLE VIII.—*New crude oil reserves proved relative to footage drilled in the United States, 1925–51*

[Annual averages]

Period	Total footage drilled (millions of feet)	Total reserves proved (millions of barrels)	Reserves proved per foot drilled (barrels)
1925–30	77	1,890	24.5
1931–34	45	507	11.2
1935–41	89	2,289	25.6
1942–45	77	1,886	24.5
1946–51	137	[1] 3,181 (3,614)	[1] 23.2 (26.3)
1951	174	[1] 4,414 (5,138)	[1] 25.3 (29.5)

[1] Figures in parentheses refer to total liquid hydrocarbons (crude oil plus natural gas liquids).

SOURCE: Footage drilled, *World Oil*, Feb. 15, 1951, p. 95, and Feb. 15, 1952, p. 113. Reserves: American Petroleum Institute.

As to the number of dry holes drilled relative to the number of successful new-field wildcat holes, statistics prepared annually by the American Association of Petroleum Geologists [*5*] show that among new field wildcats the ratio has remained about constant since 1944 at 8 to 1. Data for new field wildcats are not available for the years before 1944, but the ratio of dry holes to producers among all exploratory wells (including outpost wells to determine the outer boundaries of a known field and tests for new pools in old fields, as well as new field wildcats) is reported to have dropped from an average of 6.9 to 1 in 1938–41 to an average of 4.1 to 1 in 1947–50 [*6*]. Various sources of information differ as to the total number of wildcats drilled in various years but one Government agency concludes that "the ratio of successful to total completions has not declined significantly during recent years. In other words, a wildcat drilled today has as good a chance to be a producer as it would have had 10 years ago" [*7*].

All in all, the available evidence gives some support to the argument that discovery and development of oil in the United States are becoming more costly, but this conclusion is not clearly established. It cannot be doubted, however, that at some time in the future, discovery in this country will become much more difficult, with attendant rises in cost, so that eventually alternatives to domestic crude oil production must be sought.

ULTIMATE DISCOVERY POTENTIAL

Various estimates have been made of the amount of oil that can be expected ultimately to be found and produced in the United States. One well-known estimate, made in 1948, was 110 billion barrels—the sum of past production, current proved reserves, and estimated total future discoveries of economically producible oil [*8*]. The United States had already produced 35 billion barrels by the end of 1947, and proved reserves were about 21 billion, so that according to this estimate only about 54 billion barrels remained to be discovered and 75 billion to be produced.

The most serious challenge to this estimate is the continued success, since the estimate was made, in discovering oil roughly in proportion to the exploratory effort. Within 4 years, about 14 billion barrels of new reserves, or over 25 percent of the 54 billion barrels of oil estimated as discoverable, were proved, with no sign of a declining rate of discovery. In addition, a large part of the new reserves proved was found in areas considered already intensively explored. Thus there is a presumption that considerably more oil remains to be found and recovered than the above estimate indicates. Past estimates of ultimate discovery have all turned out to be much on the low side, and while this does not necessarily apply to all subsequent estimates, it does support the conclusion that future prospects for oil production must be inferred continuously from the success currently being encountered in exploration and discovery rather than from estimates of how much may ultimately be discovered.

IMPROVING RECOVERY

Only about 40 percent of the total oil-in-place in the average petroleum reservoir can be economically recovered at current prices with techniques currently used. The percentage recoverable varies with the characteristics of the reservoir, especially with the type of drive that forces the oil to the surface. According to modern theory there are three general types of drive, often found in combination: water drive, expanding gas-cap drive, and dissolved-gas drive. An extraction rate of 85 percent has been achieved by water drive in the east Texas field. It is believed that the remaining 15 percent, consisting of oil adhering to the surface of the sand particles, could not be extracted without actual mining and retorting. An expanding gas-cap can produce from 20 to 40 percent of the oil-in-place, while dissolved gas alone yields on the order of 10 to 20 percent.

Considerable advance has been made in the past 20 or 30 years in understanding the performance of petroleum reservoirs. This improved knowledge has led to the development of important practices for conserving and augmenting reservoir energy or otherwise improving recovery. The principal techniques involved are the return of gas or water to the reservoir to maintain the drive, or the introduction of gas or water from other sources to augment it. Methods such as these have been successfully used in secondary recovery, in order to augment reservoir energy after the economic production limits by primary recovery methods have been reached. In 1947 it was estimated that there were more than 7 billion barrels of recoverable secondary oil in the United States, and in 1950 one authority ventured the guess that probably twice as much was physically recoverable [*9*]. Only such portions of these reserves as are found in fields where secondary recovery is now under way are included in estimates of the country's proved reserves. Of course, to the extent that full advantage is taken of the best techniques in primary production, the amount left for secondary recovery decreases.

To some extent the adoption of methods to improve recovery is waiting until higher costs of discovery make secondary recovery a more attractive alternative method of increasing supplies. There is relatively little present interest in some of the techniques of increasing recovery because the cost per extra barrel recovered is higher than that of finding and developing new oil. Nevertheless, some improvements may in fact be striking enough to lead to their widespread adoption even in the absence of a rise in the cost of finding oil.

Secondary recovery or repressuring operations are likely to be practical in many cases only if arrangements can be made for unit operation of each program. Inasmuch as each program is likely to affect the oil pool as a whole, it can most advantageously be carried on if applied to the whole pool. It would not, for example, generally pay an individual leaseholder of a small part of a pool to attempt gas injection. In one of the earlier large-scale repressuring operations (at Kettleman Hills in 1931), considerable waste and loss of efficiency in the development and operation of the pool resulted from the lack of control of 540 acres out of the total of more than 16 thousand [*10*]. The operation as a whole did achieve some success, but the benefits were minimized for lack of control of less than 5 percent of the acreage. The advantages of unit operation are so clearly marked for repressuring and for secondary recovery that unitization has made considerable progress in these activities in contrast to its rare use in primary oil recovery as a whole.

Recovery may be increased not only by maintaining and augmenting the drive, but also by increasing the permeability of the material through which the oil must travel underground to reach the well. In the great Spraberry Trend of West Texas, many a well would be a dry hole were it not for new techniques of fracturing the impervious rock to create channels through which the oil can flow to the bottom of the well. The amount of oil-in-place in the Trend is now estimated at from 10 billion to 20 billion barrels, but the amount recoverable with present techniques and at present prices is calculated at only 5 or 10 percent. This new fracturing technique, still in its infancy, is now coming to be applied in other localities with similar characteristics.

It has been estimated [*11*] that about 175 billion barrels of oil-in-place had been discovered in the United States by January 1, 1950, of which 68 billion either had been produced or presumably could be economically recovered with present techniques at present prices. That included 39 billion barrels already produced, 25 billion in proved reserves, and another 4 billion barrels that presumably could be produced by application of conventional secondary recovery methods to fields where they were not yet applied. Of the remaining 107 billion barrels, it was calculated that perhaps 65 billion may eventually be recovered. In short it may be possible to increase the recovery of oil-in-place from the current 40 percent to about 75 percent.

Some of the measures that contribute to improved recovery are being encouraged by State regulatory authorities. A bonus of allowable production is given in some cases for the return or introduction of water or gas to the reservoir; and restrictions on the gas-oil ratio permitted lead to the return of excess gas to the reservoir. These regulations make valuable contributions, but they are only part-way measures toward the most efficient operation of each reservoir as a unit.

TECHNOLOGY OF EXPLORATION

Great advances in the technology of identifying geological structures favorable to oil accumulation have been achieved during the last 30 years. Such geophysical methods as the torsion balance, gravity meter, refraction and reflection seismographs, magnetometer, electrical and radiological well-logging, infrared and mass spectrometers, aerial photography, and a host of others have been of immeasurable benefit. Geochemistry, which has not been used to a great extent in the past, may play a greater role in the future.

No technique other than drilling has as yet been discovered, however, for indicating the actual presence of oil in the ground; all that wildcatters can do is to determine the location of possible traps and then to test, with the drill, whether or not oil is present in them. For many years, the rotary drill has been the chief tool in the actual locating of oil deposits. Depths greater than 20,000 feet have been reached. Even more recently, automatic controls have been developed, speeding operations, improving safety, and lowering personnel requirements.

New instruments, methods, and concepts in the fields of exploration are being developed all the time. Many areas and types of formations, formerly believed to be valueless, have been reassessed and developed, some as a result of geophysical interpretations, others as a result of new concepts and of recognition of new types of accumulation such as fractured reservoirs and stratigraphic traps. Continuing refinements of existing methods and development of new techniques and concepts are necessary if the ratio of productive wells to dry holes is to be kept within bounds.

SUPPLIES FROM ABROAD

If domestic production of oil cannot economically keep pace with growing demands, the gap can be met by additional imports. How great the imports will be will depend on the size of the demand, the willingness of the United States to accept the imports, political conditions in the producing areas, and their relationships with the United States.

The favorable conditions for expanding oil production outside the United States are reflected in the greater rate of growth of foreign production in recent years. From 1945 to

1951 annual production of crude oil in the United States increased half a billion barrels or about 30 percent, while in the rest of the free world annual production increased almost a billion barrels or about 140 percent. The 199,000 wells drilled in the United States from 1946 to 1951 brought in new proved reserves of 23.5 billion barrels. In the same period about 400 new wells completed in the Middle East brought in new proved reserves of 27.6 billion barrels.

In the Middle East growth of production is presently limited almost entirely by available facilities for transporting and processing the oil rather than by the geological potentialities. This condition is likely to continue for some time. Venezuela, presently the greatest single producing country outside the United States, also has many undeveloped possibilities, probably standing somewhere between the United States and the Middle East in the effort required to maintain and extend production. For example, in the United States 38 percent of the 44,826 new wells drilled in 1951 were dry holes, whereas in Venezuela the corresponding percentage was 11 percent of the 673 wells drilled, and in the Middle East 7 percent of the 91 wells drilled. Production per well in 1950 averaged about 238 barrels per day in Venezuela, about 5,000 in the Middle East, and only about 12 in the United States—or about 40 if stripper wells are excluded. Production per well in the United States in 1950 was somewhat limited by pro-rationing but not by enough to affect the general significance of the comparison.

Despite heavy transportation costs, foreign oil is now competing in the United States market. At present, however, most United States imports are from Venezuela, with very little from the Middle East since the markets in Europe and elsewhere in the Eastern Hemisphere are more attractive for the oil that can be supplied from the Middle East with the transportation and processing facilities that now exist. The cost of finding and producing oil in the Middle East (excluding royalties and taxes) is much below corresponding costs in the United States. Transportation rates are high but super-tankers are becoming available at costs far below present rates. With such super-tankers Middle Eastern oil could be competitively delivered to the East Coast of the United States. To the extent that pipeline transportation is used between the Middle East and the Mediterranean, costs of delivering Middle East crude can be cut even further.

Venezuela also is capable of supplying more oil to the United States. As Middle East crude increasingly displaces Venezuelan crude and products in the European markets, Venezuelan supplies could be diverted to the United States and the rest of the Western Hemisphere at prices no higher than at present. Venezuela can accordingly be expected to be the principal source of increased United States imports in the next 10 or 15 years. If, however, greatly increased production is required in Venezuela, it could probably be met only by permitting widespread exploration in areas not now under concession.

The flow of oil is of course influenced by factors other than pure economic considerations, in particular, trade agreements and restrictions, currency considerations, national security policies, and the pattern of company interests in production and marketing in various areas. Nevertheless, the fundamental conditions of potential supply of petroleum throughout the free world in the foreseeable future are favorable to support any required imports into the United States. The problems of policy likely to be raised are accordingly the degree to which the United States shall choose to import oil and the reliance that can be placed upon foreign supplies in an emergency.

SYNTHETIC OIL FROM SHALE AND COAL

Another supplement to domestic supply of liquid fuels can be found in the production of oil products from oil shale or from coal. The oil content of known deposits of oil shale in the United States, located principally in Colorado, Wyoming, and Utah, is far in excess of proved crude oil reserves. The Bureau of Mines estimates the total oil content recoverable at prices ranging up to four times the present price of crude oil to be 500 billion barrels, of which 80 billion barrels in the Mahogany Ledge is presumably recoverable at crude oil prices not much higher than at present. While a major cost of new crude supplies is that of finding the oil, the oil shale is already found. The cost problems of shale oil are those of mining, extraction, refining, and transporting the product to distant markets.

The Bureau of Mines has been experimenting for some years on low-cost techniques for mining the oil shale and producing refined products therefrom in a demonstration mine and refinery at Rifle, Colo. On the basis of this work the Bureau of Mines concluded that gasoline could be made from the shale at a cost comparable with gasoline from crude oil. In April 1950, the Secretary of the Interior requested the National Petroleum Council, his official industry advisory group, to make an independent study of the probable cost of production of liquid fuel from shale, as well as a similar study of probable costs of production from the hydrogenation of coal. The Council's conclusion was that, after allowing for the return on other products, gasoline made from shale on the basis of an operation producing 200 thousand barrels of products daily could be sold in the Los Angeles market at an average price of 14.7 cents a gallon, allowing for a 6-percent return on invested capital. This compared with Los Angeles prices averaging 12.7 cents per gallon at the refinery on October 6, 1951, for equivalent grades and proportions of gasoline.

Some unresolved differences, based principally on the cost of financing, still remain between the findings of the National Petroleum Council and those of the Bureau of Mines, but the two studies agree fairly closely on operating costs. Whether the process is now economic remains an open question, but all are agreed that the production of gasoline and other products from shale is so close to being economic that any considerable rise in the cost of crude, say of the magnitude of 25 or 30 percent, would almost certainly make the processing of oil shale attractive commercially. The economic rate of production, however, would be limited by such factors as the availability of labor and of water. A study prepared by a consulting engineering firm for the Army Corps of Engineers indicates that output could reach 6,500,000 barrels per day (2,373,000,000 barrels per year) before water supplies are strained if provision is now made to reserve water supplies for this industry.

Shale oil thus constitutes a tremendous resource if something goes wrong with the crude oil supply. If, in the normal course of events, the year to year results of exploration for crude oil deteriorate and costs of oil products from crude rise to meet those of products from oil shale, private industry can be expected to begin the building of commercial-scale plants. Although initial operations would be small relative to the total crude production of the country, they must still be fairly large in order to be efficient. Even the smaller commercial plants considered—40,-000 barrels a day—would produce far more than the thinly populated environs could absorb. A market would have to be sought as far west as California, where demand is expanding most rapidly, or east to Kansas City, St. Louis, and Chicago, where competition from the Mid-Continent field would be encountered.

The Bureau of Mines has also undertaken operations in the production of gasoline and other products from coal, using two processes that were extensively relied on by Germany for part of its oil supply in the Second World War. These two processes are known as hydrogenation (Bergius) and gas synthesis (Fischer-Tropsch). The Bureau of Mines has estimated that gasoline and other products could be made by hydrogenation of coal in Wyoming at a cost of 11.1 cents a gallon at the refinery, competitive with petroleum products. The National Petroleum Council estimates that the required selling price would be 41.4 cents. The Council also estimates actual production costs (i. e., all costs except income taxes and return on invested capital) to be 18.4 cents per gallon of total product as compared to the Bureau's equivalent figure of 10.2 cents per gallon of total product.

The large discrepancy in these two estimates of gasoline costs was attributable to large differences of estimates in the sale value of coproducts, in the amount of total investment required, and in operating costs. These differences have not yet been resolved. The Bureau of Mines retained an independent engineering firm to review some of the more important cost factors. The resulting study supported many of the Bureau's figures. The over-all result of the new findings was to raise the Bureau's estimate of actual production costs from 10.2 cents per gallon of total product to 11.4 cents, still substantially less than the corresponding 18.4 cents indicated by the National Petroleum Council.

It accordingly appears that, even if shale and coal are not yet competitive sources of liquid fuel, they are not too far away. A number of oil companies have interests in the shale deposits and are actively investigating their commercial possibilities. Synthetic oil from shale or coal thus sets a ceiling on the possible rise of crude oil prices in the long run.

Since it is almost certain that shale and coal will eventually provide an important part of our oil supplies, the principal policy issue involved is one of timing—whether to wait for the normal operation of market forces to bring these processes into large-scale operation, or in view of security considerations to speed up their adoption by subsidies at those points where they are already almost commercial.

REST OF THE FREE WORLD

The rest of the free world consumed in 1950 only a little more than half as much oil as did the United States. Oil consumption can be expected to increase much more rapidly abroad than in the United States as the pattern of consumption overseas comes more closely to resemble that of this country. In particular, automobiles and trucks are much less commonly used, but an increase paralleling the growth of motor vehicles in the United States over the past 25 years is in prospect. Furthermore, coal will probably continue to be much more expensive or less freely available in many countries abroad than in the United States. Some important industrial countries will find it necessary to import large amounts of energy fuels, and petroleum from the Middle East is likely to be the most economical form. Consequently, the oil demand of the rest of the free world can be expected to increase even more rapidly than in the United States, possibly increasing between three- and four-fold as indicated in table X.

TABLE X.—*Free world demand for crude oil and products*

[Thousands of barrels per day]

Region	1929	1950	Projected 1975	Percent increase 1950–75
United States	2,580	6,510	13,700	110
Other North America	210	590	2,300	290
South America	170	600	2,300	283
Total Western Hemisphere	2,960	7,700	18,300	138
Europe	460	1,200	4,000	233
Africa, Asia, and Oceania	300	1,100	4,500	309
Total Eastern Hemisphere	760	2,300	8,500	270
Free world excluding United States	1,140	3,490	13,100	275
Total free world	3,720	10,000	26,800	168

SOURCE: 1929 and 1950, Bureau of Mines estimates. 1975 for U. S.—vol. II, Projection of 1975 Materials Demand.

Adequate supplies should be available to meet even this growth. Not only can the present great exporting areas—the Middle East and to a lesser extent Venezuela—greatly increase their production, but some countries formerly net importers can be expected to increase their output as well. As techniques of finding oil improve, areas previously deemed unfavorable come to have important production possibilities. Canadian production is already growing rapidly and may soon support net exports from that country. Other discoveries may be made in countries not now producing significant amounts of oil. Even in the absence of these new sources of production the Middle East and other major exporting countries appear to have the resources for meeting the projected vigorous growth in demand.

The physical basis accordingly exists for an adequate peacetime oil supply at real costs substantially unchanged from those of the present. In the Middle East these potentialities can be realized by drilling more wells and by providing tankers, pipelines and refineries to transport and process the oil. In other areas the geological prospects for success in further exploration are promising.

The future balance sheet of world petroleum supplies might look something like the hypothetical pattern in table XI, in which projections are compared with actual 1950 figures.

This picture is merely one possible shape that the future pattern may take, but it does emphasize the prospective developments that set the background for the future oil problems of the free world. Those developments are a tremendously increased level of consumption and correspondingly increased dependence on production in the Middle East and in the Western Hemisphere outside the United States.

TABLE XI.—*Hypothetical pattern of free world oil supplies and demand in 1975 compared with 1950*

[Thousands of barrels per day]

Region	Production		Apparent consumption		Net imports— Net exports+	
	1950	1975	1950	1975	1950	1975
United States	5, 910	[1] 11, 200	6, 450	13, 700	−540	−2, 500
Other Western Hemipshere	2, 040	5, 900	1, 190	4, 600	+850	+1, 300
Total Western Hemisphere	7, 950	17, 100	7, 640	18, 300	+310	−1, 200
Europe	60	[1] 300	1, 200	4, 000	−1, 140	−3, 700
Middle East and other Eastern Hemisphere	2, 040	9, 400	1, 100	4, 500	+940	+4, 900
Total Eastern Hemisphere	2, 100	9, 700	2, 300	8, 500	−200	+1, 200
Free worldexcluding United States	4, 140	15, 600	3, 490	13, 100	+650	+2, 500
Total free world	10, 050	26, 800	9, 940	26, 800	+110	......

[1] Crude oil, natural gas liquids, shale oil and other synthetics.
SOURCE: 1950, Bureau of Mines. Illustrative 1975, PMPC.

It is quite possible that production in the United States by 1975 may differ considerably from the 11.2 million barrels per day suggested in table XI. If it should be much below, free world dependence on the Middle East and possibly on Western Hemisphere production outside the United States would be correspondingly greater. In view of the wartime essentiality of oil, and the hazards to the Middle East in particular and to world oil supplies and transport in general, the future pattern poses a serious problem of free world security and offers a strong challenge to public policy to encourage the growth of production capacity in the United States and the rest of the Western Hemisphere.

PROBLEMS OF PUBLIC POLICY

SAFEGUARDING SECURITY

As the scale of normal peacetime consumption grows, ever greater amounts of oil will be required for essential civilian needs in case of war. Moreover, the scale of military requirements can be expected to grow rapidly as well. At the same time the dependence of the free world on vulnerable supplies is also likely to grow. Clearly the security problems in oil are likely to become increasingly difficult as time goes on.

Wartime petroleum needs can be prepared for only by continuous day to day cooperation between industry and Government in the countries of the free world. This sort of cooperation made notable achievements in meeting the oil problems of the Second World War, and it is continuing, under the Petroleum Administration for Defense, to yield good results in the United States in the present emergency.

The problem must be approached on a world-wide basis. The United States cannot take undue comfort from the prospect that the Western Hemisphere will perhaps remain self-sufficient in oil for a long time. Its friends and allies in the Eastern Hemisphere will become increasingly dependent on the Middle East, but if supplies from that area should be substantially reduced in time of war, those allies would then have to be supplied from the remaining sources, largely in this hemisphere. The pattern of wartime supply and consumption for which preparation must be made is, therefore, a single comprehensive pattern for the entire free world.

The initial bottleneck in wartime supply would almost certainly be tankers. The convoying of tankers and wartime conditions of port operation would increase turn-around time and so reduce the over-all capacity of the tanker fleet. Tankers would be sunk. Military demands for oil would require deliveries to ports not well equipped for unloading of tankers and storing oil, so that tankers would come to be used as floating storage facilities. All in all it can be expected that, in the absence of the loss of a major producing area, such as the Middle East, tanker availabilities would initially govern wartime supply. If major producing areas (in particular the Middle East) were denied to the free world, tankers from those runs would presumably be available to transport increased production from Western Hemisphere sources.

After tankers, the next most critical facilities would be refineries. Far more vulnerable than oil fields or even tankers, they offer a tempting target for aerial bombardment and possibly for sabotage. A modern refinery takes from 18 months to 2 years to build under normal conditions, and some of the specialized capacity for products needed in modern warfare takes even longer. Given high priorities for steel, manpower, and components, refineries can be constructed considerably more rapidly, but at the expense of other parts of the war effort.

Finally, there is required the ability to achieve an extraordinary increase of crude oil production in secure areas, balanced with corresponding refining and transportation facilities first discussed.

The emergency oil production and transportation cushion must be planned for in terms of two time phases: that cushion of "standby capacity" which would be immediately available if war should break out, and the additional increases of capacity and output that could be provided with satisfactory speed after war had started.

As a short-term target, officials of the Defense Department have publicly called upon the domestic petroleum industry to provide a reserve capacity within the United States equal to 15 percent of annual consumption (about a million barrels per day at the present consumption level of about 7,000,000 barrels per day). With a reserve capacity of this magnitude, the United States could provide its share of allied military demand in the opening phase of a war in the near future.

It has not been possible to guarantee the availability of reserve capacity of this magnitude up to now, because of the limited availability of steel. The oil industry has been able to obtain the steel it needed to expand to meet rising demand, but not enough to provide a security cushion. As ample supplies of steel become available, however, the industry will probably be able to carry reserve capacity of 10 or 15 percent of demand.

Beyond this reserve capacity, there must be maintained the ability to expand production, refining, and transportation capacity rapidly enough to meet the developing requirements of a war and to offset losses that may be suffered. Refining capacity can be fairly rapidly expanded provided sufficient priority is given for the required materials and skills. It requires a longer time to construct a sizable tanker fleet.

Additional wells can be drilled fairly quickly and crude production thereby increased up to the limits set by proved and semiproved reserves. The most important type of reserve production capacity in the long run will probably be the preservation of conditions that will permit an emergency campaign of well drilling to bring big returns in increased crude production. At present and for some years such conditions are likely to exist as a normal feature of the petroleum industry. But as time goes on special provisions are likely to be required to insure that Western Hemisphere crude production could be expanded quickly, easily, and by a great amount in the event of war.

BUILDING AN "UNDERGROUND STOCKPILE"

Since it is not practicable to stockpile huge quantities of crude petroleum in the conventional manner, security needs can be met only by having underground reserves of petroleum, proved and semiproved, that are large enough to support a rapidly expanded and sustained high rate of crude output in the event of war.

As the years go by, the normal reserves on which the oil industry bases peacetime production may prove less and less adequate for security purposes. The ratio of output to reserves, although satisfactory in ordinary years may lack sufficient flexibility to permit a large and sustained increase in withdrawals during an emergency.

Even in peacetime, it is necessary in order to maintain a balanced flow of oil, for the industry to match withdrawals with at least equivalent additions to reserves, and this calls for continued high level of exploration and development. The manpower, materials, and equipment needed to support such effort in wartime are a heavy drain on a tight economy. Moreover, there is no guarantee that the use of those resources will provide the oil that is needed.

These circumstances must be kept in mind in looking for solutions to the problem of a security reserve of petroleum.

In theory, at least, the problem could be eased by making extra efforts to find additional reserves prior to any emergency need and then "sterilizing" them, to be tapped only in the event of a national emergency.

Alternatively, the same result might be achieved if industry's working reserves were expanded and then maintained at abnormally high levels relative to production, thus shifting the ratio of output to reserves. Instead of the usual ratio of 1 to 12 or 13, reserves of 16 to 18 times production might be maintained, with the surplus left unsterilized but available for stepped up withdrawal should the need arise.

An example of the first approach is the Navy's petroleum reserve at Elk Hills, Calif., where crude oil cannot be produced in quantity unless the Secretary of the Navy certifies to the President that an emergency exists and both Houses of Congress pass a resolution authorizing such production. These reserves, which looked big when they were set aside many years ago, are small in the light of today's needs. During the Second World War, peak production on naval reserve lands was less than 1 percent of the national total, and such reserves in 1952 were 2 percent of all proved reserves in the United States. Thus, the Government's security reserves of oil would have to be greatly enlarged to be of any real consequence for the future.

This approach has the evident attraction of guaranteeing that the oil would be there if and when it is needed for an emergency, but it also has many practical drawbacks. If the Government sought to build up and set aside large reserves of oil for possible war use, this would involve a prolonged and costly process of buying up private rights to established pools and could prove disruptive to the normal operations of the industry. Possibly a simpler course would be to set aside large portions of the oil lands underlying the Continental Shelf, which is still largely undeveloped but which is believed to contain vast amounts of oil. In either case, pools would have to be sufficiently drilled to determine their size and structure and to insure that they could be put to relatively prompt use in the event of war. Drilling and capping wells, and maintaining them in a state of readiness, is expensive and in the case of the Continental Shelf the cost might well prove prohibitive, even if present technical obstacles could be overcome. Beyond this, the "sterilized reserve" approach might involve additional heavy costs to provide standby refining and transportation facilities in the area so that the reserves could in fact be used if needed.

These various difficulties could be avoided if private industry, in the course of its normal operations, were permitted to develop the same reserves but were encouraged or required, as the situation warranted, to maintain a stronger reserve position relative to production than is average custom today. Annual crude production in the United States is averaging 7 to 8 percent of proved reserves, leaving little room for a large and sustained increase of output, but it is noteworthy that private companies are finding it profitable to operate some of the newer and larger pools at rates as low as 3 or 4 percent. If reserves could be expanded more rapidly than output in the next decade so that the national average rate of extraction were lowered to say, 5 percent of proved reserves, then there would be great flexibility to expand output from known reserves in time of emergency. In view of recent experience, this might well be accomplished without altering seriously the normal economics of the industry.

The most attractive opportunity for approaching the security problem in this way is provided by the Continental Shelf. If private industry were permitted and encouraged to develop these large underwater oil resources and to overcome the technical difficulties involved, but in such a way as to keep the withdrawals at a rate that could be stepped up with reasonable speed in time of emergency, the Nation's security position in oil would be greatly strengthened. This could be accomplished by leasing arrangements (either by the Federal Government or, if a portion of the rights are awarded to adjacent States, then by State governments) that would specify spacing of wells and rates of withdrawal, coupled with royalty charges sufficiently low to provide adequate incentive.

Some of the geologists consulted by the Commission expressed the belief that, even under normal conditions, the industry will find it most economical to produce oil in the Continental Shelf at a lower rate than the current average elsewhere; thus the leasing arrangements indicated above might not require any substantial change from what private industry would prefer to do in any event.

The same logic applies to all petroleum pools in the United States, particularly the newer ones and those yet to be found. Administrators of Federal oil lands should keep this goal in the forefront of their operations, and State regulatory agencies, which have jurisdiction over the bulk of production, can make a great contribution to national security by seeking the same objective.

The main challenge to industry and Government alike is to find ways of achieving a sufficiently rapid expansion of reserves to make possible a ratio between output and reserves compatible with both rising national production and a healthy oil industry. Any reasonable measure for encouraging similar results in the other oil-producing nations of the Western Hemisphere would contribute much to the security of the free world.

SHALE AND SYNTHETICS

Another basis for meeting the security problem is the tremendous potentiality of liquid fuels production from shale and possibly from coal and lignite. Constant improvements in cost-reducing technologies may make it possible to expand synthetic production of liquid fuels from these sources on an economic basis and thus ease the security problem.

Because of uncertainties as to the future volume of domestic crude petroleum production, the question arises as to whether the Government should accelerate development of synthetic liquid fuels so that they will be available in substantial quantities if the Nation has to rely upon them. Some private companies are reported to be prepared to construct small-scale commercial plants for production of oil from shale in Colorado if the extra cost of transporting the oil to the nearest refining and marketing area could be met by the Government. This appears to be a promising possibility for acquiring the technical knowledge that would be needed for a rapid expansion of synthetic production in the event of an emergency.

EXPLORATION

The prospects for future production of crude oil in the United States depend primarily on the rate of exploration and its success. In the past the rate of exploration has been responsive to market conditions. Furthermore, discoveries have largely been proportional to the rate of exploration with such year to year variability as is to be expected from the uncertainties inherent in wildcatting.

The principal influence of public policy to date upon the rate of exploration for crude oil, beyond the provision of the general legal and social framework in which the free enterprise of the wildcatter can flourish, is to be found in the tax system. In particular, the provisions permitting the expensing of the intangible costs of drilling and the charging of depletion as a percentage of the value of oil produced and sold have acted as powerful stimulants to exploration. If these provisions were removed, wildcatting activities would be sharply reduced with two possible results. Either domestic petroleum prices would eventually rise in response to reduced production, tending to restore the incentive to exploration, or more probably under present circumstances, imports would increase.

These tax provisions are discussed in volume I as they apply to the entire minerals industry. The conclusions there reached are in particular applicable to petroleum. It was there recommended that percentage depletion be retained because of its strong inducement to risk capital to enter the minerals industries fields but that the rates now provided in the Internal Revenue Code be raised no further. It was also suggested that there is one notable exception to this conclusion—exploration and development costs for minerals should be fully expensible for tax purposes because of the direct incentive this arrangement gives for capital to take risks in highly uncertain fields. Such expensing would be likely to be particularly important for the petroleum industry whose annual exploration and development costs are measured in billions of dollars.

CONSERVATION IN PRODUCTION

There has been a great deal of controversy over oil conservation, rising largely from two different concepts of waste. One, the absolute concept, regards it as wasteful if any recoverable oil is lost; the other, the economic concept, regards it as wasteful only to lose oil that could be saved at a cost less than the value of oil. The economic concept need not stop with waste of oil. If, for example, steel and human effort are wasted in drilling unnecessary wells, that is as much a matter of public concern as is improper extraction that leaves too much oil behind. Fundamentally, the economic concept of conservation boils down to efficientcy of operation and the avoidance of waste of materials and human effort, as well as oil resources.

As viewed today, past history furnishes examples of waste on a grand scale in the production of oil. In the early days of the industry wells were run wide open, frequently leading to tremendous losses above ground from fire and evaporation and below ground from impairment of the producing capacity of the oil pools, with ultimate recovery far below the amount that could be recovered under the best modern operating practice. Very little was known of the nature of oil deposits and much waste resulted from that ignorance. Furthermore, under the law of the doctrine of capture, the oil from beneath the land of many owners became the property of the one first able to reduce it to his own possession. Consequently the prize went to the one who produced the most oil the fastest irrespective of the damage that might be done to the pool as a producing unit.

The resulting wide-open flow had little relation to market demand, so that when great new discoveries were made a disruption of the market followed, the oil sometimes selling at fantastically low prices. Measures came to be adopted in the early thirties in the oil-producing States that have since established orderly methods of regulation of oil production. These measures, and the authorities which enforce them, have made notable contributions to economic conservation in the production of crude oil, and, more recently, of natural gas and condensate. Progress has been gradual, however, against a great deal of opposition based partly on misunderstanding, but more fundamentally on the conflict with the interests of individual leaseholders or royalty owners who felt that they could do better without regulations, even though all producers as a group were better off for the regulations. The doctrine is now firmly established that the State governments have the power of making and enforcing regulations designed to avoid waste and to protect correlative rights in the production of petroleum and natural gas.

The principal measure of regulation has been the device of prorationing, exercised by State authorities in most of the important oil-producing States. The mode of operation consists in setting a limit on total production of oil in each State and an allocation of allowable production among the individual wells or producing units. As the system operates at present the limits set by prorationing are geared to estimates of market demand made by the individual State authorities, usually consistent with the U. S. Bureau of Mines estimates. The Federal Government cooperates closely with the State regulatory authorities not only through the activities of the Bureau of Mines in estimating demand, but also through legislation (the Connally Act) that excludes from interstate commerce oil produced in contravention of the regulations of the State authorities.

The first achievement of State regulation of petroleum production was essentially that of adjusting output to market demand through prorationing, thereby bringing greater market stability. The conservational consequences came largely from the fact that some limitation on production per well, and perhaps more important, regulated uniformity of production among wells, does lead to a better preservation of the productive capacity of the oil reservoirs. Gradually the State authorities have extended the scope of their regulations. Limitations on the oil-gas ratio have been imposed to reduce the waste of natural gas and to prevent excessive impairment of the gas pressure. Similar regulations have been imposed to preserve the driving force of underground water pressure. It has been estimated that perhaps 50 percent more oil has been recovered during the last 20 years than would have been recovered in the absence of state regulation.* The State authorities have cooperated in seeking methods of avoiding waste through the Interstate Oil Compact Commission.

One other major form of waste—the drilling of too many wells—has been slower to feel the impact of State regulation; in some measure prorationing, as it was applied, actually gave incentive to excessive drilling by setting production quotas somewhat in proportion to the number of wells. In the most important producing States, however, the regulating authorities now have the power, within limits, to govern the spacing of wells, and so to reduce excessive drilling.

Little progress has so far been made in achieving a unified program of operations for each oil reservoir best fitted to the particular characteristics of that reservoir. An oil pool is a complex structure with ultimate recovery depending upon how skillfully advantage is taken of the particular shape and structure of the pool, and of its gas and water pressures. In the absence of a unified operation program it is likely that wells tapping pools with multiple ownership will be located improperly for maximum efficiency of development, even where regulation provides for minimum spacing.

The principal obstacle to a unified operation is the inevitable holdout, the leaseholder or royalty owner who thinks he can do better without the unit operation, even though the pool as a whole will do much better with unit operation. In some States unit operation can be made compulsory for a pool under certain conditions, usually if owners of a specified majority of the acreage agree, but such agreement has been so difficult to achieve that very few common sources of supply have so far been subjected to unit operations, except where special conditions make unit operations imperative as in condensate reservoirs or in secondary recovery. Petroleum engineers have largely demonstrated the benefits of unit operation. It is up to the lawmakers and industry leaders to devise arrangements for achieving unified operating programs with proper respect for the rights of each leaseholder to his fair share. The problem, although difficult, does not appear insoluble.

All in all, though considerable progress has been made over the past 15 years toward greater conservation of oil resources, much room remains for further progress.

CONSERVATION IN USE

There are likewise large opportunities for conservation in use of oil, especially in the design of passenger automobiles and in their operation. There is no doubt that the estimated 680 billion passenger miles of automobile travel in the United States in 1950 could have been achieved at a lower expenditure of gasoline than the 24 billion gallons actually used. If, for example, passengers rode three or four to a car in cars averaging 25 to 30 miles to the gallon, only 7 to 9 billion gallons would have been required.

The American public is willing to pay added costs for the comfort of large cars and for the pleasure of what is popularly referred to as automobile "performance"—power to accelerate rapidly, to maintain high speeds, and to climb hills in high gear.

The additional possibilities of improving mileage per gallon without using smaller cars or less powerful engines are rather limited, in spite of the dramatic fact that the automobile utilizes only 6 percent of the energy put into the gas tank. The theoretical efficiency of an automobile engine at full load is about 25 percent. The average fuel utilization efficiency of the American motor car is so low relative to the best attainable largely because it operates most of the time under a low load. The average automobile is probably capable of carrying five or six persons at steady high speeds, yet it is estimated that in 1950 the driver rode alone in more than half of the private car trips while in less than a fifth of the trips did he have two or more passengers with him.

There are three principal methods of improving the efficiency of the automobile by change of design without sacrificing comfort or performance: increasing the compression ratio, supercharging, and use of an overdrive or an automatic transmission designed for maximum efficiency. The efficiency gained from an increased compression ratio is, however, at least in part illusory because a great deal of energy is lost at the refinery in making the high-octane gasoline that must be used. Supercharging designed to increase economy presents difficult engineering problems. The biggest scope for improvement therefore probably lies in greater use of the overdrive or of an automatic transmission. It has been estimated that a combina-

*Robert E. Hardwicke, "Adequacy of Our Mineral Fuels," *Annals of the American Academy of Political and Social Science*, May 1952.

tion of high compression ratio and fully automatic transmission or suitable overdrive might double automotive efficiency from the usual 15 or 20 miles per gallon to 30 or 40, without any loss in performance characteristics.

The average utilization efficiency, with allowance for the greater work done in moving a given distance at high speed, can also be increased by giving the private automobile the kind of highways and streets on which it can operate at its maximum efficiency. That means the construction of city express highways along which cars could run at 40 or 50 miles an hour with a minimum of stops, and cross-country highways on which even higher speeds can be safely maintained. Much greater gains are likely to be achieved in the United States from further development and improvement of the street and highway system than from fuel economies derived from improved designs of cars and engines.

CONSERVATION ON FEDERAL OIL LANDS

Production of crude oil from federally controlled lands in recent years has run about 6 percent of total production in the United States. Proven reserves on these lands constitute about 9 percent of those of the entire country.

Production from such lands is likely to increase, particularly if the submerged oil lands of the Continental Shelf remain under Federal control. Recent Supreme Court decisions have confirmed Federal rights to the submerged lands adjoining the States, but legislation is currently being considered to transfer some of these rights to the States. In either event the opportunity should not be lost for insuring that this great potential source of petroleum be developed in a manner consistent with efficient productive practices and with the needs of security.

At present, federally controlled oil lands are leased under terms that permit Federal authorities to require adoption of efficient operating practices, within the general context of State regulation and private ownership of other parts of fields in which the federally controlled oil lands are located. About 50 percent of the production from federally controlled lands comes from fields with unit operation. In many cases the federally owned lands constitute only part of the fields in which they are located, so that their operation must be conducted in a manner not greatly different from that of neighboring holdings, governed largely by the regulatory policies of the States. Departures from technically desirable operating conditions are often necessary in order to avoid drainage by neighboring leaseholders, or for other reasons associated with the absence of unit operations.

The major responsibility for the regulation of operations in fields only partly federally controlled must remain with the State authorities, with the Geological Survey continuing to require Federal lessees to follow the best practices consistent with the operations on neighboring tracts. Unit operation can be required in fields that are entirely publicly owned. It should be possible to maintain reserves at those fields at the highest level commercially feasible relative to annual production.

IMPORTS AND TARIFFS

The energy economy of the United States has prospered on the basis of using the cheapest available fuels and can prosper most in the future if our import policy continues to permit oil consumers to have access to the lowest cost sources consistent with security. Geological and economic conditions throughout the world favor an increasing reliance on imports to meet a considerable part of the future growth of United States consumption, even though United States production of oil can also be expected to continue to grow. Consumption is expected to increase more rapidly than production, so as to leave room both for increasing imports and a healthy domestic petroleum industry.

The present excise tax on imports of crude oil and fuel oil stands at 21 cents a barrel for all imports over a quota, which in each year is equal to 5 percent of the previous year's run of crude to refineries in the United States. Other refined products are taxed at a comparable level, except for gasoline and lubricating oils, which are taxed at prohibitive levels.

It is clearly to the interest of the United States and the rest of the free world to develop the oil production capacity of the Western Hemisphere. In view of this fact and of the general desirability of reducing trade barriers throughout the free world, the tariff on crude oil should eventually be abolished.

In the short run, however, the problem involves many complicated questions affecting broader foreign diplomatic, economic, and trade policies. Within that larger framework considerations other than those that are the special concern of this Commission must largely govern the tariff policy. Nonetheless, heavy weight should at all times be given to the importance of demonstrating, clearly and consistently, to oil exporting nations our basic long-run policy of encouraging foreign oil development and imports to the United States, to the fullest extent consistent with security.

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Chapter 2 Natural Gas

THE SITUATION IN BRIEF

THE CONSUMPTION of natural gas in the United States has been rising dramatically since the twenties. More than five times as much was marketed in 1950 as in 1925, and the increase in consumption in 1951 was the largest in history. Natural gas now supplies more than 18 percent of the energy used in the United States as compared with 4 percent of a much smaller total energy use in 1920. This impressive growth was based on great new supplies of natural gas that have become available largely through discoveries resulting from the extensive search for oil. In the past two decades there has been a rapid development of gathering and transporting facilities to carry these supplies to markets. Extensive markets have been developed near the source of production where gas prices have been far below those of competitive fuels for the energy contained, while in more distant markets consumption has been stimulated both by the superiority of natural gas in specialized uses and by favorable prices.

There is no doubt that a potential market exists for all the natural gas that can be produced, transported, and distributed in the United States, so long as it is offered at prices more favorable than for other fuels for the energy contained. The future position of natural gas in the energy economy therefore depends on how much more of that fuel is discovered and how efficiently the Nation recovers and uses that which is found.

Natural gas is subject to greater regulation than its principal competitors, coal and fuel oil. Its distribution is regulated by State public utility commissions in a manner similar to the regulation of electric power, its interstate transportation by the Federal Power Commission somewhat after the same pattern, and its production by the State authorities who regulate petroleum production. Many problems arise from the different aims and methods of these regulatory agencies, as well as from the fact that regulated natural gas competes with unregulated fuels.

There are four important challenges to our natural gas economy:

a) To stimulate maximum economic discovery of natural gas resources.

b) To avoid waste in the production of natural gas and to insure that full advantage is taken of the driving force of natural gas in lifting oil in order to get maximum economic recovery of the oil and gas.

c) To improve the pattern of use so that relatively more gas goes to those uses in which it has a special advantage, and relatively less to those that could be served just as well by other fuels.

d) To lay the basis for an orderly transition to other fuels at that distance but inevitable date when natural gas production falls off.

New discoveries of natural gas largely depend on the extent of exploration for oil, although exploration for gas itself is also becoming important. Present oil and gas prices and tax provisions are favorable to exploration, and for many years gross additions to proved reserves of natural gas have been running about twice as large as production.

Regulation by State authorities of the conditions of production has helped to reduce the percentage of gas wasted in the field and to increase the effective use of the driving force of gas in lifting petroleum. Much room for improvement remains, however. The standards adopted vary considerably from State to State, and there is need for the adoption of higher standards and the improvement of operating practices.

Much also remains to be done in improving the pattern of use so that, over time, greater economic benefits will be derived by the Nation from its natural gas resources. As distribution, processing, storage, gathering, and transportation facilities are developed, market forces can be expected to bring a steady improvement in directing gas to those uses and those markets that can be served by natural gas to the greatest economic advantage. The natural gas industry should have ample incentive to improve the pattern of use in this manner, since the special advantage uses can afford to pay a higher price. State and Federal policy must join with private enterprise in encouraging a rapid adjustment of the production and consumption patterns of natural gas.

Sooner or later, and probably before the end of the century, the meteoric natural gas industry will pass its peak. It is not now and may never be possible to supplement domestic supplies with large imports, though at least modest imports from Western Canada to the Pacific Northwest seem assured and conceivably it may later become economical to import natural gas from Mexico. Nor is there yet developed a substitute gaseous fuel, as there is a substitute liquid fuel, derived economically from abundant solid fuel reserves. Gas manufactured from coal with presently known techniques is far too expensive. Some thought must now be given to the prospect of ultimate exhaustion of natural gas resources in guiding the present development of the industry, as well as to the encouragement of research on the economical production of substitutes from coal or of research into other energy sources such as solar energy to replace gas when the time comes.

USE AND SUPPLY OF NATURAL GAS

Gas is a perfect fuel for stationary heat and power installations. It offers maximum cleanliness, produces no residual waste products, requires the simplest equipment for burning, and requires no storage equipment on the premises of the con-

TABLE I.—*Production of natural gas in the United States, 1935–50*

[Billions of cubic feet]

Year	Estimated gross production [1]			Repressuring	Estimated net production	Losses and waste [2]	Marketed production [3]
	From gas wells	From oil wells	Total				
1935	1, 493	1, 005	2, 498	90	2, 408	439	1, 969
1936	1, 484	1, 161	2, 645	74	2, 571	346	2, 225
1937	1, 614	1, 326	2, 940	85	2, 854	381	2, 473
1938	1, 567	1, 494	3, 061	102	2, 960	601	2, 358
1939	1, 833	1, 501	3, 334	171	3, 162	624	2, 538
1940	2, 095	1, 599	3, 694	353	3, 331	597	2, 734
1941	2, 491	1, 613	4, 104	644	3, 459	566	2, 894
1942	2, 885	1, 569	4, 454	753	3, 701	556	3, 146
1943	3, 227	1, 934	5, 161	825	4, 336	820	3, 516
1944	3, 650	1, 964	5, 614	883	4, 731	916	3, 815
1945	3, 888	2, 014	5, 902	1, 062	4, 840	798	4, 042
1946	3, 807	2, 383	6, 190	1, 038	5, 152	999	4, 153
1947	3, 770	2, 963	6, 733	1, 083	5, 650	1, 068	4, 582
1948	4, 589	2, 590	7, 179	1, 221	5, 958	810	5, 148
1949	4, 986	2, 561	7, 547	1, 273	6, 274	854	5, 420
1950	5, 603	2, 876	8, 480	1, 397	7, 083	801	6, 282

1 Marketed production plus quantities returned to ground, plus losses and waste.
2 Partly estimated. Includes direct waste on producing properties and residue blown to the air.
3 Includes consumption, exports, and net change in underground storage.

SOURCES: U. S. Department of the Interior, Bureau of Mines, *Minerals Yearbook*, various years; also reported in American Gas Association, *Gas Facts*, 1950 edition, p. 46.

TABLE II.—*Disposition of marketed production of natural gas in the United States, 1935–50*

[Billions of cubic feet]

Year	Marketed production [1]	Industrial use: Field use	Industrial use: Other industrial use	Industrial use: Total	Residential use	Commercial use	Lost in transmission	Net change in underground storage	Exports
1935	1, 969	580	916	1, 496	314	100	41	11	7
1936	2, 225	619	1, 086	1, 705	343	112	47	11	7
1937	2, 473	651	1, 262	1, 913	372	117	52	14	5
1938	2, 358	659	1, 153	1, 812	368	116	48	15	2
1939	2, 538	681	1, 283	1, 964	391	119	54	8	3
1940	2, 734	712	1, 365	2, 077	444	134	59	15	6
1941	2, 894	686	1, 531	2, 217	442	145	65	16	8
1942	3, 146	721	1, 643	2, 364	498	184	71	21	9
1943	3, 516	781	1, 889	2, 670	529	205	82	19	11
1944	3, 815	855	2, 059	2, 914	562	221	94	10	15
1945	4, 042	917	2, 145	3, 062	607	230	98	25	18
1946	4, 153	898	2, 213	3, 111	661	242	103	19	18
1947	4, 582	934	2, 405	3, 339	802	285	128	9	18
1948	5, 148	1, 022	2, 704	3, 726	896	323	127	57	19
1949	5, 420	1, 060	2, 795	3, 855	993	348	138	66	20
1950	6, 282	1, 187	3, 253	4, 440	1, 198	388	171	59	26

[1] Includes consumption, exports, and net change in underground storage.

SOURCE: U. S. Department of the Interior, Bureau of Mines, *Minerals Yearbook*, various years; also reported in American Gas Association, *Gas Facts*, 1950 edition, p. 46.

sumer. The flow characteristics of gas make it particularly amenable to automatic operation and control, and to flexible use. It has zero warm-up and burn-down periods. Exact temperatures can be attained and maintained with little effort. It is also an excellent raw material for the chemicals industry.

Whenever oil is found some gas is found along with it dissolved in the oil. Some additional free ("associated") gas also is frequently found in contact with the oil. In both cases the pressure of the gas provides a driving force that causes the oil to flow, or shares this function with a water drive. The dissolved gas also improves the flow characteristics of the oil. In earlier years the main economic function of the gas was to "drive" the petroleum to the surface, after which it was vented to the air and burned. For years a heavy surplus of gas existed in source areas, particularly the Southwest, while a large potential demand remained unsatisfied in distant market areas—a paradox that reflected the difficulty of transporting gas. Vast quantities were physically wasted.

Gradually, substantial local use began to be made of surplus gas from oil fields. Industries that needed large quantities of cheap fuel gravitated toward the gas fields. Great technical progress was made in returning gas to the ground to "repressure" oil pools, thereby both increasing the low-cost recovery of oil and conserving gas for later consumption. Finally, and of greatest importance, the industry since the 1930's has rapidly increased its gathering lines and its long distance pipelines—a combination that has opened up tremendous markets over a large portion of the United States.

In 1950 about one-third of the gross production of natural gas came from oil wells, and two-thirds from gas wells. Production from gas wells is closely tied in with the oil industry, however, because most of them are in fields discovered in the process of looking for oil. At present about 4.6 thousand cubic feet (M cu. ft.) of economically recoverable natural gas is being discovered per barrel of recoverable petroleum, but the ratio is expected to rise as a result both of deeper drilling for oil and of exploration for gas by itself. As a rough rule of thumb it has been estimated that for every barrel of recoverable oil discovered in the United States in the future there will be discovered about 6 M cu. ft. of recoverable natural gas. The energy content of 6 M cu. ft. of natural gas is approximately equal to that of a barrel of oil, so that future oil and gas discoveries in the United States are likely to be approximately equal in terms of recoverable energy contained. Consequently, in the long run we may expect the share of natural gas in total energy produced to approach that of crude petroleum from domestic sources.

The production of natural gas, like that of petroleum, is highly concentrated in the Southwest. Texas is the leading producer, accounting in 1950 for about 52 percent of the country's gross production. Louisiana is next with about 13 percent, followed by California and Oklahoma at 9 percent and 8 percent, respectively. The Appalachian field (Pennsylvania, West Virginia, Ohio, Kentucky, and New York), which provided about 70 percent of national production in the decade before the First World War and still produces about as much as it did then, now accounts for less than 6 percent of national production and has a little more than 2 percent of proved reserves.

The production and disposition of natural gas in the United States for the years 1935 to 1950 are shown in tables I and II. The estimated gross production in 1950 was about 8.5 trillion cubic feet. This is the total gas reported as having been withdrawn from the ground. It includes some of the gas vented to the air, where that has been estimated, but does not include all such vented gas, whose production is frequently not reported. Of this 8.5 trillion cubic feet, about 1.4 trillion was returned to the ground for future withdrawal and in order to maintain pressure to facilitate future recovery of petroleum or natural gas liquids. About 0.8 trillion was reported as loss and waste before marketing, leaving 6.3 trillion as marketed production.

As shown in table II, about 70 percent of 1950 marketed production went into industrial uses—almost 20 percent into field uses and more than 50 percent into other industrial uses. Residential and commercial consumption absorbed about 25 percent of marketed production, while the remainder (about 4 percent) was accounted for by transmission losses, net additions to underground storage, and exports.

Field uses include power for drilling, and raw material and fuel for plants that extract gasoline and other liquid products from the gas. In this last use only the difference between the gas taken into such plants and the gas returned to the line after removal of liquid products is counted, since the returned "stripped" gas can be consumed elsewhere.

In nonfield industrial uses the largest consumers are electric power generating plants, oil refineries, and carbon black plants, in that order. These three activities in 1950 consumed almost half the natural gas used industrially outside of field uses. The most important remaining industrial consumption is in the metal industries. (See table III.)

Well over half of the gas marketed is consumed in the general area in which it is produced. Texas, California, and Louisiana consume more than half the gas used throughout the country. In 1950, 2.5 trillion cubic feet (about 40 percent of net marketed production) went into interstate shipments, as compared with 0.2 trillion, or 17 percent in 1925. About 75 percent of the gas moving across State lines originated in Texas, Louisiana, and Oklahoma. The principal net importing markets in 1949 were Illinois, Ohio, and Pennsylvania, though since then the pipelines have been extended to New York, New Jersey, and New England.

GAS IS CHEAP ENERGY

The current average price of natural gas in the field is much lower, for the energy contained, than that of crude petroleum. A barrel of petroleum sells at the wellhead in Texas or Louisiana for about $2.65 on the average, while its thermal equivalent in natural gas sells on the average for about 30 cents in the same producing regions. (See table IV.) That average price of 5 cents per M cu. ft. largely refers to gas sold at old contracts at low prices; contracts are currently being made in Texas and Louisiana at double or more the price in old contracts. Provision is often made for later price rises, typically at the rate of 1 cent for each subsequent 5-year period. Field prices are, of course, higher at fields that are closer to markets. For example, the average 1950 prices at the well were about 12 cents in California, 19 cents in Ohio, and 25 cents in Pennsylvania.

For those customers who can purchase and use the natural gas at or near the Southwest fields the low prices represent tremendous bargains. For the large industrial energy users the relevant comparison is between the price of residual fuel oil, about $1.75 at a Texas refinery, and the cost of equivalent energy in natural gas at 30 to 36 cents on old contracts, or 60 to 70 cents on new contracts.

TABLE III.—*Industrial consumption of natural gas in the United States, by type of industry, 1932–50*

[Billions of cubic feet]

Year	Total	Field use	Carbon black plants	Petroleum refineries	Portland cement plants	Electric public utility power plants [1]	Other industrial	Selected industries [2]					
								Food and kindred products	Paper and allied products	Chemical and allied products [3]	Primary metal industries	Glass	Clay and similar products
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1932	1,168	529	168	67	21	107	275	...	...	...	...	...	...
1933	1,185	491	190	66	22	103	312	...	...	...	...	...	...
1934	1,385	555	230	80	27	128	366	...	...	...	...	...	...
1935	1,496	580	242	80	27	125	442	...	...	...	...	...	...
1936	1,705	619	283	93	37	156	517	...	...	...	...	...	...
1937	1,913	651	341	113	40	171	597	...	...	...	...	...	...
1938	1,812	659	325	110	37	170	511	...	...	...	...	...	...
1939	1,964	681	347	98	40	191	607	80	33	55	149	64	45
1940	2,077	712	369	128	42	183	643	...	...	...	...	...	...
1941	2,217	686	365	148	54	205	759	...	...	...	...	...	...
1942	2,364	721	336	202	65	239	801	...	...	...	...	...	...
1943	2,670	781	315	244	52	306	972	...	...	...	...	...	...
1944	2,914	855	356	315	36	360	992	...	...	...	...	...	...
1945	3,062	917	432	338	38	26	1,011	...	...	...	...	...	...
1946	3,111	898	478	332	58	307	1,038	...	...	...	...	...	...
1947	3,339	934	485	364	60	373	1,123	109	69	154	168	87	74
1948	3,726	1,022	481	441	72	478	1,232	...	...	...	...	...	...
1949	3,855	1,060	428	422	85	550	1,311	...	...	...	...	...	...
1950	4,440	1,187	411	455	97	629	1,661	...	...	...	...	...	...

[1] Includes small quantities of manufactured gas, believed to be negligible.
[2] These data available only from the Census of Manufactures for 1939 and 1947; amounts are included in "other industrial."
[3] Excludes carbon black.

SOURCES: U. S. Department of the Interior, Bureau of Mines, various publications; U. S. Department of Commerce, Bureau of the Census, Census of Manufactures, 1939 and 1947.

TABLE IV.—*Average value of natural gas at the wells and at points of consumption in 1950, by States*

[Cents per thousand cubic feet]

State	Average value at wells	Average value at points of consumption			
		Field	Industrial	Commercial	Residential
Alabama	5.0	....	18.0	51.9	80.9
Arizona	....	....	20.3	35.4	84.6
Arkansas	3.5	6.0	9.0	37.0	50.5
California	11.9	12.2	22.1	41.4	66.4
Colorado	6.2	6.2	15.3	48.6	57.4
Georgia	....	....	18.4	37.9	67.0
Illinois	10.1	7.8	24.1	65.2	97.6
Indiana	7.0	7.1	33.7	90.5	110.6
Iowa	....	....	19.9	54.6	68.8
Kansas	6.6	7.0	13.3	32.7	48.1
Kentucky	19.7	19.6	25.2	48.0	56.4
Louisiana	5.3	5.2	9.7	30.2	60.2
Maryland	19.8	20.0	74.0	133.3	140.0
Michigan	13.2	14.3	50.3	77.2	85.4
Minnesota	....	....	22.0	48.5	72.3
Mississippi	6.3	8.2	12.9	40.4	70.3
Missouri	14.3	16.3	20.3	46.1	69.9
Montana	5.3	9.6	15.0	32.8	47.3
Nebraska	12.4	9.1	18.7	41.3	66.2
New Mexico	3.0	3.4	8.3	33.3	66.0
New York	25.1	21.9	60.1	80.6	88.7
Ohio	19.4	20.9	39.8	56.2	60.4
Oklahoma	4.9	4.4	11.6	31.3	45.4
Pennsylvania	25.3	28.9	36.0	53.0	62.1
Tennessee	10.0	....	17.9	56.9	72.7
Texas	4.7	4.7	7.6	38.9	63.1
West Virginia	16.8	19.9	27.2	37.4	40.7
Wisconsin	....	....	71.2	130.6	156.1
Wyoming	6.0	6.2	14.0	36.7	51.0
Other States [1]	5.9	4.3	22.5	70.8	86.2
Total	6.5	6.2	16.0	47.4	68.5

[1] Includes Delaware, District of Columbia, Florida, New Jersey, North Dakota, South Dakota, Utah, and Virginia.

SOURCE: Bureau of Mines, *Mineral Market Report* No. MMS 2027.

Because costs of transportation and distribution of natural gas are higher than those for petroleum and petroleum products, the price advantage of natural gas tends to be reduced the farther one goes from the areas of production. Nevertheless, natural gas is now selling in many markets, even at great distances from the principal fields, at a substantially lower price energywise than competitive fuels for industrial use, and either cheaper or at roughly a competitive price for domestic and commercial uses. In the latter uses the inherent superiority of natural gas supports in some markets a premium price for natural gas over its nearest competitor, furnace oil.

The present structure of prices in the natural gas industry cannot be easily described because the rapid changes in the industry have led to a set of price relationships that reflect conditions of different times and so does not present a uniform picture. The general price relationships may, however, be illustrated by some of the operations of one transportation and distribution system in 1950. Gas was purchased at the field in Texas and Louisiana at an average price close to 5 cents per M cu. ft. and was sold to main-line industrial customers or to gas distributing utilities in Ohio, about a thousand miles from the source of supply, for about 19 to 21 cents per M cu. ft. The utilities resold the gas to their industrial customers at the average price of 42 cents and to residential customers at the average price of 54 cents. At these average prices the main-line Ohio customers were getting gas at considerably less than half the cost of equivalent energy in the form of heavy fuel oil. The industrial customers of the utilities were buying energy about 30 percent cheaper than if they had bought residual fuel oil at tank-wagon prices, and the residential consumers about 40 percent cheaper than if they had bought furnace oil. Of course, a new pipeline company buying all its gas at new contract prices of 10 or 11 cents per M cu. ft. would presumably have to charge correspondingly higher prices, though still well below the prices of competitive fuels within a thousand-mile radius.

The potential demand for natural gas at or near present prices to consumers far exceeds the amount currently being marketed. The construction of additional facilities for transportation and distribution will help meet some of the unsatisfied potential demand, but the excess demand will eventually have to be squeezed out either by company or governmental allocation or by such increases of price at points of consumption as will make the energy costs of natural gas comparable in competing uses with the cost of other fuels, with allowance for differences in convenience of use.

The pattern of consumption is complicated by the fact that residential and other heating loads are so different in winter and summer. Gas pipeline and distributing companies, which must have sufficient capacity to meet winter peaks in northern markets, have excess capacity in summer. Furthermore, gas that is produced in the field on a year-round basis in conjunction with petroleum must be sold. Gas suppliers therefore try, in nonheating periods, to keep up the volume of sales by making "off-peak," "interruptible," or "dump" sales to large-scale industrial customers at whatever rate is necessary to meet the prices of competing fuels, particularly residual fuel oil and coal. This enables the gas transporter both to dispose of gas which he is obliged to take delivery on under firm contracts and to improve his "load factor," thereby adding revenue from his off-peak sales as an additional source of income.

An additional complicating factor arises from the desirability of building pipeline capacity large enough to serve the markets that can be expected to develop only gradually after the gas is available. While waiting for the regular market to develop, the pipeline companies can meet some of the costs of the extra capacity by using it to transport gas for sale at low prices to large industrial customers. These customers can be gradually displaced as the demand of higher-paying consumers grows.

While this system of off-peak and capacity-carrying sales is clearly economically advantageous to both supplier and purchaser, it does result in a large consumption of gas for purposes that could be met equally well by coal or residual fuel oil.

THE FUTURE OF NATURAL GAS

The same uncertainties that cloud the long-run future of petroleum supply from domestic sources in the United States also affect estimates of future supplies of natural gas. Proved economically recoverable reserves of natural gas at the end of 1950 were 186 trillion cubic feet, or about 26 times the 1950 net production of 7.1 trillion cubic feet.

Few estimates have even been attempted of the total amount of "economically recoverable" natural gas that can be expected to be discovered in the future. The only well-known projection so far published indicates that 510 trillion cubic feet, including reserves already proved, may remain to be produced in the future [*1*].

This estimate is closely linked to the estimate of ultimate potential petroleum reserves discussed in the chapter on oil. Both estimates are highly speculative. The prospects for future gas production, like those for oil, can more safely be evaluated on the basis of the relation of rates of discovery to rates of production than on estimates of ultimate potential. Natural gas discovery rates have been highly satisfactory relative to production over the recent past. New reserves proved from 1945 to 1951 have been more than twice as large as net production over the same period, as shown in table V. When new discoveries and developments run closer to annual production it may be taken as warning of an imminent slowdown of production.

TABLE V.—*Estimated new discoveries and developments relative to production of natural gas, United States*

[Billions of cubic feet]

Period	Estimated new discoveries and developments [1]	Production [2]	Ratio of new discoveries and developments to production
1918 and earlier	23, 296	8, 296	2. 8
1919–34	68, 062	21, 062	3. 2
1935–44	105, 013	33, 513	3. 1
1945–51	99, 531	42, 588	2. 3

[1] The sum of accumulated production and estimated reserves at the end of the period minus the corresponding sum at the beginning of the period. Reserve estimates at beginning and end of the periods before 1945–51 were of very poor comparability.

[2] Marketed production prior to 1934; net production for 1935 and later.

SOURCE: *World Oil*, Feb. 15, 1952, pp. 181, 186.

The important fact is the expectation that new discoveries will run about 6 M cu. ft. of recoverable gas per barrel of recoverable oil so that in the long run that relationship can be expected to hold in production. (See table VI.) If, then, the United States oil industry manages to produce over the distant future from 2 to 4 billion barrels of crude oil a year, there should be an annual rate of net gas production of 12 to 24 trillion cubic feet.

When oil discoveries taper off and decline, a roughly concurrent slowdown of natural gas production can be expected. While substantial imports of natural gas may eventually come in from Canada and Mexico, they are likely to be small relative to the total future United States demand.

The decline of natural gas production may come sooner if, as is possible, production should for a time outrun discoveries. Thus, even if long-run petroleum output settles down to 2½ billion barrels a year, natural gas production might in the meantime reach a peak of say 18 to 20 trillion cubic feet and then gradually decline to the long-term level of 15 trillion, later to fall off from that level as domestic petroleum production falls off from the 2½ billion barrel annual level.

THE FUTURE PATTERN OF PRICE AND USE

There are many uses (particularly household and commercial uses and in those industries where delicate automatic temperature control is important) in which natural gas has such considerable advantages over competitive fuels that it would be chosen even if its price were higher than the prices of other fuels. A distinction can accordingly be drawn between the special advantage uses for which natural gas would be preferred even at higher prices than competitive fuels, and the general uses for which it will be bought only if it is as cheap as, or cheaper than, competitive fuels.

It may be estimated from table III that special advantage uses absorb only about 40 percent of total marketed production, exclusive of field use. It is not possible to calculate the special advantage uses exactly, but they may be roughly placed as the sum of residential and commercial uses plus some fraction, say one-fourth, of the "other industrial" group of table III, or altogether about 2 trillion cubic feet in 1950. It may, therefore, be inferred that, as transportation and distribution facilities are constructed to permit the satisfaction of demand for additional special advantage uses, there will be room for the supply of these uses not only from the expansion of production but possibly also from displacement of general uses. The first step in the estimation of the future pattern of demand and consumption must then be to consider the possible extent of special advantage uses. The largest of these will be residential and commercial consumption.

In 1950 about 20 to 25 percent of all homes in the country were heated by gas. In view of the rapid spread of natural gas availability and the present rates of installation of gas-burning house heating equipment, it can reasonably be expected that by 1975 about half of the homes in the country will be heated by natural gas. That means 30 million heating customers, possibly consuming about 140 M cu. ft. each, or about 4.2 trillion cubic

TABLE VI.—*Marketed production of natural gas relative to crude oil production in the United States, exclusive of the Appalachian field* [1]

[Annual averages]

Period	Marketed production of natural gas		Production of crude oil (millions of barrels)	Ratio of natural gas to crude oil production (percent)
	Billions of cu. ft.	Millions of barrels crude oil equivalent [2]		
1906–10	108	18	70	13
1911–20	225	38	276	14
1921–30	945	158	740	21
1931–40	1, 728	288	1, 033	28
1941–45	2, 951	492	1, 503	33
1946–50 [3]	4, 680	780	1, 852	42
1951	7, 035	1, 173	2, 182	54
Expected eventual				[4] 90–95

[1] Kentucky, New York, Ohio, Pennsylvania, and West Virginia.

[2] On basis of 6,000 cubic feet of natural gas=1 barrel of crude oil.

[3] For 1947 and later years marketed production includes gas stored and lost in transmission.

[4] On the basis of 6,000 cubic feet of gas recovered per barrel of crude oil, and 90 to 95 percent of that marketed.

SOURCE: Natural Gas—*World Oil*, Feb. 15, 1952, p. 186. Crude Oil—*World Oil*, Feb. 15, 1952, p. 176–179, and American Petroleum Institute, release of March 12, 1952.

feet a year. Other nonindustrial special users, such as commercial establishments and households using gas for cooking and hot water but not for space heating, might add another trillion cubic feet of annual demand. (See vol. II, Projection of 1975 Materials Demand.)

Total residential and commercial demand may thus more than triple by 1975 to about 5 trillion cubic feet. A rough allowance might also be made of about a trillion cubic feet of future consumption for special advantage industrial use. How much will then go into general industrial uses will depend fundamentally on the available supplies, and more immediately on the price structure likely to result from the relation of those available supplies to future demand.

The different adjustments of the consumption pattern to various possible levels of supply are too complicated to present in detail, but a few hypothetical examples may serve broadly to illustrate how market forces would operate in the absence of regulation to the contrary. If 1975 net production should be no larger than that of 1951, natural gas would then be in short supply relative to increased demand. Waste and loss could probably be halved by more extensive collection systems to about half a trillion cubic feet, leaving a marketed production of 7½ trillion. Field use would quite possibly be as large as in 1950—say about a trillion cubic feet—leaving 6½ trillion for other uses. These could almost entirely be absorbed by special advantage uses, leaving almost all general energy uses to be satisfied by other fuels—presumably fuel oil and possibly lignite in the Southwest, and some combination of fuel oil and coal or its products in the rest of the country. Under these circumstances natural gas might sell at the Southwest fields at a price, for the energy contained, above that of residual fuel oil at the refineries in that area.

With supplies larger by several trillion cubic feet, the additional gas would probably go mostly to general energy consumption in the producing areas, with gas used outside those areas largely for special energy uses. The field price could then be expected to be below the equivalent energy cost of residual fuel oil, but not a great deal below.

If, to take a quite different assumption, 1975 net production should be as much as two and a half times that of 1950, or 15 trillion cubic feet, the pattern of consumption need not change from that of the present in its main essentials, except for the more than proportional growth of special advantage uses. Other uses might double in proportion to the expected doubling of the country's total energy consumption. The relative shifts in consumption then need not be of major significance. Nor need the price structure be much different from that which is now taking shape.

SPUR TO EXPLORATION POSSIBLE

If exploration should be active enough to support a growth of domestic petroleum production in proportion to consumption, it would be likely also to support a natural gas production level in 1975 of well over 20 trillion cubic feet. In that case natural gas would tend to displace oil and coal from some general energy uses they now serve. It might then continue to sell to industrial consumers in markets close to the main sources at prices well below those of coal or petroleum products of equivalent thermal content, depending largely on the rate of long-distance pipeline construction in the meantime.

A close relationship will exist, in any event, between natural gas supplies and domestic petroleum exploration. If natural gas should be in short supply relative to demand, and if its field price should rise correspondingly, that fact would add considerable stimulus to the exploration for oil and gas. For example, the recent rise in the new contract price of natural gas in the Southwest to about 11 cents per M cu. ft. as contrasted with an older average of about 5 cents means that the 4.6 M cu. ft. of natural gas likely to be discovered per barrel of oil are now worth about 28 cents more at the new prices than at the old. If in the future about 6 M cu. ft. of natural gas can be expected to be discovered for every barrel of oil, each 5-cent price rise of natural gas would be the equivalent, in its effect of stimulating exploration, of a 30-cent increase in the price of a barrel of oil. On the whole the cost of finding a barrel of oil to date has probably been on the order of 30 or 40 cents in 1950 purchasing power, so that the possible increase of natural gas prices would be quite significant relative to that cost.

If Middle Eastern oil competes in the United States market and if shale oil production should become economic, there will be a ceiling on the possible price rise of crude oil. Under these circumstances, a rise of natural gas prices might be almost as powerful an increased stimulus to oil exploration as any prospective price rise of crude oil. It would also stimulate gas exploration in its own right. In addition to this tendency to encourage discovery of more oil and gas, a higher price for natural gas would probably induce some reduction in the field losses and waste that now absorb over 10 percent of the net production of natural gas. The higher price would stimulate investment in gathering and handling equipment that it would not pay to install at lower gas prices. It might, however, discourage those practices that involve return of gas to the ground, and would probably also lead to a more rapid depletion of proved reserves.

SPECIAL PROBLEMS

It is sometimes argued that end-use control is necessary to prevent gas from being used now for low value general uses, in order that it may be saved for higher value special advantage uses later. The desirability of eliminating low value general uses (such as for boiler fuel at points distant from the fields) as rapidly as possible is universally recognized. There is, however, some controversy over whether this should be achieved by a prohibition of low-grade uses, or by positive measures to encourage such a development of the gas industry that it no longer pays to use gas for low-grade uses.

The development of underground storage near markets is already leading to the discontinuation of the off-season sale of natural gas for boiler fuel to electric generating utilities in the East. For example, natural gas from the Texas-Louisiana area can be put into underground storage in abandoned Pennsylvania gas fields, or similar geological structures, in the summer, rather than being sold for boiler fuel; the stored gas can then be sold for high-grade winter uses such as house heating. In this way also, a given sized pipeline (from field to storage areas) can serve a larger number of special advantage customers. Further development of such storage can greatly contribute to the reduction of off-season consumption in low-grade uses and so support a greater flow to seasonal special advantage uses.

SHIFTING TO HIGH-GRADE USES

During the period of rapid extension of pipelines, sales of natural gas for low-grade uses help to absorb the cost of developing and carrying the high-grade markets. As those markets are developed the gas industry will find it worthwhile to shift its supplies to them. The argument for direct end-use control must be tempered by consideration of the difficulties in the way of a rapid development of facilities to extend the market to high-grade uses, and the contribution of industrial sales in carrying part of the costs of such development. There appears to be no economic basis for designing curbs on low-grade uses that would be more valid and more suitable than market forces in guiding the gas to the highest grade use.

There is obvious justification, however, for the Federal Power Commission's consideration of the type of consumption to be served in connection with its granting of pipeline certification. It must be the objective of all concerned to see that highest priority is accorded those facilities that serve the highest grade uses, and the Federal Power Commission plays an important part in this process. Because of the costs of transportation and distribution, some classes of use that are considered low grade far from the fields must be considered high grade near the fields.

AVOIDANCE OF WASTE AT THE WELL

Casinghead gas and gas "stripped" of its liquids are sometimes disposed of as waste by being vented to the air and flared. The flaring, or other wastage, of natural gas at the rate of 1 cubic foot for every 10 produced is one of the most dramatic features of the gas industry.

Some of the gas now flared or otherwise wasted is not now worth the expense of saving it, but much of it is, especially if future needs are taken into account. Some producers are not always sufficiently alert to the present and future economics of the situation to do what in the long run it will pay them to do. In many cases the best conservation practices are economic only if uniformly followed by all producers from a common source; there may be no incentive for each producer by himself to avoid wastage. State commissions have therefore had to act to limit wastage of natural gas.

State legislation in the last 15 years, together with higher field prices and improvement of techniques of transporting the gas to market and of returning it to the ground to maintain pressure, have led to a considerable reduction in the percentage of natural gas production that is flared, though the quantity flared is nearly as large as ever. The practice of flaring is still frequently encountered where it does not currently pay to gather the gas or return it to the ground, or, less frequently, where the impatience of producers or their limited capital prevents adoption of the most economical techniques of handling the gas. State conservation measures have achieved good results, but have not yet everywhere been carried to the point where all uneconomic practices have been eliminated.

The economies of returning casinghead gas or stripped gas to the ground depend in large part on the adoption of unit operation—the orderly development and operation of a field as a single unit. It would hardly pay a producer to return gas underground only to have it withdrawn by somebody else. Experience has shown that unit operation is not enough by itself to avoid wastage of natural gas or of the petroleum that is lost by an uneconomic withdrawal of the gas, but it is an important step in conjunction with other arrangements and regulations. In the absence of unitization, however, proper regulation can achieve many of the same benefits.

In the leasing of Federal oil lands, certainly, care must be taken to insure the economic use of natural gas both for sale and for maintaining the pressure in the oil reservoirs. Imminent development of oil resources underlying the Continental Shelf presents a special problem of gas conservation. At best it will be costly and technically difficult to avoid enormous amounts of flaring. Under some geographical patterns of development, gathering natural gas might be out of the question economically, whereas alternative patterns might make it feasible. That method of development must be selected that will insure the ultimate recovery of as much of both gas and oil as is economically practical.

BURNING GAS FOR CARBON BLACK

Next to flaring, the most dramatic and apparently wasteful use of natural gas is the making of carbon black. Natural gas is burned off in order to catch carbon black from the smoke. Producers of carbon black stood ready to take the gas near the fields at a steady rate at a time when other customers were lacking. They obtained long-term contracts permitting them to buy gas at very low prices. In view of the fact that there are now demands for natural gas that can afford to pay much higher prices and that there will be even more in the future, there has been some sentiment in favor of prohibiting the buring of gas for carbon black. Some States already prohibit the practice or restrict it to types of gas not suitable for other uses without further processing.

Carbon black is required for the manufacture of rubber tires, and, if other sources or substitutes were not available, carbon black manufacturers would probably pay a competitive price for natural gas. However, as the price of natural gas rises and as new contracts have to be made, or as additional restrictions are placed on the use of natural gas for this purpose, manufacturers can turn more to residual products of petroleum as a source material, and can possibly transfer some of their operations to foreign fields where there are no other customers for the natural gas. Finely divided silica is being developed as a substitute for carbon black though it is not yet possible to judge whether this substitute is likely to become a major competitor. Its developers are confident, however, that it can successfully compete with carbon black within the next 15 years.

EVENTUAL SUBSTITUTES FOR NATURAL GAS

Over the next 25 years or so, such substitutions as will be required of other fuels for natural gas need not cause serious problems. Some industrial users, such as electrical generating stations, who have been getting natural gas at bargain prices, largely in off-peak seasons, will probably have to shift to full-time use of coal or fuel oil, a process that has already begun on the East Coast. There will be some modest increase of their costs on this account but no serious further problems can be expected.

At some point beyond 1975, however, more serious problems are likely to arise when natural gas supplies will eventually have shrunk to the point that the general uses in gas producing areas and special uses in all areas are forced to shift to substitute fuels. Costly dislocations may result in the economy of the Southwest, heavy capital costs of conversion will be forced upon nearby and distant customers, and the extensive transportation, distribution, and utilization systems may be rendered useless. The impact could be reduced if it becomes economic to manufacture gas for at least some of these gas customers, presumably from coal, which could then be distributed through portions of existing transmission and distribution lines, though large segments of such lines would probably no longer be used. The present and currently prospective costs of deriving gas from coal, either by underground gasification or above-ground manufacture, are so high that the processes do not promise to be economic for any but those very high-grade special uses, such as household cooking, that can afford to pay very high prices. Improved methods of obtaining gas from coal are being sought, however, and the prospects may be considerably improved by 1975.

Meanwhile, in guiding the rapid development of the natural gas industry, it is important for regulatory authorities to bear in mind the ultimate exhaustion of natural gas supplies, with the aim of avoiding costly over-expansion. The Federal Power Commission has customarily required, as a condition for authorizing construction of a pipeline, that a certain number of years' supplies be reserved for the particular pipeline, usually 20 years, although shorter periods have sometimes been countenanced. As the natural gas industry matures, an even longer horizon may be appropriate.

It will become increasingly important for the Federal Power Commission, in considering "dedicated reserves" for a proposed pipeline, to take into account the eventual impact of new dedications upon the useful life of existing pipelines, upon the consumers they serve, and upon the long-range supply position of communities in the producing area. Excessive building of pipelines and over-commitment of limited reserves could lead, when reserves are gone, to premature obsolescence of costly capital equipment, for operators and consumers alike. The owners of the pipelines and those who extend them credit can generally be expected effectively to safeguard continued supplies for their transportation and distributing systems. However, the regulatory authorities must also have a strong responsibility in this direction.

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Chapter 3 Coal

The Situation in Brief

Despite a rapid increase in energy demand in the United States in the last 25 years, coal's share of the market has steadily declined. Both less convenient use and—with bulkier handling in transportation—higher prices have caused coal to lose out in many market places to oil and gas. Some markets, however, are expanding and this trend—particularly greater consumption to produce electricity—is likely to continue. While coal's percentage share of the 1975 energy total is likely to be still less than now, actual volume of coal at that date may be 60 percent above present levels. Sometime after that date—whenever the cost relationship shifts and domestic oil and gas production become either too high in cost or too low in volume—coal is expected gradually to take over the heavier part of the energy burden in the United States. Reserves are more than ample.

The extent and the timing of coal's upward turn will depend importantly on technological developments: better mining and processing methods, cheaper transportation methods, more efficient utilization. Advances in manufacture of gas or liquid fuels from coal, as well as chemicals, could increase consumption.

Coke is a special problem. The Nation is consuming coking coal rapidly in relation to its proportion of reserves, but the main problem is in building enough ovens to take care of needs. Capacity for some 40 to 50 million tons a year needs to be built within the next 10 years.

Coal requirements of other free nations are being met partly with United States exports; probably oil will be the chief reliance for energy expansion in Western Europe. Japan's traditional sources are chiefly within Soviet territories and it currently relies on the United States. Canada depends upon the United States for increasing supplies.

UNITED STATES DEMAND AND SUPPLY

To what extent will coal share in the possible doubling of energy requirements of the United States within the next 25 years, and in further increases thereafter?

During the last 25 years, the share of coal in the energy market declined steadily. Total consumption of energy increased by 60 percent. In terms of bituminous coal equivalent, it rose from some 815 million short tons in the mid-twenties to about 1,300 million tons in 1950. The net increase was satisfied entirely by petroleum products, natural gas, and hydroelectric power. Coal, which supplied two-thirds of the total energy consumed in the mid-twenties, dropped to slightly more than 40 percent in 1950. In round figures, consumption of bituminous coal and anthracite dropped from about 600 million short tons a year in the twenties to around 500 million now. In 1950 demands on United States coal production amounted to 522 million tons including 493 million tons consumed domestically and exports of 29 million tons. The distribution of domestic consumption is shown in table I.

The downward trend of coal's percentage share in the total energy stream may continue for the next 25 years, unless war intervenes, but the past decline in volume is expected to reverse from here on and rise perhaps 60 percent by 1975.

Table I.—*Consumption of coal in the United States, by class of consumer: 1925 and 1950*

Class of consumer	1925		1950		
	Millions of tons	Percent of total	Millions of tons	Percent of total	Percent change from 1925
Industrial	n. a.	n. a.	217	44. 0	n. a.
Coke ovens	75	13. 3	103	21. 0	+38. 7
Steel and cement mills	(1)	(1)	16	3. 2	(1)
Other industrial	[1] 248	[1] 44. 1	98	19. 8	[1] 19. 0
Electric utilities	36	6. 4	92	18. 6	+155. 6
Residential and commercial (retail)	n. a.	n. a.	122	24. 6	n. a.
Bituminous coal	(1)	(1)	87	17. 6	(1)
Anthracite	56	10. 0	35	7. 1	−37. 5
Railroads	137	24. 4	61	12. 5	−54. 7
Miscellaneous	10	1. 8	1	. 2	−90. 0
U. S. total	562	100. 0	493	100. 0	−11. 9

n. a. Not available.

[1] Figures for bituminous coal used by steel and cement mills and for residential and commercial purposes are included in figures for "Other industrial."

Source: Bureau of Mines, U. S. Department of the Interior; National Coal Association, *Bituminous Coal Annual*, 1951.

Coal has some uses for which other fuels do not compete, such as coke in metallurgical uses, but such special demands account for only about 20 percent of domestic coal consumption. The remaining 80 percent faces competition from petroleum products and natural gas which are certain to gain the major part of the residential heating market and substantially all the railroad market. Most of the new railroad locomotives recently installed burn Diesel oil. Even if the coal-fired gas turbine is developed to the point at which it can successfully compete with the Diesel engine, its fuel efficiency would then be so great that it would contribute little to the total demand for coal.

BIG USE: THERMAL GENERATION

These declining uses of coal will be more than compensated by increased consumption in industry and electric utilities. By 1975, over 300 million tons of coal and lignite (in terms of bituminous coal equivalent) may be required for electric power generation in spite of anticipated further increases in the efficiency of conversion. Total foreign demand for United States coal is likely to remain high since increasing exports to Canada are expected to offset declining exports to Western Europe.

These are the factors which lead to the estimate that total demand for United States coal will grow some 60 percent over the next 25 years, from the 1950 level of 522 million tons (including exports) to more than 800 million tons.

Synthetic oil production from coal, if it became economic, might push demand even higher. A major war could sharply increase dependence on coal because energy requirements would rise while supplies of other fuels—particularly of imported petroleum—might be reduced. During the Second World War, the demand for coal rose more than 35 percent, from about 480 million tons in 1940 to 650 million tons in 1943 and 1944. A similar or greater increase would have to be anticipated in a future full-scale war.

Coal currently requires much more labor in its production, transportation, and use than its principal competitors, petroleum and natural gas. It is easier to raise liquids and gases from the ground, to handle them mechanically, and to control them automatically than to perform similar operations for coal. On the other hand, exploration for oil and natural gas adds a considerable expense burden, whereas immense reserves of coal are already known.

The decline of coal relative to oil and gas can, accordingly, be arrested by one or both of two developments: (*a*) a fall in coal costs through new ways to produce and handle coal with greater economy of labor, (*b*) a rise in the cost of competitive fuels relative to coal. Both developments are expected to happen. The time cannot be forecast, but sometime later than 1975 the share of coal in the total supply of energy can be expected to increase markedly. Gas, liquid fuels, and electricity can be produced from coal. The United States has enough coal to meet its energy requirements for a long time to come. When the prices of other fuels begin to rise significantly in relation to coal and most economical hydroelectric power sites have been developed, the demand for coal will go up substantially.

Numerous obstacles will have to be overcome in the development of the Central and Western coal regions.* Central coals are generally poorer in quality than Appalachian coal, though adaptable to a wide range of industrial uses; they are entirely suitable for power generation and for production of synthetic fuels.

Western coal will have to surmount greater handicaps. Long hauls are ruled out by the low fuel value of the coal and its tendency to spontaneous combustion. The region is too arid to support a large population and intensive industrial development. Inadequate water supply may limit use of the coal either for large-scale production of synthetic fuels or for steam generation of electric power. Large-scale use of western coals for electric power production could become possible, though, with development of coal-fired gas turbines, as these would eliminate the dependence on water supplies.

*The Central coal region includes the Mississippi Valley field extending from Illinois into western Indiana and into western Kentucky; a field extending from Iowa into northwest Missouri and Kansas and then into Oklahoma and western Arkansas; a field in Michigan; and a field in mid-Texas not mined at the present time.

Production and Productivity

United States production of 556 million short tons of bituminous and anthracite coals in 1950 represented more than one-quarter of world production and was 100 million tons greater than that of the entire Soviet bloc.

The United States is also foremost in coal productivity per man-day. In 1949, underground coal miners in the United States produced an average of 6.7 tons per day†—more than 3 times the average daily output of the Polish miner; 4 times the British and German; 5 to 6 times the French, Belgian and Russian; 10 times the Japanese. Since foreign miners work longer hours, the United States advantage is even greater in terms of output per man-hour. Also, productivity in United States mines has been rising more rapidly than in other countries. During the past 25 years, United States output per man-hour rose by 72 percent, from 0.5 tons in the mid-twenties to 0.86 tons in 1950, a rise partly attributable to the increase of open-pit or strip mining.

This increased productivity in the United States has offset the gradual exodus of labor from the coal mines—a trend that has created such serious problems in Europe. In the mid-twenties, nearly 600,000 miners were necessary to produce some 600 million tons of bituminous coal in the United States; in 1947, the most recent year of full utilization of coal production capacity, some 420,000 miners produced more than 630 million tons.

These remarkable achievements were assisted by favorable geological conditions as well as by continuous improvements in mining methods. Indeed geological conditions are largely responsible, both for the higher absolute level of productivity in the United States and for the more rapid increase of productivity over that of Europe.

The greater thickness of the seams in the United States, the smaller overburden (the average depth of European mines is greater than the maximum depth of American mines), the prevalence of horizontal seams in which locomotive haulage can be used effectively, the relative absence of faulting—all these have been favorable to rapid mechanization. The abundance of economically minable coal beds has permitted the use of the labor-saving (though coal-wasting) room-and-pillar system of mining. These factors will continue to favor an increasing level of productivity in the United States.

Two other geological factors, favorable in the past, will not hold good much longer. The fact that beds minable through drift or slope entries are becoming scarce and that vertical shafts often will have to be used, especially in the Appalachian fields, will tend to increase costs. Of even greater importance, deposits that are economically minable by strip methods are limited.

Mechanization Boosts Production

Strip mining for coal is relatively recent and became practical only when large power shovels, excavators, and bulldozers became available to remove heavy overburden. Its output per man is about three times as high as in underground mining,

†Excludes surface personnel of underground mines.

and 95 percent of the coal can be recovered as compared with some 50 percent underground.

Strip mining increased rapidly during the war and now accounts for 25 percent of domestic production. Substantial reserves suitable for stripping exist in Ohio, Indiana, Illinois, and farther west, but further expansion is likely to require removing a thicker overburden. Increasing overburden seems to have been the reason that no increase in man-hour productivity has occurred in strip mining since 1930. If, as is likely, strip mining continues to supply only about the present percentage of production, it will cease to push upward the average of total productivity, and further progress will depend on improvements in underground mining.

Productivity per man-day of underground bituminous mines has increased by 28 percent since the mid-twenties—from 4.5 tons to 5.75 tons in 1950—despite a considerably shortened work day. Productivity per man-hour actually increased by 53 percent, substantially all due to mechanization. Power cutters and drilling machines replace the pick and hand-operated drill of yesterday; mechanical loaders do the work of the hand shovel. New explosives replace the old blasting powder with far greater efficiency and safety. Hand-cutting of bituminous coal in underground mines has dropped in 25 years from 16 percent to less than 2 percent. In the mid-twenties only about 1 percent of bituminous coal was loaded mechanically in underground mines; today 70 percent is. Timbering machines and roof bolting devices have made their appearance, and the transport of coal in the mines is speeded by electric engines, larger cars, and belt conveyors.

The last few years have seen the advent of "continuous mining" which uses a single mole-like machine to combine all operations formerly performed individually and separately, at the face, into a synchronized operation.

Considerable progress has been made in mechanical processing—cleaning, washing, and sizing—which has improved the quality of the coal and adapted it to particular consumer needs. In 1950, 39 percent of bituminous coal produced was mechanically cleaned as against less than 5 percent a quarter century ago. Mechanical cleaning is increasingly necessary as mechanization increases the proportion of impurities and finer sizes.

OTHER FACTORS IMPEDE PRODUCTIVITY

More rapid progress would undoubtedly have been made in productivity if the coal industry had not been depressed, partly because of low general economic activity during the thirties, partly because of competition from other fuels. There was little incentive for large-scale investment in the face of a shrinking market. Funds for research and for modernization have been inadequate. The war demand was readily met by increasing the number of days of operation, by enlarging the working force slightly, and by advancing into reserves at existing mines. Few new mines were opened or shafts sunk.

Recent high levels of economic activity have permitted profitable operation of most coal mines, and technological improvement has quickened. Research programs have been expanded, but they are small compared with programs in the petroleum or chemical industry.

Moreover, tremendous possibilities exist for improving the techniques of coal production, preparation, transportation, and utilization. Some already are sufficiently advanced to justify large-scale investments by the coal industry if it could be assured of a sustained high demand.

RESERVES AND RESEARCH

The coal reserves of the United States are estimated at 2,500 billion short tons, of which about half may be deemed recoverable with present techniques. The recoverable reserves contain more than 80 percent of the energy of all recoverable mineral fuel reserves. United States coal reserves are about 40 percent of the world total—as much as those of the Union of Soviet Socialist Republics and China combined.

About 30 percent of United States coal is in the Appalachian and interior regions; the rest is west of the Mississippi. Virtually all Eastern coal is bituminous. Seventy-five percent of Western coal consists of sub-bituminous coal and lignite, and most of the bituminous coal also is not suitable for coking. Only 1 percent of United States coal reserves is anthracite—nearly all in Pennsylvania.

The small size and financial resources of most coal companies make it impossible for all but the largest to undertake individual research programs. A significant individual effort is the research laboratory of the Pittsburgh Consolidation Coal Co. at Library, Pa., which is investigating coal hydrogenation, gasification, and pipeline distribution of pulverized coal.

The coal mining industry is contributing to such private research organizations as the Battelle Memorial Institute and to research laboratories of universities. Three hundred coal companies have joined with railroads and equipment manufacturers in supporting Bituminous Coal Research, Inc., which is investigating the development of a continuous mining machine, stainless steel belting for coal mine conveyors, coal-fired gas turbines, household space heaters and automatic boilers, smoke abatement, and the adaptation of a wider range of coals for coking.

This work is supplemented by private research in other industries (for example, the work of the Koppers Co. in synthetic fuels technology) and by Government projects. Notable Government projects are those conducted by the Bureau of Mines in the Fischer-Tropsch and hydrogenation plants at Louisiana, Mo., and in other laboratories. The Bureau of Mines and the Alabama Power Co. are jointly experimenting with underground gasification of coal at Gorgas, Ala.

Total expenditures for coal research and development amount to approximately 23 million dollars a year. In contrast, the petroleum industry spends more than 120 million. The bituminous coal industry is estimated currently to be spending about 15 million. The Bureau of Mines obligated $7,669,000 in fiscal year 1951 for coal research and development, ncluding work on synthetic fuels.

Prospects for further increases in productivity in underground mining are good and will become better as coal markets improve and as operators and investors accordingly gain greater confidence that the long-term trend is upward. Physical difficulties of extraction will grow but can be more than offset by further improvements in methods of extraction and haulage.

A rising demand for coal will accelerate technologic improvement, and there will be incentives for opening new mines and new coal areas. New mine layouts will be far better adapted than present mines to continuous mining. In old mines, continuous mining machines frequently turn out coal more rapidly than it can be hauled to the surface, and the full value of the machine is not realized. New mines can use belt conveyors in solving this problem. It is possible that by 1975 productivity per man-hour in underground coal mines may be almost tripled, and total productivity in underground and strip mines combined may be more than doubled.

CAPACITY FOR POSSIBLE WAR

The prospective increase in productivity has an important bearing not only on the cost of coal, but also on the prospects for maintaining reserve capacity for use in case of possible war. Between 1938 and 1949, the theoretical production capacity of the United States bituminous coal industry rose by 30 percent, from 600 to 780 million tons.

Theoretical production capacity assumes the current labor force working 280 days per year at the current level of productivity. Attaining the actual capacity, presently estimated at about 700 million tons, would depend on whether or not steel, mining machinery, operating supplies, and transportation facilities were available. The increase between 1938 and 1949 may be reversed and present adequate reserve capacity endangered, if expansion of strip mining is slowed down, and if the labor force resumes its gradual downward trend. Continuing technological progress in coal is, therefore, important to the security and general economic growth of the United States.

The Problem of Coke

While the total coal supply has always been adequate, except during work stoppages, this has not been true of coke. Total United States reserves of good quality coking coals are estimated at about 50 billion tons, 80 percent in West Virginia, Pennsylvania, and Maryland. They are being depleted more rapidly than other types of coal, since they account for about 15 to 20 percent of production although only 2 percent of total reserves. Much of the better grades have been mined, and the iron and steel industry has been adjusting to lower grades.

Coke can be produced from medium-volatile bituminous coal which has low sulfur and ash content, although a blend of low-volatile and high-volatile coal is most commonly used. About 50 percent of low- and medium-volatile coking coal currently being produced normally is used for other than metallurgical purposes. If the iron and steel industry should run short of coking coal, its needs could be met by diverting it from less essential uses.

Considerable progress has been made in developing new blends with anthracite fines, petroleum coke, or low-temperature char. It is also possible to produce a low-volatile, smokeless fuel by low-temperature carbonization of high-volatile bituminous coal. Excessive impurities often can be removed by improved preparation procedures and equipment. With further development of these techniques, United States supplies of acceptable coking coal can be stretched sufficiently to meet future requirements, though at slightly higher costs than in the past.

INSUFFICIENT COKE-MAKING CAPACITY

The real problem has not been in the supply of coal suitable for coking, but in coke-making capacity.

Coke for steel manufacture is produced by integrated steel companies and their affiliates, by merchant and gas utility plants, and by beehive coke ovens. Historically, the steel industry has constructed coke-making facilities to operate its furnaces at 75 percent capacity and has depended upon others for the rest. When the steel industry operates at full capacity, all three coke-making sources are utilized, beehive ovens being called on last.

During the next 5 years, it will be difficult to construct enough new ovens and at the same time maintain existing ovens at a rate adequate to meet requirements for the expanding pig iron production. The stringency will be increased by a decline in utility coke-making as natural gas supplants coke-oven gas. A Bureau of Mines survey concludes that capacity for approximately 2.5 million tons of utility coke will go out of existence during the next 10 years.

The number of beehive ovens, which currently contribute approximately 7 million tons (9 percent of the total), will also decline rapidly. Beehive ovens waste byproducts; moreover, as reserves of satisfactory coking coals available to beehive operators dwindle, the coke they produce tends to become substandard. Over the next 10 years, beehive production is expected to decline by 3.5 to 5 million tons.

In addition to this estimated loss of 6 million to 7.5 million tons, over-age slot-type ovens that now produce an estimated 23 million tons are expected to be withdrawn from operation. These declines are occurring at a time when the expanding steel industry requires between 10 and 15 million tons over and above previous production. Consequently, new coke-making capacity of 40 to 50 million tons must be built during the next 10 years.

Private industry will be inclined to risk money in coke-oven construction only if convinced that a high level of steel operation will be sustained over a long period. There are indications that the high level of demand for steel during the past few years and the current rearmament program have led the steel industry toward such a conviction. In the long run, therefore, coke-oven construction is likely to catch up with requirements.

The Cost Outlook

Despite the increase in output per man-hour, the price of producing bituminous coal since the prewar period has increased more rapidly than the price level in general. The average value per ton of bituminous coal f. o. b. mine stood in 1950 at 262 percent of the 1935–39 average ($4.85 as compared with $1.85), while the wholesale price index averaged 200 and the general price level averaged 183 [*1*].

This increase can be attributed largely to the fact that coal miners' average hourly earnings (in dollars of constant purchasing power), including adjustment for portal-to-portal pay and employers' contributions to the miners' welfare-and-retirement fund, increased more rapidly than output per man-hour, with a consequent rise in labor costs per unit output. This placed coal at a price disadvantage relative to gas or oil in many areas: the average wholesale price of bituminous coal doubled between 1935–39 and 1950, while the average delivered price of natural gas for industrial use remained practically unchanged. The wholesale price of fuel oil increased in rough parallel with coal, but since handling charges are greater for coal than for other fuels, coal was placed at an even greater disadvantage in the retail market. Between 1935–39 and 1950, the average price of bituminous coal to the domestic consumer has more than doubled, while the price of fuel oil increased only 87 percent and the price of gas remained practically unchanged. The average price of anthracite increased 91 percent during the same period. In many parts of the country, natural gas and fuel oil sold at lower cost to the consumer than coal of equivalent heating value. Fuel oil has been underselling coal of equivalent heating value at New York harbor in 10 out of 19 nonwar years since 1928. The competitive position of coal would have been even worse if railroad freight rates had increased in proportion with the general price level, but they have risen only about 50 percent since 1935–39.

In the rail market, the price of Diesel oil has increased slightly more since 1935–39 than that of bituminous coal, but the greater efficiency of Diesel engines made fuel-operating costs only a fraction of those of coal-fired steam engines. Relative costs in the first 4 months of 1951 are shown in table II.

TABLE II.—*Fuel costs of locomotive operation, January–April 1951*

Locomotive type	Per yard switching locomotive-hour	Per thousand gross ton-miles road freight service	Per thousand passenger train car-miles
Coal steam	$2.45	$0.33	$57.00
Oil steam	3.10	.40	50.00
Electric	1.12	.29	37.00
Diesel	.69	.17	30.00

Whether coal prices will continue to increase in relation to other fuels will depend on such factors as the rate of increase in coal mining productivity compared with other fuels and the economy as a whole; the course of real wages in coal mining and other industries; and the development of new techniques of preparing, shipping, and utilizing coal.

The prospective increase in productivity in underground coal mining and the anticipated further progress in the techniques of preparing coal for the market are favorable to cost reduction. There also is room for considerable cost reduction after the product leaves the mine. Cheap methods of bulk movement are being developed, including long-distance conveyor belts and the use of pipelines to move coal.

The cost of coal to the consumer will be brought down also, indirectly, through greater efficiency in conversion and use, and through the more effective use of the byproducts of coal conversion. Efficiency of coal conversion to electric power can be expected to increase by at least 25 percent in the next quarter century, and even more if the coal-fired gas turbine proves out. The rapidly expanding chemical industry will generate an ever-increasing demand for the byproducts of carbonization, hydrogenation, and the Fischer-Tropsch process. Large-scale production of synthetic liquid fuels from coal, particularly in conjunction with electric energy generation and chemical byproducts, may eventually develop into a tremendous use of coal and contribute importantly to the Nation's supply of energy at relatively low costs.

ROLE OF LABOR

Substantial reductions in the cost of coal at the mine head would be possible, relative to the general price level, if coal miners' real wages should remain unchanged. But coal miners' wages may be expected to increase at least as much as other wages if only to retain an adequate working force in the industry.

Rising real-wage rates are compatible with cost reduction as long as they do not completely absorb the savings due to technological improvements or outstrip them as in recent years. Now that coal miners have reached the top of the wage scale, further wage increases are likely to be more nearly in proportion to the general rise of wage levels. At the same time, the pace of technological progress in the coal industry is likely to quicken.

Organized labor recognizes the importance of technological progress. Labor, management, and the general public all have a large stake in achieving the more stable industrial relations necessary to improve the competitive position of coal. In recent years, lack of assurance of a continuous supply has contributed to the displacement of coal by other fuels. Large-scale work stoppages cut deliveries to markets, often at times when coal stocks were low.

THE GENERAL OUTLOOK

This Nation's abundant reserves of coal make coal a major long-range source of fuel and raw materials for a wide variety of industries. Sooner or later several major United States industries will have to sink their tap roots deeply into our coal reserves, as did the railroads earlier. Steel has long been rooted to coal and will need increasing amounts. The electric power industry too has been a major customer but now shows signs of becoming a far larger one and a major collaborator toward putting coal more abundantly into use in a variety of ways. Likewise the fast-growing chemicals industry, long tied indirectly to coal through the route of coke and the steel industry, holds promise of becoming a much greater user along with the oil industry, which when need and technology are ripe, can turn to coal conversion to secure an important portion of the nation's liquid fuel supply. Nor is it inconceivable that the natural gas industry may some day turn heavily to coal as a source of product to fill its pipelines.

These great coal-using industries, present and potential, have the financial and technical abilities to provide major leadership, along with Government and progressive members of the coal industry itself, toward deriving abundantly greater benefits for the Nation, and for other free nations as well, from our rich coal resources. The jobs to be done are evident. They will require intensive technological effort and large capital investment. The job is almost certain to get done someday as the need increases; the big issue is whether it will get along rapidly enough to keep the coal industry from going through another interim period of depression at great cost to the Nation. The challenge to avert such a misfortune rests largely with the several industries concerned.

COAL IN OTHER FREE COUNTRIES

Since the Second World War, Western Europe and Japan, both vital to the security of the United States, have found themselves short of coal and dependent on imports, with the United States and the Soviet bloc as the principal sources of supply. At the same time, Canada has become increasingly dependent on imports of coal from the United States. Assured coal supplies from the United States will be important, perhaps essential, to the future industrial development of these areas.

Energy Economy of Western Europe

The total energy consumption of Western Europe (including the United Kingdom) in 1950 was equivalent to 630 million metric tons of bituminous coal. Per capita consumption of energy was thus less than one-third that of the United States.

The economy of Western Europe is still predominantly based on coal. In 1950, 75 percent of its total energy supply was derived from solid fuels, 14 percent from petroleum, and 11 percent from hydroelectric power.

While Europe still has large coal reserves—though not as economically minable as those of the United States—and considerable undeveloped hydropower, it has no reserve production capacity immediately available. As a result, Western Europe has been unable to meet rapid increases in the demand for energy during recent years, and has had to import coal and oil for an increasing proportion of its total requirements. Polish coal has been imported at a rate of 10 to 12 million tons a year. During the past 18 months, Polish coal has been available only in reduced quantities and on onerous terms. Imports into Western Europe from the United States reached a peak of 37 million metric tons in 1947, dropped to almost nil in 1950, and are running again at a rate of more than 25 million tons a year.

Long-term projections of Western Europe's energy requirements are particularly hazardous because of the difficulty of interpreting past trends. Between 1913 and 1950, total European consumption of energy rose only about 20 percent. Practically all this increase was accounted for by increases in petroleum and hydroelectric power. Fluctuations during this period have been violent as a result of two world wars and the intervening depression.

These movements in total energy requirements reflect the slowness of economic growth and the large fluctuations of European production of goods and services during the past few decades. Past trends are, therefore, not a reliable guide to energy requirements during a more rapid and continuous increase in total production. Experience shows, however, that energy requirements range between 35 and 75 percent of the increase in industrial volume.

If Western Europe's aggregate gross product increases by 75 percent over the next quarter century and is accompanied (as is likely) by a doubling of the physical volume of industrial production, total energy requirements may be expected to increase by about 50 percent, from 630 million metric tons bituminous coal equivalent in 1950, to around 950 million tons by 1975. Most of this increase will be met by increased petroleum imports, which are expected to more than triple during the next quarter century. Hydropower should be more than doubled and solid fuel consumption remain substantially unchanged. These projections depend, of course, on increased availabilities of petroleum at a real cost not much above present levels. (See table III.)

Table III.—*Energy consumption of Western Europe 1938, 1950, and projection for 1975*

[In millions of metric tons, bituminous coal equivalent]

Year	Total	Solid fuels	Petroleum	Hydropower
1938	532	440	52	40
1950	630	475	85	70
1975 (projected)	950	500	300	150

European Oil Consumption. By 1975 it may be expected that about one-third of Western Europe's energy requirements will be met by petroleum, as compared with 14 percent in 1950 and 10 percent in 1938. A major factor will be high production costs of coal in Europe and low production costs of oil in the Middle East. Another is the great growth of demand for liquid fuels in transport uses.

Western Europe's petroleum consumption has increased by 66 percent since 1938, despite interruption of refinery construction during the war, maintenance of artificially low coal prices, and despite exchange difficulties, trade restrictions, tariffs, and high petroleum taxes. If the next 25 years bring rapid economic growth, Western European petroleum consumption should rise at an accelerated rate.

Europe's Hydropower. Western Europe still has considerable undeveloped hydropower resources, but much of this is located on the Scandinavian Peninsula far removed from Europe's industrial centers. In 1938, less than 15 percent of Western Europe's waterpower resources had been developed. In 1950, this figure had increased to nearly 25 percent. By 1975, it is estimated that about half of Europe's waterpower will have been developed, providing for about 15 percent of Europe's total energy consumption as compared with 11 percent at present.

The Future for Coal in Europe. Coal consumption will probably not increase substantially above the present level. The average cost of coal at the mine head, which at present varies from about $8 per ton in the United Kingdom to $10 or more on the Continent, may be expected to increase by 50 percent or more in relation to the average price level as prices are decontrolled and as mines have to be deepened, more difficult seams worked, and miners' wages raised. Geological conditions will continue to hamper mechanization. Real wages of coal miners will have to be increased more rapidly than those of other workers in order to maintain an adequate labor force.

These increases in the cost of producing coal in Europe will occur during a time when increasing amounts of petroleum will become available from the Middle East. These petroleum supplies should, in the absence of interruption from political developments, be the principal source from which Europe's increased energy requirements are to be met. Coal imports from the United States will taper off, though it is possible that American coal will retain a permanent foothold in Southern Europe to the extent that petroleum cannot be substituted for coal.

Japan's Coal Needs

In 1951, Japan's total energy consumption, like its industrial production, almost regained the prewar level. Japan's total energy consumption is now equivalent to 93 million metric tons of bituminous coal. Half of this is based on coal and lignite; 40 percent is contributed by hydroelectric power; 5 percent each is accounted for by petroleum and by wood and charcoal.

Between 1930 and 1939, Japan's industrial production increased by 115 percent and total energy consumption rose by 70 percent. By 1975, Japan's industrial output may be expected to increase more than threefold and its energy requirements to more than double.

A substantial part of the energy increase will be hydroelectric power. Although Japan has developed nearly half its suitable water power sites, its hydroelectric power capacity probably will be doubled by 1975. Its hydroelectric power output then would be equivalent to nearly 80 million tons of bituminous coal.

Petroleum consumption may be expected to increase fivefold or more, but even so it would contribute only about 20 to 30 million tons, bituminous coal equivalent. This would leave coal requirements of some 70 to 80 million tons yearly.

Japan will experience great difficulties in covering these requirements. Its coal beds—primarily in Hokkaido and Kyushu—are generally deep, thin, steeply pitched, and of relatively poor quality. Average output per worker is between one-half and two-thirds of a ton per day—less than one-tenth of that in the United States. Possibilities of mechanization are limited by increasingly difficult mining conditions; output per man actually declined since 1933 and increased production was made possible only by a rapid increase in the labor force. Total production—about 44 million tons in 1951—has not yet regained the prewar peak of 57 million tons, reached in 1940.

Before the war, Japan imported between 7 and 10 million tons, almost all from areas now under Soviet control (Sakhalin, China, Manchuria). Japan was—and still is—dependent on imports for almost all its metallurgical coking coal and for some high-calorie gas coal and anthracite. On the other hand, Japan exported some boiler coal (1.8 million tons in 1938).

The loss of its customary sources of coal imports has forced Japan to turn to the United States for coking coal. During 1951 Japan imported about 2 million tons of coking coal and 300,000 tons of anthracite from the United States. Exports of boiler coal amounted to about 700,000 tons. Net imports thus amounted to 1.6 million tons, but another 2 million tons were withdrawn from stocks. Imports are scheduled to rise to 3 million tons in 1952. Imports from the United States of at least this magnitude are likely to continue as long as Japan cannot be supplied from sources on the Asiatic mainland.

Canada Looks to U. S. Coal

Canada's energy consumption has increased by 70 percent since 1939. In 1950, coal still accounted for 46 percent of total energy consumption (excluding fuel wood); petroleum, 22 percent; hydroelectric power, 29 percent; natural gas, 3 percent.

Well over half the coal consumed in Canada is imported, almost all from the United States; and Canada's dependence on such imports is increasing. Coal imports from the United States rose from 11.6 million metric tons in 1939 to nearly 25 million tons in 1951; their share in Canada's total consumption rose from 44 to 60 percent. (See table IV.)

Canada's dependence on coal imports is explained primarily by transportation costs. Canada has large coal reserves in Alberta and Nova Scotia, but they are far from principal markets. Two-thirds of Canada's industry is concentrated in the Toronto-Ottawa-Montreal triangle, which can be supplied more cheaply from United States mines.

There is no clean-cut trend to Canada's energy requirements. They have gone up sharply during the past decade when industrial development was rapid; but during the preceding quarter century when industrial development was slow, fuel consumption also increased slowly. If a rate of industrial growth comparable to the past decade is assumed, Canada's total energy requirements would about triple during the next 25 years. The largest increases would undoubtedly occur in petroleum, natural gas, and hydroelectric power; but coal consumption may be expected at least to double. Perhaps two-thirds of Canada's coal would come from the United States—more than 50 million tons yearly.

Table IV.—*Energy consumption of Canada*

[In millions of metric tons, bituminous coal equivalent]

Year	Coal			Petroleum	Natural gas	Hydropower	Grand total
	Domestic [1]	Imported [2]	Total				
1926...	13.2	16.1	29.3	3.8	0.7	9.0	42.8
1939...	12.8	13.9	26.7	8.1	1.3	14.4	50.5
1950...	15.4	24.8	40.2	19.0	2.5	25.4	87.1

[1] Bituminous, sub-bituminous, and lignite.
[2] Bituminous coal, anthracite, and coke.

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Chapter 4 Electric Energy

The Situation in Brief

The demand for electric energy in the United States during the next 25 years may be expected to increase two and one-half times if there is to be a doubling of the Nation's output of all goods and services in that period. With such a growth, the electricity demand around 1975 would be about 1,400 billion kilowatt-hours, compared with the generation of 389 billion kilowatt-hours in 1950.

The country has enough of all energy resources—waterpower, oil, gas, and particularly coal—to support a rise in electric energy supply of this magnitude. The major question is whether supply will in fact be expanded rapidly enough in relation to demand and without a rise in real costs.

The requirements of a successful program of electricity expansion are threefold:

First, every opportunity must be taken to harness undeveloped waterpower potential at a rapid pace, wherever economically feasible. Since much of this development will have to be at Federal multipurpose sites, Government surveys, planning, and authorization and appropriation procedures should be markedly hastened.

Second, full advantage should be taken of opportunities that exist to improve technical efficiencies and otherwise effect economies to hold down or reduce costs of electricity production, particularly in thermal generation plants.

Third, existing capacity and future installations should be geared into broadly designed, integrated operations covering wide regions. This approach holds great promise for the most efficient use of sources of electric power.

In the rest of the free world as a whole, demand for electric energy may be expected conservatively to increase at a rate as great as that of the United States, with expansion fastest in the comparatively underdeveloped countries. Such a growth rate probably will press hard on the relatively tight gas, oil, and coal resources of some free countries, especially the industrial countries of Western Europe. Where hydroelectric resources exist, therefore, every effort should be made to develop them.

RAPID GROWTH OF ELECTRICITY

Electricity has had a phenomenal growth in the United States ever since it was introduced commercially in 1882. Since 1920, its use has approximately doubled every 10 years, contributing greatly to increased labor productivity, larger national economic output, and improved living standards.

By 1950 electricity was being used for lighting and other purposes in 92 percent of all houses in the United States and in 83 percent of rural homes. It is estimated that electric motors provided at least 90 percent of the mechanical power used in industrial plants. An analysis of comparable industries, as covered by the Census of Manufactures, shows that the use of electric energy per man-hour of labor increased from 2.61 kilowatt-hours (kw.-hr.) in 1929 to 4.60 in 1939 and to 5.71 in 1947. By 1950, the average was estimated at 6.29 kw.-hr.

Total consumption of electric power in the United States in 1950 had reached 334 billion kw.-hr. compared to 74 billion in 1925. By far the largest part of the 1950 total, about 200 billion kw.-hr., was used for industrial purposes; residential and farm consumption was about 75 billion kw.-hr.; and commercial consumption, some 50 billion kw.-hr.

Production of electric energy in 1950 was 389 billion kw.-hr. with transmission and distribution losses accounting for 55 billion kw.-hr. Generating capacity amounted to 82.8 million kilowatts (kw). About one-quarter of the electricity produced in 1950 was supplied from hydroenergy, and three-quarters from thermal generation.

Table I shows the growth of electricity production in the United States from 1902 to 1950, broken down between hydro and thermal generation. For the most part electric energy in this Report is measured in kilowatt-hours. The term kilowatts is used as the measure of capacity to produce energy, or to measure demands for electric power at an instant or short interval of time. The relationship can be explained as follows: one kilowatt of electric generating capacity operating for 1 hour will produce 1 kilowatt-hour of electric energy; for one entire day—24 kilowatt-hours of energy; and constantly for a year—8,760 kilowatt-hours of energy. Few generating plants operate at a constant rate because demands for energy vary with the hour of the day, the day of the week, and the season of the year. Furthermore, all generating plants must be taken out of service for routine and emergency maintenance and repairs.

TABLE I.—*Growth of electric energy production in the United States*

[Billions of kilowatt-hours]

Year	Hydro	Thermal	Total*
1902			6.0
1907			14.1
1912	7.4	17.4	24.8
1917	13.9	29.5	43.4
1922	21.3	39.9	61.2
1925	†26.2	†58.5	84.7
1927	32.9	68.5	101.4
1932	36.0	63.4	99.4
1937	48.3	98.2	146.5
1942	69.1	164.0	233.1
1947	83.1	224.2	307.4
1950	100.9	287.8	388.7

* In some cases will not add due to rounding.
† Estimated.

SOURCE: Federal Power Commission, Electric Power Statistics 1946–51, Bureau of the Census, *Historical Statistics of the United States, 1789–1945*, p. 156, Series G—171–182.

Most of the electricity in the United States is produced by privately owned utility companies, although a significant portion is also accounted for by industrial concerns that supply their own power and by municipally owned, cooperative, and federally owned facilities. The pattern of production in 1950 by ownership of generating plants is shown in table II.

FUTURE DEMAND AND SUPPLY

The Nation's demand for electricity is expected to continue to rise rapidly up to 1975, though at a somewhat slower pace than in the past. In the 25-year span from 1925 to 1950, total national output of goods and services approximately doubled while consumption of electricity increased 3½ times. If total national output should double again from 1950 to 1975, demand for electricity may increase 2½ times. This projection, prepared by the Commission's staff, is, of course, only a rough approximation intended to suggest the general magnitude of probable increase.

TABLE II.—*Electric energy generation by type of ownership*

[Billions of kilowatt-hours]

Generated by—	Thermal	Hydro	Total	Percentage of grand total
Privately owned electric utility corporations	217	51	268	68.9
Privately owned industrial plants	54	5	59	15.2
Municipal and cooperative electric systems	15	7	22	5.6
Federal electric systems	2	38	40	10.3
Total	288	101	389	100.0
Percentage of grand total	74.0	26.0	100.0	

SOURCES: Edison Electric Institute, *Statistical Bulletin* #18, July 1951. Federal Power Commission, "Production of Electric Power in the United States," monthly reports, 1950 and 1951.

Table III shows this 1975 projection by main classes of customers and for each class compares the 1925–50 percentage increase with the projected increase from 1950 to 1975. A fuller explanation of these 1975 projections is given in volume II of this Report ("Projection of 1975 Materials Demand").

TABLE III.—*Consumption of electric energy in the United States, actual, 1925 and 1950; projected, 1975*

[Billions of kilowatt-hours]

Class of consumer	1925 [1]	1950 [1]	1975	Percent change	
				1925 to 1950	1950 to 1975
Residential [2]	6.5	74.5	311	1,046	317
Commercial [3]	8.9	50.4	194	466	285
Industrial: [4]					
Major electro-process	4.1	37.5	207	815	452
Other	53.2	160.6	470	202	193
Miscellaneous	1.0	10.7	25	970	107
Total consumption	73.7	333.7	1,204	353	260
Losses [5]	11.0	55.1	196	400	256
Total generation	84.7	388.8	1,400	359	260

[1] Edison Electric Institute.
[2] Includes farm customers.
[3] Small light and power sales of electric utilities.
[4] Large light and power and railway sales of electric utilities, plus generation for industrial use in nonutility plants.
[5] Losses incurred in transmission and distribution.

EXPANSION OF GENERATING CAPACITY

In order to meet the projected electric power needs during the next 25 years, generating capacity would have to be increased by about two and one-half times the 1950 level, that is, from some 83 million kilowatts to close to 300 millions, on the basis of the 1950 relationship of capacity to production. Including a small amount for replacements, this would mean an average gross addition of close to 10 million kilowatts of capacity each year. By comparison, the gross additions in 1950 were about 7 million kilowatts and in 1951 about 8 million. The projected rate of expansion is readily feasible, though meeting these requirements would necessitate some expansion of the heavy electric power equipment manufacturing industry, would place a heavy load on the construction industry, and would call for large amounts of materials. It would also necessitate a sustained high rate of capital investment in electric generating and transmission facilities, especially by private utilities. To avoid shortages that might inhibit economic growth and perhaps impose costly dislocations in the areas affected, this expansion of generating capacity will have to be timed to pace the growth of demand in each region and locality.

A sufficient and timely rate of expansion by the private utility industry might be impeded by uncertainty of investors as to future markets and earnings, by financing difficulties, shortages of material and equipment and the like. In the past, the expansion of Federal hydroelectric facilities—the planning, authorizing, and appropriating procedures—has been time-consuming and inadequately geared to the rate of growth of demand. Unless deterrents to private expansion are averted, and unless orderly and more expeditious procedures for public hydro expansion are developed, future growth and security will be hampered.

BASIC ENERGY SOURCES FOR ELECTRICITY

Corresponding increases would have to take place in the total supply of basic energy for generation of electricity—in the aggregate supply of developed water flows and of coal, gas, and oil fuels, though the proportions of these several sources might change. This fact raises three crucial questions: can the energy resources of the United States support such a large expansion of electricity production? Can such expansion occur without encountering increases in the real costs of electricity large enough to have a deterrent effect on economic growth? If war should break out before 1975, will there be enough electricity to support a maximum effort?

The growth of electricity production has imposed a steadily increasing load upon the basic energy resources of the United States. At the same time a great shift has occurred in the "mix" of basic energy sources used for generating electricity. These changes are shown in table IV.

TABLE IV.—*Primary energy sources used for electricity production in the United States, 1925 and 1950* [1]

Source	Amount of basic energy consumed		Kw.-hr. produced (billions)	
	1925	1950	1925	1950
	Millions of short tons			
Coal	53	113	52	191
	Billions of cubic feet			
Gas	67	777	3	55
	Millions of barrels			
Oil	15	93	4	42
Total thermal production			59	288
	Millions of kw. capacity			
Hydroelectric	7	19	26	101
Grand total			85	389

[1] Includes electric utilities and industrial user-owned generation.

SOURCE: Federal Power Commission.

Hydroelectric production multiplied fourfold from 1925 to 1950, but its contribution to total electricity supply nevertheless fell from nearly one-third to one-quarter in this period. There still remains a considerable undeveloped hydroelectric potential in the United States that could be economically used, but it is physically limited and is clearly inadequate to provide more than a fraction—perhaps one-quarter, at best—of the expanded supply of electricity needed between now and 1975. The bulk of expansion will have to be provided by thermal (fuel-fired) generation.

Thermal generation actually carried the largest part of the growth from 1925 to 1950, with an almost fourfold increase in supply and with its contribution to total electricity supply expanding from just over two-thirds in 1925 to about three-fourths in 1950. During this period oil and natural gas expanded dramatically as major fuel sources for electric generation; the contribution of oil for this purpose rose to 10 times and gas to 18 times. Coal's contribution, on the other hand, increased to less than fourfold; whereas coal supported nearly nine-tenths of thermal generation in 1925, it accounted for only two-thirds by 1950.

Though the extent of future discovery and production of petroleum and natural gas in the United States is uncertain, as discussed elsewhere in this volume of the Commission's Report, vast reserves of coal and lignite give the Nation the resource base for a tremendous expansion of thermal electric generation.

WILL COSTS OF ELECTRICITY RISE?

The big question remains as to whether an expansion of the magnitude indicated above can be accomplished without substantial increases in the real cost of electric energy.

The general economic objective of keeping costs of all materials as low as possible applies with particular force to electricity, because it enters into the cost of practically all goods and services produced in the economy and into the budget of nearly every family. Even though electricity typically represents only a small fraction of total production costs for most items, a substantial increase in its real costs, reflected in correspondingly higher prices to industrial and other consumers, could have a considerable retarding effect on economic growth. The impact would be particularly serious upon the electro-process industries, which thrive because of low-cost electric power and upon which the United States must depend heavily for solving some of its difficult materials problems. Table V shows the electricity requirements for selected materials whose growth will be highly important to the United States economy from now to 1975.

In the manufacture of aluminum, for example, reduction plants require approximately 9 kw.-hr. of electric energy for each pound of aluminum produced. At about 2 mills per kw.-hr., the cost of energy per pound of aluminum is close to one-tenth of the present price of the metal. Each increase of 1 mill in the cost of power, therefore, results in an increase of nine-tenths of a cent in the cost of the metal, or nearly a 5 percent increase in the total price. Relatively small price changes in such materials as aluminum may affect considerably their competitive position and the extent of their long-run growth.

TABLE V.—*Power requirements for selected electro-process materials*

	Approximate kw.-hr. required per ton of product
Titanium metal*	40,000
Aluminum metal	18,000
95 percent silicon metal	17,500
Electrolytic magnesium	16,000
35 percent hydrogen peroxide (100 percent basic)	16,000
Electrolytic manganese	10,200
Silicon carbide	8,600
70 percent ferrotungsten	7,600
Sodium chlorate	5,200
Rayon	5,200
Phosphoric acid (via electric furnace)	3,900
Electrolytic zinc	3,400
Chlorine	3,000

*Kw.-hr. per pound of titanium from the President's Materials Policy Commission staff report on titanium.

SOURCE: Adapted from chart of "Process Power Requirements," *Chemical Engineering*, March 1951, p. 115.

Changes in production technology will probably increase the number of electro-process materials and will enlarge the power requirements of many other materials by 1975. Broadly and over the long-run, as important materials like copper become more difficult to obtain, the Nation will need to develop substitutes, such as aluminum, to replace them. Moreover, as high-grade reserves of important minerals dwindle, more electric energy will be needed in some cases to use lower grade ores. To mine and concentrate the low-grade iron ore of the Lake Superior region will require 75 to 80 kw.-hr. per ton of concentrates as compared with an average of 3 kw.-hr. per ton of usable high-grade ore. [*1*] Unless sufficient electric energy is available at favorable costs the expansion of substitute materials and of output from low-grade ores will be retarded.

Until fairly recently, electro-process industries have turned mainly to large-scale hydro sources for low-cost energy, such as the Shawinigan Falls development in Quebec, the Niagara Falls developments in Ontario and New York, and the Government hydroelectric systems in the Tennessee Valley and in the Pacific Northwest. As the general utility demand for electric energy has grown in these limited areas of low-cost hydropower, however, the electro-process industries have been increasingly unable to compete with the prices offered by other industries and by general utility consumers. Today most of the power from Shawinigan Falls is used for general utility purposes, and large blocks of additional low-cost hydroelectric power will not be as readily available at Niagara Falls or in the Tennessee Valley for the expansion of electro-process industries as they have been in the past. The growth of general utility requirements will in time encroach upon all these low-cost hydropower supplies, including those now being developed. Accordingly, there will be need for a large-scale expansion of low-cost electricity supplies from fuel-fired generation.

The great contribution of electricity to the economic growth of the United States to date has resulted not only from the tremendous expansion of supply and use, but also from the decline in real costs and real prices of electricity. Between 1925 and 1950 the average price paid for electric power by industrial and commercial customers, adjusted for changes in the purchasing power of the dollar, dropped 58 percent, and by residential users 70 percent. The declining real costs of electric power reflected in these falling prices to consumers were made possible primarily by steady technical advances in the production, transmission, and distribution of electricity, by the economies inherent in larger volume operations and sales, and by declining fuel costs.

There is serious question whether a reversal of this long downward trend in the cost of electric power can be prevented. Several factors tending to push the cost upward are already at work and others are in the offing.

First, future increments of hydropower will cost more on the average than present hydroelectric supply, which for the Nation as a whole now has an average cost lower than thermal electricity. A few large, low-cost hydro sites remain to be developed. There are other available sites that can be economically developed, but they will entail higher average costs for the electricity produced.

Second, the real cost of oil and particularly natural gas for thermal generation may rise considerably, thus forcing up thermal electric costs. If limited supplies and higher costs of oil and gas force a greater shift to coal, there will be an additional upward pressure on electric generating costs insofar as oil and gas are presently cheaper sources of energy than coal in certain areas.

These increases in real cost are exclusive of upward changes in money costs that might result from general price inflation, higher wage rates, increased property taxes and the like.

THE PROBLEM OF SECURITY

If war should break out, a burden would be thrust upon the electric power industry and those industries that supply it, as demonstrated by the experience of the Second World War. Not only did the requirements of many existing industrial customers increase considerably, in line with increased demands for their products, but there emerged a new demand for large blocks of electric power to support new industrial capacity, as in the case of aluminum. Fortunately the Nation entered the war with a comfortable cushion of generating capacity and large blocks of new hydro capacity nearing completion. Even so, generating capacity had to be expanded considerably, in spite of some displacement of nonessential civilian loads. Altogether, total production of electric power increased from 180 billion kw.-hr. in 1940 to 280 billion kw.-hr. in 1944, a rise of 56 percent. Generating capacity rose in the same period from 51 million kw. to 62 million.

In the event of another war, there would be similar need for a cushion to provide a fast increase in electric energy supply to match the upsurge of industrial demand. In coming years the expansion of generating capacity must not simply keep in step with rising peacetime demand but a step ahead in order to insure a security cushion.

There is always the strong possibility of enemy air attack on United States cities and industries. In order to meet emergency needs for electricity in particular areas resulting, for example, from damage to generating facilities in such areas, or simply from abnormally heavy industrial war demands there, it would be important to have maximum flexibility in obtaining electric power supplies from other areas. Such flexibility requires the full development of high-voltage transmission interconnections within power regions and of tie lines between regions. Most of these would have significant economic value in peacetime and all would be of great importance in case of war.

EXPANSION IN FUEL-ELECTRIC GENERATION

As indicated earlier thermal generation will probably have to supply at least three-quarters of the needed growth in electric energy supply up to 1975. Beyond 1975 thermal generation will have to carry an even larger share of the growth load. Opportunities for achieving this expansion and at the same time holding costs to a minimum are promising. They lie in two main directions: (1) raising the engineering and economic efficiency of generating plants and (2) reducing fuel costs. Opportunities to reduce transmission costs and to secure advantages from fuller integration and coordination of electric systems apply also to hydroelectric power and hence will be treated later.

INCREASING THERMAL GENERATION EFFICIENCY

Great advances have been made over the last 25 years in raising the efficiency of fuel-fired generating plants, with the result that plants being built today are far more economical to operate than many older plants with smaller units still in use. As time goes on, these older, high-cost plants will be retired and this shift will exert a downward influence on average thermal generation costs. A recent study by the Federal Power Commission compares the cost performance of generating stations having more than 75 percent of capacity installed after 1931 to stations having more than 75 percent of capacity installed prior to 1931. [2] The comparison assumes equivalent fuel costs and operating plant factors for the various plants, and is based on stations of roughly equivalent size.

The study shows that average over-all production costs in the more recently constructed stations were close to 25 percent lower. All cost components except supervision and engineering were less; labor costs were 15 percent less; maintenance, 43 percent; water, supplies, and other expenses, 18 percent; and fuel costs, 21 percent.

The same study indicates that substantial economies are enjoyed by large stations (of about 100,000 kilowatt capacity) as compared with small ones; their total costs tend to be 25 to 40 percent lower. The trend is toward such large, low-cost plants with larger units. The average capacity of stations installed from 1942 to 1946 was about one-third larger than in the period 1927–31, and the average size of stations being installed today is considerably greater than in 1946.

Data published annually by the Federal Power Commission during the subsequent years 1947 to 1951, inclusive, bear out these general conclusions. [3] Despite higher construction costs, higher operating labor and fuel costs the total costs have been further reduced in many instances. This is attributed to betterment of thermal efficiencies with larger units operated at higher pressures and temperatures and reduction of investment costs through elimination of part or all of the relatively expensive station building. Continuous operation at high capacity factors has also been an important factor in the relatively low kw.-hr. costs of these new postwar plants.

Fuel costs constitute about 75 percent of "production costs" and 50 percent of total costs, including capital allowances but excluding taxes of thermal stations. Consequently, improved thermal efficiency represents a major approach to reducing costs. Around 1900, somewhat more than 7 pounds of coal were required to generate one kilowatt-hour of energy; by 1925, only 2 pounds were required, and by 1950 only 1.9 pounds. Further improvements cannot be expected at the same rate, but a one-third reduction by 1975 below the 1950 figure seems possible, as against the 40 percent decline in the preceding quarter century, and the 70 percent decline between 1900 and 1925.

A more specific example of cost-reducing opportunities may be obtained from a comparison of costs in three reasonably comparable steam plants in Washington, D. C., where installations were made at three significantly different periods: the 1920's, the 1930's and early 1940's, and in 1949–50. In spite of size and plant-factor differences, the three plants may be compared, in rough terms, for cost indications. Total production expenses per kw.-hr. during 1950 in the most recent and modern plant were about 20 percent lower than in the intermediate-age plant, and about 50 percent lower than in the oldest plant. Fuel expenses per kw.-hr., with all three plants using coal at roughly the same purchase cost, were about 15 percent lower in the most modern plant than in the intermediate-age plant, and 35 percent lower than in the oldest plant. Corresponding figures were 33 and 70 percent for operation labor, supervision, and engineering: and 68 and 90 percent for maintenance (including labor, material, and other expenses). Average B. t. u. consumption per net kilowatt-hour generated was 10 percent lower in the newest plant than in the intermediate-age plant, and 30 percent lower than in the oldest plant.

WAYS TO HOLD DOWN FUEL COSTS

There are also opportunities for holding down the costs of the fuels themselves. These are discussed in more detail elsewhere in this volume in the chapters on oil, gas, and coal but deserve brief mention here.

Since fuel-fired generation of electricity has wide flexibility in choice of fuel, there is always incentive to use the lowest cost fuel or combination of fuels, often in conjunction with hydro-generation. Large amounts of natural gas are accordingly used in those areas, particularly in the Southwest, where gas is indigenous and relatively cheap as compared to coal, which must be transported from mines far away. Whether or not natural gas will in the future be abundant enough and cheap enough to be competitive with coal for thermal generation in areas distant from gas fields, it is likely that gas will remain in heavy use for this purpose in gas-producing areas up to 1975. Similarly, fuel oil is likely to remain an important fuel for thermal generation in areas with large refinery capacity. Conceivably oil and gas will be sufficiently abundant to account for a considerably higher proportion of total fuel for electric generation than at present; if not, coal can move in to take up the slack. In any event, coal will remain the predominant fuel for electricity production for the Nation as a whole, and it offers the greatest opportunities for holding down fuel costs. Table VI illustrates how electricity requirements around 1975 might be met from various basic energy sources, assuming relatively favorable gas and oil supply conditions.

TABLE VI.—*Primary energy sources and production of electricity, 1950, and a possible pattern of sources and production, 1975*

Source	Consumption of basic energy		Kw.-hr. production (billions)	
	1950	1975	1950	1975
	Millions of short tons			
Coal	113	320	191	800
	Billions of cubic feet			
Gas	777	1,600	55	150
	Millions of barrels			
Oil	93	300	42	150
Total thermal production			288	1,100
	Millions of kw. capacity			
Hydroelectric	19	60	101	300
Grand total			389	1,400

During 1950, the average cost of coal at the mine was close to \$5 a ton, though it was as low as \$1–\$2 per ton at open pit mines. To this must be added the cost of transportation, unless the steam-electric generating plants are located in the vicinity of the mines. Transportation costs in 1950 averaged about \$2 per ton and in some areas considerably higher. There are tremendous possibilities, discussed in the coal chapter of this volume, for improving techniques of coal production, preparation, and transportation and thereby exerting a downward pressure on thermal generation costs. The electric power industry itself can take action to reduce coal costs in many cases by installing thermal stations directly at mine heads, thus substituting the cost of transmitting electric power to customers for the cost of shipping coal to generating stations near customers.

Another saving opportunity exists in the use of inferior solid fuels. Prior to 1939 approximately half of the electric power production in Germany came from "braunkohl" plants, which produced not only power but also briquets, chemicals, and liquid fuels from lignite and sub-bituminous coals. In the United States there are extensive deposits of such low-grade coals that can be strip-mined at low cost and that can be competitive with other fuels after realizing the coproducts yielded by low-temperature carbonization. The plan to use lignite for power at a large aluminum reduction plant now under construction in Texas is based on evidence that power may be produced at satisfactory costs from such lignite char. Since the B. t. u. content of lignite or char per ton is too low to stand the costs of transportation, the power must be generated near the lignite beds. While this limits the market for lignite to produce power for general utility use, electro-process plants may find it profitable to locate near such energy sources. For example, power plants near lignite beds could perhaps be developed for base-load electric energy production in such areas as the Dakotas and Montana to supplement Missouri River hydroelectric developments.

If these various opportunities are vigorously pursued, there is a strong possibility that the costs and prices of thermal electricity for most areas of the Nation can be kept from rising (in relation to the general level of prices) and perhaps even further reduced.

OPPORTUNITIES IN HYDROELECTRIC ENERGY

Hydroelectric power has the advantage of being based on a nonexhaustible source of energy—the constantly replenished flow of water in rivers and streams. In some areas it also has the advantage of providing electric energy at substantially lower costs than thermal generation.

Cost accounting complexities make it difficult to compare costs of hydro and thermal generation with precision, particularly if comparisons are attempted between Government multipurpose projects and private steam plants. Information compiled by the Federal Power Commission on total costs of privately owned electric utilities provides a valid basis, however, for concluding that on the average the cost of electricity supplied today by hydro plants is substantially below the cost of electric energy from thermal plants. Wide variations in cost exist, of course, among individual plants in each category. Moreover, wherever it is necessary to supplement hydro with thermal capacity to meet market loads, the benefits of the low-cost hydro energy can be fully achieved only by incurring the higher cost of the complementary thermal energy.

Enabling legislation has made it possible to develop rivers for irrigation, navigation, flood control, recreation, and pollution abatement along with development for electric power. During the past 50 years there has evolved a concept of multipurpose development that is now embodied in Federal policy with respect to water resources. In many areas there is a growing need for the nonenergy functions served by these projects. Without hydroelectric power production, however, many multipurpose projects would not be economically feasible since all purposes share the costs of development. Similarly, hydroelectric power costs also may be lower because of this sharing of joint costs with other purposes.

Unfortunately there is a definite limit to the number of sites in the United States at which low-cost hydropower can be developed, though such sites have by no means been fully utilized.

FUTURE EXPANSION POSSIBILITIES

The Federal Power Commission has estimated that the total hydroelectric power potential of the United States is about 105 million kilowatts, with an average annual generation potential of about 478 billion kilowatt-hours. This estimate (which excludes small sites of less than 2,500 kw. potential) is necessarily subject to many qualifications and later revisions but in the view of the Federal Power Commission it nevertheless serves to indicate the long-range economic waterpower potentialities of the Nation.

At the beginning of 1950, a total of 16.5 million kw. of capacity (excluding sites under 2,500 kw.) was actually installed, only 16 percent of the estimated potential of 105 million kw. The average annual generation from this installed capacity is estimated at 87 billion kw.-hr., about 18 percent of the estimated total potential of 478 billion kw.-hr. Forty-seven projects then under construction would add another 5.6 million kw. of capacity, bringing installed capacity to nearly 22 percent of total potential and average annual generation to about 24 percent of the estimated total potential.

The remaining 78 percent of potential capacity is made up of a wide variety of sites, large and small, low-cost and high-cost, some carefully studied and others only superficially appraised. Sixty-nine projects, accounting for about 12 percent of total potential, were in various stages of planning by Federal agencies and a number of others were being seriously considered by private utilities. More than 1,000 other sites, mostly relatively small ones, were apparently not receiving serious attention by anyone and many of these may upon closer examination not prove economically feasible to develop by 1975. Table VII summarizes these estimates of the Federal Power Commission. The estimates have been based in some cases upon preliminary investigations and must be revised from time to time as additional information is obtained and new studies made. Detailed investigation may find some projects infeasible for physical, economic, or other reasons.

TABLE VII.—*Potential hydroelectric power in the United States* [1]

Status	Number of projects	Installed capacity, kilowatts	Average annual generation, 1,000 kw.-hr.
DEVELOPED POWER			
Federal	55	6, 098, 912	35, 497, 600
Non-Federal [2]	497	10, 401, 359	51, 613, 750
Total	552	16, 500, 271	87, 111, 350
UNDEVELOPED POWER			
Projects under construction:			
Federal	30	[3] 4, 889, 575	[3] 26, 112, 000
Non-Federal	17	[4] 708, 020	[4] 3, 490, 200
Total	47	5, 597, 595	29, 602, 200
Federal projects in planning stage	69	[3] 12, 651, 570	[3] 54, 580, 100
Other projects	1, 695	[5] 69, 820, 960	[5] 306,916,205
Total undeveloped power	1, 811	88, 070, 125	391, 098, 505
Total potential power	2, 363	104, 570, 396	478, 209, 855

[1] SOURCE: "Potential Hydroelectric Power in the United States," Federal Power Commission, May 1950.
[2] 2,500 kilowatts or more installed capacity.
[3] Including additions to existing plants.
[4] Including additions to and redevelopments of existing plants.
[5] Including authorized additions to existing plants and plants under construction.

THE BEST REMAINING SITES

Decidedly the most important and attractive hydroelectric sites remaining to be developed in the United States are those located in the Great Lakes drainage area (at Niagara Falls and on the St. Lawrence) and in the Pacific Northwest (the Columbia River basin).

The principal advantage in energy costs enjoyed by the Great Lakes drainage area and, to a much lesser degree, the Pacific Northwest region is the quantity and continuity of the flow of their principal streams. The Great Lakes form a natural storage reservoir unsurpassed anywhere in the world. This reservoir in part does naturally what storage reservoirs elsewhere must be constructed to do, namely, even out the flow of the rivers that drain the region.

The Columbia River and its tributaries have a large volume of water flowing approximately 1,200 miles from sources in the American and Canadian Rocky Mountains, and dropping as much as 3,000 to 6,000 feet to the ocean. The Columbia runs at flood in summer when the snow on the mountains is melting. Since the snow melts gradually, the river varies less in flow than most other American rivers, but nevertheless still requires a great deal of conservation storage.

The Federal Power Commission has estimated that the redevelopment of Niagara Falls to use additional stream flow, released for power generation by a United States-Canada treaty in 1950, would provide a net increase of 1,132,000 kw. of dependable capacity, and a net increase of 7,884 million kw.-hr. in average annual energy production to the United States. The costs of energy at the site would be very low and would thus make possible economic transmission of electricity over long distances to New York and New England markets at delivered prices well below rates now prevailing in those markets. [4] Even though modern new steam plants could generate power much more cheaply than older existing plants in the latter markets, the costs would still be higher than hydroelectric energy from this project.

The proposed St. Lawrence Seaway and Power project would develop an estimated 12.6 billion kw.-hr. in an average water year, half of which would be available to the United States and half to Canada. Again, the generating costs would be very low, thus making bulk transmission to higher cost distant markets economically feasible and desirable. [5]

In 1950, the Bonneville Power Administration marketed 13 billion kw.-hr. of low-cost electricity from the Bonneville and Grand Coulee plants on the Columbia River. New projects now under construction should increase the power available for marketing to about 37 billion kw.-hr. by 1960. The cost of this increased power may be somewhat higher than at present developed sites, but would still be comparatively low.

Smaller quantities of energy can be produced by projects now planned for construction in the Missouri and the Arkansas drainages, in the South and Middle Atlantic areas, and in other regions. Considerable energy could also be made available by the complete development of New England streams. For most drainage areas except the Niagara, St. Lawrence, and Columbia, however, energy for round-the-clock base load can generally be more economically produced at thermal-electric generating stations. Nevertheless, the proposed hydroelectric plants may have a cost advantage—over thermal capacity having a low-load factor and used for peaking purposes—if they are alternated between storing water at night and operating by day to help meet heavy daytime loads.

In addition to the 16.5 million kw. of hydroelectric capacity installed as of early 1950, another 8 million kw. is now completed or under construction. An additional 8 million of relatively low-cost power could be added by the construction of the St. Lawrence project, the redevelopment of Niagara Falls and by the completion of the immediate programs of the Bureau of Reclamation and the Corps of Engineers on the Columbia River. Plans for these projects are practically complete and need only Congressional authorization and appropriations. Thus it is clearly feasible, within 10 to 15 years, to double the installed hydro capacity over the early 1950 level. In addition, there would remain other sites that probably could be economically developed before 1975. An output of hydroelectric energy on the order of three times the 1950 level might be achievable by 1975.

REDUCING COSTS OF HYDRO GENERATION

The generation of electric energy from falling water is physically a much more efficient operation than the generation of electric energy by fuel. Modern hydroelectric plants have an over-all engineering efficiency of 80 to 85 percent in converting the power of falling water to electric energy delivered to the transmission line. There is thus not much room for improvement.

The main opportunities are in the direction of reducing the initial cost of construction and installation. The costs of producing hydroelectric energy are largely fixed costs, consisting chiefly of interest on investment and depreciation. So-called variable costs, including operation and maintenance expenses, for large modern hydroelectric installations average less than $1 per kilowatt per year [*6*]. They may be as little as one-tenth of a mill per kilowatt-hour. Even these costs do not vary proportionately with output. Construction costs and interest rates are therefore the most important elements in the cost of hydroelectric energy.

The past 25 years have brought important improvements in construction methods for large dams. Especially important have been larger earth-moving equipment, long-distance conveyor systems to move aggregates, and improvements in cement and cement extenders. Continued improvements can be expected in the construction techniques and machinery used for placing mass concrete, and in moving and compacting earth fills for large dams. Such improvements will tend to offset the increasing costs expected in the acquisition of reservoir lands and in the relocation of railroads, highways, and utilities.

Popular interest has been expressed in the long possibility of modifying the wide seasonal fluctuations of stream flows in some areas by artificially inducing rainfall during periods of low stream flow, thereby raising the hydro potential at sites along the river, increasing the utilization of installed generating equipment, and lowering the unit costs of energy production. While this is a theoretical possibility, its practicability, even in the long run, is still questionable.

OTHER OPPORTUNITIES

Additional opportunities to improve both hydro and thermal electric service to particular areas, and to hold down costs, lie in the further improvement of transmission methods, the fuller integration and coordination of individual electric systems, and cooperative planning of expansion.

Because electric plants, particularly at hydro sites, are often located at some distance from markets for electric energy, part of the energy generated is lost in transmission. Losses range from 5 to 15 percent, depending upon distance and line loadings. The opportunity exists for using higher voltages—up to 350,000 volts or higher—in order to decrease transmission losses. There are also other possibilities for reducing costs of long-distance power transmission. In the last 10 years important increases in the capacity of lines have reduced the cost per kilowatt of power transmitted. It is now economically feasible with a high load factor to carry power from 200 miles up to 600 miles at lower costs than only a few years ago.

Significant economies in the cost of electric energy have been achieved in the last 30 years by the coordinated operation of thermal and hydroelectric generating plants of utility systems and industrial firms. Early examples of pooling include the Connecticut Valley Power Exchange and the Pennsylvania-New Jersey interconnection. Wide areas of the United States, such as the Pacific Northwest, now have practically complete coordination of electric utility and industrial power generation through interconnections by high-capacity transmission circuits. An outstanding example is the 17-State power pool which extends from the Gulf of Mexico on the south to the Great Lakes on the north. There remain, however, a number of areas where interconnection is incomplete.

An excellent example of additional opportunities is the proposed California tieline, which would link the major systems in California with the Pacific Northwest Power pool. This interconnection would permit the transfer of energy from the Northwest hydroelectric systems to reduce steam-electric generation in California, directly conserving residual fuel oil in that area. It would also substitute for standby generating capacity that would otherwise have to be installed in the Pacific Northwest in order to meet power requirements in periods of low streamflow.

Another good opportunity is in New England where, because the State of Maine prohibits the export of low-cost hydroelectric power, important hydro potential remains undeveloped. Removal of this restriction would lessen the dependence on high-cost thermal energy for which many New Englanders are now obliged to pay.

As advances in the science of power transmission increases the distance of power transmission and reduces the cost, the size of the integrated areas could be increased and more interregional interconnections would become practicable.

Still greater economies can be achieved if generating faciliaies are cooperatively planned by related systems, whether private or public. Such planning has been achieved to a high degree over large areas of the United States served by private utility systems, as in the Southeast and North Central areas. It has also been achieved by agreement between nonaffiliated utility systems, as in portions of Maryland, Virginia, and Washington, D. C. There are encouraging beginnings of cooperative planning between private utilities and public power agencies. The Tennessee Valley Authority and the neighboring utility systems have made significant strides in cooperative agreements in connection with the power requirements of the Atomic Energy Commission and otherwise. Complete cooperation in the planning of power supplies, however, is still far from achieved in spite of the obvious need.

ELECTRICITY FROM NUCLEAR ENERGY

One of the possibilities of the future is that nuclear fission can be used to generate large amounts of electric power. The process already has been demonstrated on a small scale by the Atomic Energy Commission in an experimental plant at its reactor testing station in Idaho. The same reactor is being used to test the principle of "breeding" atomic fuel, a process by which nonfissionable material may be converted into fuel at a rate more rapid than fuel is consumed in operating the reactor. Successful breeding of atomic fuel would do much to make electric generation economical, in commercial terms, and would help to overcome one of the major blocks against widespread generation of power by considerably increasing the amount of potentially fissionable material.

Most thought, manpower, and materials are understandably being devoted currently to military applications of atomic energy. However, industry is attempting with A. E. C. help in a number of independent surveys to determine how electricity can be produced economically with nuclear reactors. The method under consideration is, in effect, to generate electricity as a byproduct of plutonium production.

At this time, it does not appear that nuclear fission can be regarded as a contribution in any substantial degree to electric generation during at least the next 10 or 15 years, and the probability is that the atomic energy industry will remain a heavy net consumer of electricity.

ELECTRICITY IN OTHER FREE NATIONS

The generation of electric energy in 1950 in all other free countries taken together amounted to almost 400 billion kilowatt-hours, or roughly the same as in the United States. With reasonably favorable developments, the rate of growth in consumption of electric power in these countries as a group should be little if any less than the growth projected for the United States, with the most rapid growth taking place in the comparatively underdeveloped countries.

The combined fuel and hydraulic resources in the rest of the free world are huge, but unevenly distributed. Western Europe has scanty reserves of oil and gas, coal reserves that are increasingly difficult to exploit, and comparatively limited waterpower sites that can be economically developed. Japan and certain parts of South America likewise appear to have limited resources for electric energy generation. But Canada, much of Latin America, the Middle East, India, and Africa should have ample resources of either fuels or waterpower.

In view of the great comparative advantages of hydroelectric generation, the fullest economic development of the free world's waterpower sites appears most desirable. At the present time, about 5 percent of the world's total supply of energy of all types is produced in hydroelectric plants. [7] The total that could be produced annually at known hydroelectric sites in the free world exclusive of the United States, if and when developed, is estimated at more than 3 trillion kw.-hr. compared to about 200 billion kw.-hr. produced in 1950.

If plants were constructed at all of the world's hydroelectric sites, they would produce each year for an indefinite period as much electric energy as could be generated by burning 2 billion tons of coal per year. This is approximately the current rate of world coal consumption for all purposes. These estimates are, of course, necessarily crude and should not be regarded as representing an appraisal of what would in fact prove economically feasible to develop.

The extent to which the world's hydroelectric sites will be exploited in any given period will depend upon a number of factors. In those countries where falling water is the principal undeveloped energy source, development may be much earlier and much more complete than in countries where hydropower is competitive with energy from coal, oil, and natural gas. Comparative costs will be extremely important. If fuels are available for thermal generation, hydroelectric sites will be developed only if they can produce power more cheaply than the thermal plants. In many regions, hydro and thermal generation will have to be developed together for the best results. In some instances, the development of abundant waterpower sites may permit the export of electricity to nearby countries, or the development of important electro-process industries. Canada provides an example of such possibilities.

UNTAPPED HYDRO POTENTIAL IN CANADA

Canada has important waterpower resources that have not yet been tapped. The 9.3 million kw. installed by the end of 1950 are almost entirely in the southernmost 100-mile strip of that country. Estimates of Canadian hydroelectric potential made by the Canadian Water Resources Division place the total at 32 million kilowatts. Competent Canadian engineers believe this to be a conservative estimate, for three reasons: (*a*) it assumes no storage developments; (*b*) it allows for no diversions from one watershed to another; and (*c*) it is based on inadequate streamflow records and incomplete mapping.

All present Canadian developments are single-purpose projects except those contemplated on the St. Lawrence River. The need to control floods, to improve navigation, and to provide for irrigation has not been a problem in Canada because its population is small compared with its land area. Substantial quantities of the undeveloped hydroelectric potential are within economic transmission distance of existing markets. At sites too distant from existing markets for economical transmission, metallurgical, or forest-product plants can be economically developed to use the power. Such a site is now being developed in British Columbia at Kitimat, where the Aluminum Co. of Canada is constructing a hydroelectric plant that will eventually produce approximately 9 billion kw.-hr. per year.

The power will be used for aluminum production and the manufacture of forest products, principally pulp and paper. Similar developments in eastern and northern Quebec may be possible.

A significant part of the potential hydroelectric power development in Canada is on the Columbia River and its tributaries in British Columbia. This can best be developed in cooperation with the United States. For example, an investigation is now being made of a site on the big bend of the Columbia River in Canada where 20 million acre-feet of water can be stored to increase the firm power production of installations downstream, principally in the United States. Only by coordinating the operations of storage reservoirs with the operations of downstream plants can maximum power production be realized. The development of transmission lines for the interchange of power across the boundary, coupled with storage developments, will increase the power available in both countries.

It is presently doubtful that very much Canadian power will be available for use in the United States in view of the established Canadian preference for exporting refined and processed materials (such as petroleum products, pulp, paper, and lumber) rather than promoting exports of raw materials such as crude petroleum, logs, natural gas, and hydroelectric power.

Even if Canadian hydroelectric energy is not available for export as power, it would be possible for the United States to obtain somewhat equivalent results if it were willing to expand its importation of electro-process materials, such as aluminum.

POTENTIALS IN OTHER COUNTRIES

The Mexican hydroelectric potential is not large enough to promise much help to other countries, although it may be significant for the industrial development of Mexico. In South America, Brazil has a significant hydroelectric potential that, coupled with other Brazilian resources, could support local economic growth and contribute to easing the energy problems of other free nations if electro-process materials were produced for export. Peru, Argentina, Colombia, and Venezuela also have significant hydroelectric power potentials.

More than 40 percent of the world's estimated potential of hydroelectric power is in Africa. The Belgian Congo and mandates together have an estimated potential in excess of 97 million kw., while the French Congo has another 37 million kw. Other areas, such as British East Africa, Ethiopia, Liberia, and Portuguese East Africa, have large hydroelectric potentials. Coupled with the mineral wealth of Africa, these hydroelectric potentials could make large contributions both to local economic development and to the production of electro-process materials for the free world. The principal problem involved is the transportation of materials to and from power sources. In most cases, distances appear to be too great to transmit power to either the raw materials or the markets.

In Western Europe known sources of hydroelectric power are about 25 percent developed at the present time, though there is no satisfactory estimate of how much of the balance would be economically feasible. Further development of hydropower would lessen somewhat the general economic strains induced by large imports of Middle East oil and North American coal. Important gains would also be made if existing and futrue hydro plants, mainly in southern Europe, were integrated with the thermal-electric capacity of northern Europe, thereby reducing the cost of electric power and conserving fuel.

Table VIII indicates the estimated size of the principal developed and potential hydroelectric resources of the world. The figures of potential water power are based on minimum flow available for 95 percent of the time and 100 percent efficiency. The effect of storage has been disregarded except for constructed reservoir sites, the potential power being based on the existing flow. The amount of developed power by countries is based on the installed capacity of waterpower at constructed plants, which averages 2 to 4 times, and may be as much as 10 times, the potential power at low flow at the same sites. Thus potential power may be considerably understated, particularly when compared with developed power. This fact should be considered in comparing potential power with developed power and also in estimating the percentage of a nation's waterpower resources that is utilized.

TABLE VIII.—*Principal world sources of hydroelectric power at end of 1950*

Region	Hydroelectric power (millions of kw.[1])	
	Developed	Potential
Africa:		
Angola		4
Belgian Congo and Belgian mandate		97
British East Africa		5
Ethiopia		4
French mandate in Cameroons		14
French Congo		37
Liberia		4
Madagascar		5
Nigeria and British mandate in Cameroons		10
Portuguese East Africa		4
Other		19
Total		205
Asia:		
Chinese Republic		16
French Indo China		4
India, Pakistan, and Ceylon		29
Japan	7	5
Siam and Malay States		4
U. S. S. R.	1	48
Other	2	7
Total	10	113
Europe:		
France	5	4
Italy	6	4
Norway	3	7
Spain	2	4
U. S. S. R.	2	10
Other	12	22
Total	30	51
North America [2]		
Canada	8	25
Mexico	1	6
United States	21	27
Other	1	7
Total	31	65
Oceania:		
Borneo, including New Guinea and Papua		8
New Zealand	1	4
Other		5
Total	1	17
South America:		
Argentina		4
Brazil	2	12
Colombia		4
Peru		5
Venezuela		4
Other	1	12
Total	3	41
Grand total	75	[3] 490

[1] Source gives data in horsepower. Since this Report uses kilowatts, data have been converted by using factor of 0.7457.

[2] Data for Canada and the United States do not agree with data used in this Report because of assumptions of efficiency and because these data are based on minimum flow instead of average flow of streams.

[3] Data are qualified by source, viz: "The estimates of potential power for the United States, Canada, and most of the countries of Europe are based on known sites. For other countries, particularly Asia (except Japan), Africa and South America (except Brazil), the estimates are based mostly on rainfall and topography and therefore are not so reliable."

SOURCE: "Developed and Potential Water Power of the World," Geological Survey, U. S. Department of the Interior, Washington, D. C., 1951.

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