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2Da-II. UNITED STATES AND WORLD RESOURCES OF ENERGY[1]

by

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Submitted by the Government of the United States of America

Abstract

Energy resources must be viewed as a range extending from reserves in known deposits minable at present prices to resources that may become usable in the future through further exploration and technologic advance. Appraised in this framework, domestic resources of the fossil fuels of the types now considered usable contain 950 billion to more than 22 trillion barrels of oil equivalent, and if very low grade organic-rich deposits are included, the potential may be nearly 350 trillion barrels of oil equivalent. World resources contain about 3.9 trillion to more than 80 trillion barrels of oil equivalent, and if very low grade resources are considered the potential may be about 4.3 quadrillion.

The energy potential of uranium resources in the United States ranges from about 35 billion to more than 48 quadrillion barrels of oil equivalent, the larger figure depending not only on the use of low-grade ore but also on the successful development of the breeding process. The energy potential of world uranium resources similarly ranges upward from 58 billion to an order of magnitude of about 850 quadrillion barrels of oil equivalent. The energy potential of thorium resources of the United States ranges from 1.2 trillion to 72 quadrillion barrels of oil equivalent, and of the world from 8.3 trillion to about 1.2 quintillion barrels. If nuclear fusion can be controlled for power generation, the potential energy from resources of deuterium and lithium[6] are orders of magnitude larger than the fissionable mineral resources. Deuterium alone contains potential energy of 1.3 sextillion barrels of oil equivalent. Water power, geothermal energy, solar energy, and tidal power also represent large potential sources.

The almost staggering contrast between the magnitude of known reserves minable at present prices and potential resources minable only at higher prices or more advanced technology underscores the critical importance of research, exploration, and development in meeting future needs.

Introduction

World consumption of energy in 1963 was about 23.3 billion barrels of oil equivalent, of which about 47 per cent was supplied by oil and gas. Per capita consumption in the countries over the world ranged from about 0.03 to 42 barrels of oil equivalent, and averaged about 7.2 barrels. The world average rate of increase in energy consumption during recent years has been about 4.9 per cent per year, although it has been as much as 15 per cent per year in a number of rapidly industrializing nations.

At the recent average rate of increase, by the year 2,000 world energy consumption would reach an annual level of about 137 billion barrels of oil equivalent, about 19.6—22.8 barrels per capita for a world population of 6—7 billion people. Cumulative consumption from 1964 through 2,000 would be about 2,400 billion barrels of oil equivalent—3 times the total used in all previous history. Projections over such long periods are risky, of course, and this one is not intended to be a forecast. Most of the forecasts that have been made assume that the rate of increase will start to taper off within a couple of decades and hence that the annual consumption at the end of the century will be somewhat lower than a projection based on recent trends. In view of the fact that the projected world per capita consumption would still be far lower than even present North American levels, however, it is desirable to aim at an even higher rate of growth for the world at large. The above projection, therefore, may be taken as a goal that we hope will be much exceeded.

How will these growing future demands be met? How long can oil and gas maintain their dominance in the future world energy market? These questions are of special significance to ECAFE countries, for they include on the one hand a substantial part of the world population with below average consumption, and if their economies and levels of living are to attain desired standards they must have access to steadily increasing supplies of energy. On the other hand, some ECAFE countries are currently large producers of oil and gas, and they are concerned about the magnitude of both world markets and competing sources of energy.

To give at least partial answers to these questions, it is pertinent to examine the extent of world energy

[1] From ECAFE document I&NR/PR.3/127.

resources, not only of oil and gas, but other present and potential sources as well. Estimates of United States resources, which are somewhat better known than those in many other parts of the world, are included for comparison.

Most of the estimates that follow were prepared first to serve the needs of the Natural Resources Committee of the Federal Council for Science and Technology [Federal Council for Science and Technology, Committee on Natural Resources, 1963, Research and development on natural resources: Washington, D. C., U. S. Govt. Printing Office, 134 p.], and with some modifications in coverage they have been used for other recent studies undertaken within the Federal Government [see also U. S. Dept. Interior, Energy Policy Staff, 1963, Supplies, costs, and uses of the fossil fuels: Washington, D. C., 34 p. 2 figs.]. They are provisional, not only in the sense that all resource estimates are provisional, but also in the sense that they will be replaced shortly by new estimates currently in preparation by members of the U. S. Geological Survey.

Meaning and Classification of Resource Estimates

Most energy source materials lie hidden beneath the earth's surface and their extent is difficult to determine. Compounding the problem of appraising the magnitude of energy resources is the fact that the kinds of materials usable as energy sources are constantly changing as the advance of technology permits us to recover energy from materials that were once too low grade or too inaccessible to mine, and to utilize materials that were not previously visualized as economical sources of energy.

These factors, of course, combine to enlarge our usable supplies of mineral fuels. Development of geophysical techniques for petroleum exploration, expansion of geologic knowledge concerning the habitat of oil, improvement in drilling techniques, and development of methods of secondary recovery are among the scientific and technologic advances that have made it possible to find and recover a far larger amount of oil than was thought to exist a few decades ago. Similarly, technologic advances in transportation have made possible widespread and quantitatively important use of natural gas, whereas the great bulk of it was discarded before. Uranium and other nuclear materials were not even thought of as commercial sources 25 years ago, and oil shale and other organic-rich shales, not yet used as energy sources except on an insignificant scale, almost certainly will become important in the future.

The concept that supplies of usable minerals are extended by the advance of scientific knowledge forces three important conclusions pertinent to preparation of resource estimates: 1) even though searching estimates are prepared, they can never represent a final inventory of resources of the commodity in question, but are at best a quotation reflecting the status of knowledge of resources at the time the estimates are made; 2) in making and interpreting estimates of mineral resources it is necessary to differentiate between deposits that are known and closely appraised and those that are either not closely appraised or are as yet undiscovered but are believed to exist, on the basis of geologic evidence; and 3) it is necessary to distinguish between deposits that are minable or recoverable at present costs and those that cannot be mined now but might be recovered under more favourable economic or technologic conditions. To appraise the future availability of energy supplies, therefore, several categories of resources are examined:

1) Known recoverable reserves—deposits whose location and general magnitude are established and that are recoverable at or close to present prices and with established technology. Generally, the figures include estimates of other authors described as measured, indicated and inferred, or proved, possible, and probable reserves [for definitions, see F. Blondel and S. G. Lasky, Mineral reserves and mineral resources: Econ. Geol. v. 51, 1956, p. 686-697].

2) Undiscovered recoverable resources — deposits whose specific location is unknown but whose presence and character are indicated by geologic evidence.

3) Known marginal and submarginal resources — deposits whose location and general magnitude are established and that may become recoverable as technology advances or economic conditions change, but cannot be recovered now.

4) Undiscovered marginal and submarginal resources—deposits whose specific location is unknown but whose presence and character are indicated by geologic evidence.

Estimates of reserves and resources depend upon the methods utilized, the assumptions adopted, and the basic information available. Wide divergence in estimates prepared by different observers is therefore not uncommon. Over the past few years, for example, estimates of crude oil "reserves" have ranged from 31 to 590 billion barrels. Some of these are estimates of reserves in known recoverable deposits only, and some include resources that may eventually be found and recovered as technology advances. Some are projections based on existing knowledge or economic conditions, and others assume that technologic or economic changes will take place. And some may be purely statistical projections of the past and present rates of discovery, while others take account of geologic concepts of origin and accumulation.

Knowledge of resources is best represented by estimates that reflect a range of values and assumptions, which is accomplished by the four definitions above and by the estimates given in subsequent tables. The totals presented here are generally larger than those published previously, mainly because the estimates here take more account of undiscovered and marginal resources. Seen in this perspective, the differences in estimates of recent years are not so large as might first appear. For example, the estimate of known recoverable reserves of petroleum in table 1 corresponds to the minimum estimates of recent years; those of undiscovered recoverable resources correspond approximately to estimates of "ultimate" reserves that allow for new discoveries but not much change in technologic or economic conditions. The estimates of undiscovered marginal and submarginal resources represent resources of potential value that are commonly excluded from other resource estimates.

Fossil fuels

The energy content of known United States reserves of fossil fuels recoverable at or close to present prices and with established technology is about 950 billion (950×10^9) barrels of oil equivalent, and that of undiscovered and/or marginal and submarginal resources, minable under changed conditions or higher prices, is a little more than 21 trillion (21×10^{12}) barrels. Of the presently minable deposits, coal contains nearly 84 per cent of the total energy and most of the remainder is about equally divided among petroleum and natural gas liquids, natural gas, and shale oil. Oil shale deposits contain about 28 per cent of the marginal and submarginal resources; shales, not included in the above estimates, containing 10 per cent or more organic matter, hold an energy potential of 38 trillion barrels and those with 5-10 per cent organic matter have a potential of about 275 trillion barrels.

The energy content of known recoverable world reserves of fossil fuels is about 3.9 trillion barrels of oil equivalent. Undiscovered and/or marginal and submarginal resources contain about 78 trillion barrels of oil equivalent (table 2). Shales with more than 5 per cent organic matter probably have an energy potential of nearly 4.3 quadrillion (4.3×10^{15}) barrels.

Nuclear fuels

Known United States reserves of uranium minable at a price of \$5-\$10 per pound of U_3O_8 are about 166,000 tons, and 244,000 tons additional have already been delivered to the Atomic Energy Commission (table 3). Assuming complete burn-up of contained U^{235}, delivered and minable uranium contains about 35 billion barrels of oil equivalent; assuming complete burn-up of U^{235} and U^{238} (possible only with breeding), the oil equivalent is about 5 trillion barrels. Unappraised and undiscovered resources of the same quality as those being mined probably contain oil equivalents of 65 billion to 9.3 trillion barrels (depending on burn-up). Lower-grade uraniferous deposits, which with present technology would cost up to \$100 or more a pound of U_3O_8 to mine, contain energy equivalents of 340 trillion to 48 quadrillion barrels (depending on burn-up). World uranium reserves minable at \$5-\$10 a pound are at least 710,000 tons, with an oil equivalent of 60 billion to 8.6 trillion barrels, and may be far larger (table 4). About 260,000 tons have already been delivered to the United States and other countries of the non-Communist world and should be added to these reserves to indicate the amount available under present conditions. Low-grade resources are enormous. The ocean alone contains nearly 4.2 billion tons of uranium; recent studies indicate that it may be recovered from sea water at a cost of \$13-\$26 a pound. Uranium in other low-grade sources is probably of the order of 70 billion tons.

Thorium will be available as an energy source only when the breeder reactor is practicable, and because it has not been in much demand its resources are not as well known as those of uranium. Known domestic recoverable reserves minable at \$5-\$10 a pound of ThO_2 are 100,000 tons, with an oil equivalent of 1.2 trillion barrels, assuming complete burn-up (table 5). Unappraised and undiscovered resources of the same and lower quality probably contain the oil equivalent of more than 72 quadrillion barrels. World reserves minable at \$10 a pound or less contain the energy equivalent of 8.3 trillion barrels and the energy equivalent in lower grade resources are far larger (table 6).

The fusion reaction now yields only explosion energy. If it can be sustained and controlled for the production of electric power, the natural fuels would be deuterium and lithium[6]. According to Friedman and other [Friedman, I., Redfield, A. P., Schoen, B., and Harris J., 1964, The variation of the deuterium content of natural waters in the hydrologic cycle: Rev. Geophysics, v. 2, p. 177 244], the oceans contain about 2.5×10^{13} short tons of deuterium, the energy equivalent of which is about 1.3 sextillion (1.3×10^{21}) barrels.

2Da-II. Table 1. PROVISIONAL ESTIMATES OF UNITED STATES RESOURCES OF FOSSIL FUELS[a]
(Energy in 10^9 barrels of oil equivalent shown in parenthesis)

	Known recoverable reserves[b]	*Undiscovered recoverable resources*	*Known marginal and submarginal resources*	*Undiscovered marginal and submarginal resources*
Coal (short tons)	220×10^9 (795)	Not estimated	$1{,}400 \times 10^9$ (5,000)	$2{,}600 \times 10^9$ (9,500)
Crude oil (barrels)	47×10^9	200×10^9	40×10^9	300×10^9
Natural gas (cu. ft.)	276×10^{12} (49)	$1{,}200 \times 10^{12}$ (215)	Not estimated	850×10^{12} (150)
Natural gas liquids (barrels)	7.7×10^9 (6)	30×10^9 (24)	Not estimated	60×10^9 (48)
Oil in bituminous rock (barrels)	1.3×10^9	Not estimated	Not estimated	10×10^9
Shale oil (barrels)	50×10^9	Not estimated	$2{,}000 \times 10^9$	$4{,}000 \times 10^9$
Total (rounded) energy	(950)	(440)	(7,000)	(14,000)
Grand (rounded) total, all classes	(22,400)			

Energy equivalents: 1 short ton of coal = 21×10^6 Btu; 1 barrel petroleum, oil from bituminous rock, or shale oil = 5.8×10^6 Btu; 1 barrel natural gas liquids = 4.62×10^6 Btu; 1 cubic foot natural gas = 1,035 Btu.

[a] Compiled by D. C. Duncan and V. E. McKelvey, U. S. Geological Survey. Explanation, definitions, and sources of data are on the following pages.

[b] As defined here, this category includes measured, indicated, and inferred reserves. Estimates of indicated and inferred reserves of oil, gas, and natural gas liquids are not available, however, the estimates shown for them are proved (i.e., measured) reserves and therefore not wholly comparable to the estimates shown for coal, oil in bituminous rocks, and shale oil.

Explanation of resource estimates

Coal. Known recoverable reserves are those in thick coal beds lying at depths less than 1,000 feet, and assume 50 percent recovery of coal in place. The minimum thickness for beds of bituminous and higher rank coal included in the estimate is 3.5 feet and that of subbituminous and lower rank coal is 10 feet.

Known marginal and submarginal resources include coal left in first mining of known recoverable reserves, coal in thin beds at shallow depth, and coal lying at depths between 1,000 and 3,000 feet below surface. The estimate refers to coal in place, and includes coal in the measured, indicated, and inferred categories of P. Averitt, U.S. Geol. Survey Bull. 1136 (with additional data reported by H. Beikman, et al., Washington Division of Mines and Geol. Bull.47), less that reported here in the known recoverable class, rounded to two significant figures.

Undiscovered marginal and submarginal resources refer to coal believed to be in place to depths of 6,000 feet or more. No separate estimate has been prepared of undiscovered thick coal at shallow depths. Compiled from estimates by M. R. Campbell, Coal Resources of the World, 1913, less the sum of known reserves and known marginal and submarginal resources, rounded to two significant figures.

Campbell's estimate of 1913 included coal 14 inches or more thick, extending to depths as much as 6,000 feet below surface, and totalled about 4.2 trillion short tons in place. The estimate included substantial tonnages of coal that is now known to be more than 6,000 feet below surface in some fields. This estimate, which was based on limiting criteria more nearly comparable to those used for world coal resource estimates of the World Power Conferences (30 cm minimum thickness, 1200 m maximum depth for high rank coal and 500 m maximum depth for lignite), is substantially larger than the more recent restrictive estimates of U.S. coal reserves which exclude thin low-rank coal, all coal more than 3000 feet below surface, and most of the undiscovered and incompletely appraised coal. New estimates that are presently being prepared by the U.S. Geological Survey will be somewhat smaller, due in part to the exclusion of thin low-rank coal, and some very deeply buried coal.

Petroleum. Known recoverable reserves include proved reserves of American Petroleum Institute (31 billion barrels as of Dec. 31, 1963) plus reserves economically recoverable by established secondary-recovery methods in practice (16 billion barrels) as estimated by Interestate Oil Compact Commission as of January 1, 1962. The API estimate includes primary reserves plus those secondary reserves recoverable by methods already in practice in each field. The IOCC estimates refer to oil recoverable by established methods but not yet in practice in all fields.

Known marginal and submarginal resources include additional oil in known deposits considered to be physically recoverable by newer secondary-recovery methods but possibly at increased costs. The original oil in place in known deposits is estimated by IOCC to be 346 billion barrels. Production of 73 billion barrels to January 1963, plus primary and secondary reserves of the above estimates total 160 billion barrels or 46 percent of the estimated oil in place. A somewhat larger recovery, as much as 65 percent of the oil in place, is considered possible eventually with future improvements in recovery techniques; hence the known marginal and submarginal resources might be as much as 110 billion barrels.

Undiscovered recoverable resources include oil in possible extensions of known fields and in undiscovered fields thought to be discoverable under present conditions. Both estimates are based on unpublished estimates of A.D. Zapp, U.S. Geological Survey, who derived them from analysis of extent of favorable ground compared with total footage of exploratory drilling completed thus far. For outline of method, see A.D. Zapp, U.S. Geol. Survey Bull. 1142-H. An extension of these studies by the U.S. Geological Survey suggests that the ultimately recoverable crude oil may be more than originally estimated by Zapp. A more conservative estimate of ultimate crude oil reserves of the United States by M. King Hubbert (Nat. Acad. of Sci., Pub. 1000-D, 1962), totals 175 to 225 billion barrels. Hubbert's estimate included past production and was based largely on projections of past production and proved reserves.

Undiscovered marginal and submarginal resources include oil thought to be present in less favorable areas, at greater depths, and in less productive accumulations than those considered commercially usable under present conditions.

Natural gas. Known recoverable reserves include proved reserves as of the close of 1963, from American Gas Association and American Petroleum Institute. No estimate has been prepared of known marginal and submarginal gas resources.

Estimates of undiscovered recoverable resources are based on a ratio of 6,000 feet of gas discovered per barrel of oil. Recent estimates of this ratio range from 6,000 to 6,000 ft. of gas per barrel of oil, and hence the undiscovered recoverable resources of gas may be as high as 1,500 or $1{,}600 \times 10^{12}$ cu. ft.