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Oil reserves and production

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The growth of world energy requirements over the last two decades has created an increasing demand for crude oil. Production has doubled in each of the decades to meet the demand and it is forecast that the demand for crude oil will continue to increase to 1985. The annual production rate has now reached the level of the average annual discoveries over the last 25 years, and the remaining proved recoverable reserves will probably decline continuously as production rates continue to grow. The declining reserves will be insufficient to support the forecast demand after about 1978 when the demand may be limited by the availability of crude oil. It is estimated that about half of the ultimate recoverable reserves have been found to date. The discovery of the remaining reserves will present difficult technical problems.

1. INTRODUCTION

Petroleum occurrences are widespread in the sedimentary basins of the world but petroleum accumulations that are large enough to justify production operations and hence classification as a reserve are less frequent. The minimum size of accumulation needed to justify production depends on the economics of the operations and reserves are therefore influenced by economic circumstances. The reserves, production and demand for oil discussed in this paper are based on the technical and economic circumstances foreseen in September 1973. The economic situation has been changed already by price increases introduced by the producer countries, one effect of which will be to make alternative fuels more competitive with oil and thus eventually tend to lower the demand for oil.

Reserves and production of the U.S.S.R., Eastern Europe and China are not considered in this paper, and unless otherwise stated the world reserves and production do not include the resources of those countries.

The proved recoverable reserves are the volume of oil remaining in the ground which geological and petroleum engineering information indicate with reasonable certainty can be recovered in the future from known reservoirs under existing economic and operating conditions.

The ultimate recoverable reserves are the total quantity of oil that will be recovered from sedimentary rocks of the world and are the sum of cumulative production to date, present proved recoverable reserves and estimated recoverable reserves still remaining to be discovered.

The reserves/production ratio is derived from the proved recoverable reserves at the end of a year and the annual production for that year. This ratio provides a useful relationship by which to study trends but it does not define the life of the reserves as it does not take account of the pattern of future production. A reserve/production ratio of 10 has become established by economics of the industry in the United States, but in the rest of the world where production developments are less rapid a minimum ratio of about 15, which implies a proportionately larger reserve base, is probably more realistic.

Coal and natural gas are converted to oil equivalents on the basis of their calorific value. Nuclear and hydro-electric power are converted on the basis of the heat value of the electricity generated.

2. GROWTH OF WORLD ENERGY DEMANDS – EXCLUDING U.S.S.R., EASTERN EUROPE AND CHINA

The total energy demand of the world increased at an annual average rate of 4.5% between 1950 and 1970. The annual average growth rate of oil, natural gas and nuclear and hydro-electric power exceeded the growth rate of the total energy demand throughout the period and their share of the demand increased at the expense of solid fuels (figure 1; table 1).

TABLE 1. GROWTH OF WORLD ENERGY DEMAND, EXCLUDING U.S.S.R., EASTERN EUROPE AND CHINA, 1950–1970

	1950	1960	1970	% change, annual average 1950–70
	10^{17} J (10^9 barrels oil equivalent)			
total energy	654 (10.7)	935 (15.3)	1610 (26.2)	+ 4.5
oil	220 (3.6)	410 (6.7)	852 (14.2)	+ 7.0
natural gas	79 (1.3)	165 (2.7)	330 (5.4)	+ 7.0
water power } nuclear power }	12 (0.2)	24 (0.4)	37 (0.6)	+ 6.1
solid fuels	342 (5.6)	336 (5.5)	366 (6.0)	+ 0.2

The annual average growth rate of both oil and natural gas was 7%, a rate of growth which doubles annual production every 10 years. The contribution of oil to the world energy demand requirement increased from 33% of the total in 1950 to 54% in 1970. Over the same period the contribution of solid fuels dropped from 53% of the total in 1950 to 23% in 1970.

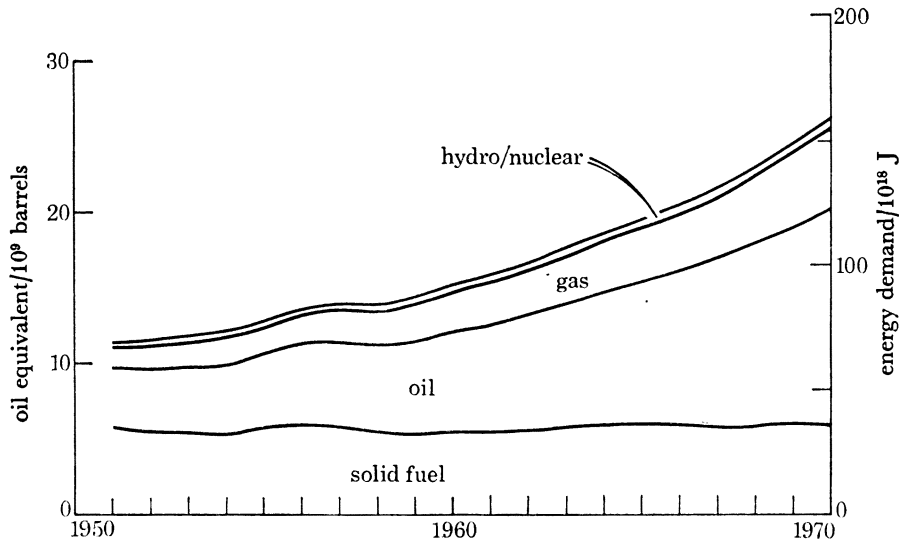


FIGURE 1. Growth of world energy demand, 1950–70, excluding U.S.S.R., Eastern Europe and China.

It is forecast that world economic growth for the next 12 years will continue at a slightly faster rate than in the last 10 years. The continuing population growth and demand for improved living standards will ensure sustained growth in demand for goods and services. Historically, energy demand has moved broadly in line with the growth in national output, though the energy requirement per unit of gross national product (g.n.p.) has tended to decline over time as economies reach an advanced industrial stage of development. For the world as

a whole a continuing slight decline of the ratio of energy to g.n.p. is forecast. The range of annual energy consumption in 1970 from 320×10^9 J (the equivalent of 53 barrels of oil) per head in the United States to 60×10^9 J (10 barrels) for the whole of the world (figure 2) illustrates the potential for growth of demand that exists in the world.

In estimating the world energy requirements, forecasts of economic growth in each major area of the world have been made. While short-term fluctuations in supply and demand and Government intervention could change the energy demand, it is considered unlikely that the pattern of social and industrial usage of fuel will change significantly during the next 5 years. General awareness of a potential energy shortage may have a longer term effect on demand patterns which is difficult to quantify.

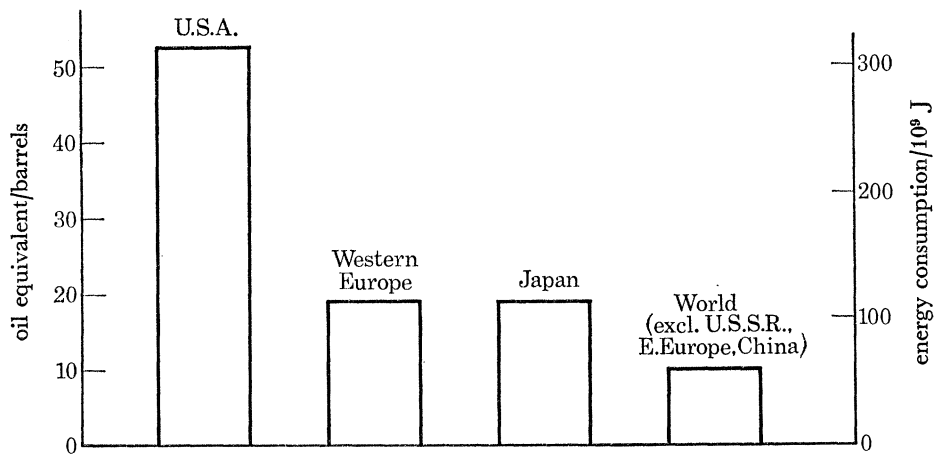


FIGURE 2. Primary energy consumption per head of population, 1970.

In forecasting the energy requirements to 1985 it has been assumed that economic growth will not be limited by energy supplies during the period under review, and the level of oil demand is forecast after taking into account the likely supply of other fuels (figure 3 and table 2). It is forecast that the world energy demand will grow at an annual average rate of 5.3%, and after allowing for the likely growth of other fuels, the oil supply will be required to grow at an annual average rate of 5.5% to satisfy the demand. If this demand is satisfied oil will therefore continue to provide an increasing share of the total energy demand; by 1985 this share is forecast to be 60%. The increase is mainly at the expense of the solid fuels, which it is forecast will supply 16% of the energy demand by that time.

TABLE 2. WORLD ENERGY DEMAND FORECAST 1972-1985, EXCLUDING U.S.S.R., EASTERN EUROPE AND CHINA

	1972	1977	1982	1985	% change, annual average 1972-85
	10^{17} J (10^9 barrels oil equivalent)				
total energy	1730 (28.2)	2240 (36.6)	2900 (47.3)	3380 (55.4)	+ 5.3
oil	980 (16.0)	1330 (21.8)	1750 (28.3)	2020 (33.0)	+ 5.5
natural gas	354 (5.8)	430 (7.0)	550 (9.0)	650 (10.6)	+ 4.8
water power	37 (0.6)	49 (0.8)	61 (1.0)	73 (1.2)	+ 5.0
nuclear power	6 (0.1)	31 (0.5)	67 (1.1)	104 (1.7)	+ 26.4
solid fuels	35 (5.7)	40 (6.5)	48 (7.9)	544 (8.9)	+ 3.4

To meet the potential demand it will be necessary for annual production rates to increase to $5.25 \times 10^9 \text{ m}^3$ (33×10^9 barrels) by 1985, or approximately twice the annual production in 1972. However, the present production forecasts suggest that crude oil availability may limit demand by 1978 and thereafter oil scarcity is a real possibility. Also, if the present estimates of ultimate recoverable reserves are correct, it is unlikely that they will be able to support a production of $5.25 \times 10^9 \text{ m}^3$ in 1985 and maintain a satisfactory ratio of reserves to annual production.

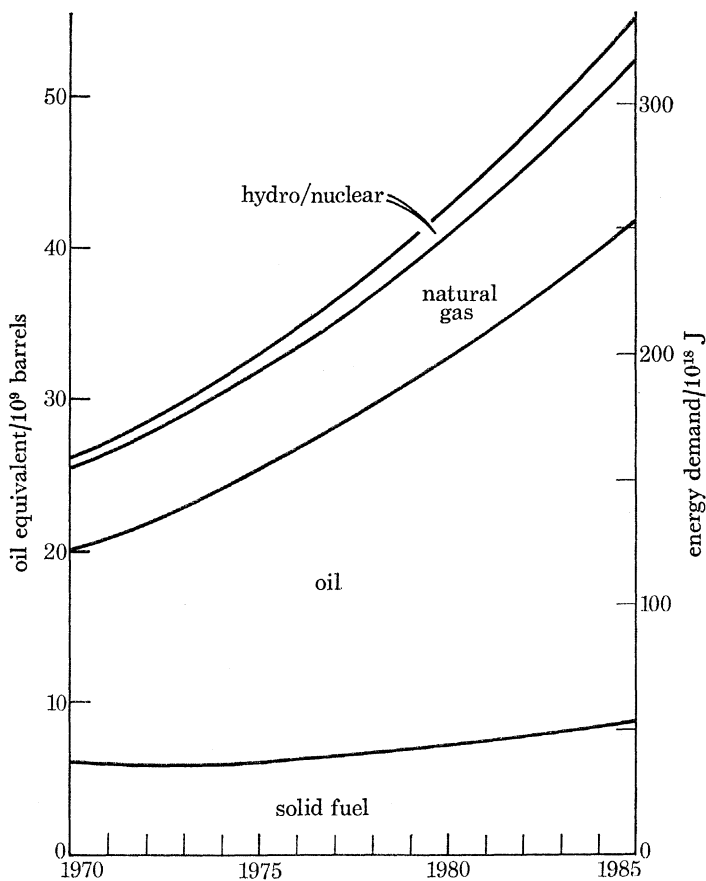


FIGURE 3. Forecast growth of world energy demand, 1973-85, excluding U.S.S.R., Eastern Europe and China.

3. PRODUCTION AND RESERVES

The world's resources of fossil fuel are finite in amount and have been generated in the course of geological time. They are now being consumed at rates that will lead to their exhaustion in a matter of hundreds of years, a negligible period on the geological time scale, and not therefore renewable within the time span of our industrial society.

In the case of petroleum, production has been increasing exponentially at a rate of 7% per annum for several decades. This rate of growth doubles production in 10 years and also doubles the cumulative production during the same period. Production rates have now reached the level at which the cumulative production for a decade represents a substantial proportion of the world's estimated ultimate recoverable reserves and it is obvious that such growth rates can only be supported for a limited period. From the birth of the oil industry in 1859 to 1962 it is

estimated that $18 \times 10^9 \text{ m}^3$ (114×10^9 barrels) of oil, or $7\frac{1}{2}\%$ of the present estimated ultimate recoverable reserves, were produced. By the end of 1972 a further $7\frac{1}{2}\%$ had been produced. Since 1859 oil production has expanded to meet the growing demand for energy but in the next phase of the production history the rate of increase of production must fall, eventually to zero, and thereafter production rates will slowly decline.

The nature of petroleum makes the estimation of the world's ultimate recoverable reserves difficult and various estimates have been published. The difficulties arise from the irregular distribution of reserves, which preclude any simple relation between reserves and sedimentary volumes or basin types, and the special geological circumstances that are necessary for an accumulation to be technically and economically producible. These circumstances occur within sedimentary basins from depths of about a hundred metres to more than 6000 m, which is the probable lower limit for significant oil accumulations. In the last 20 years a number of authorities (table 3) have estimated the world's ultimate recoverable reserves of oil to be between 160 and $400 \times 10^9 \text{ m}^3$ (1000 and 2480×10^9 barrels).

TABLE 3. ESTIMATES OF WORLD ULTIMATE RECOVERABLE RESERVES OF CRUDE OIL

year	source	reserves	
		10^9 m^3	10^9 barrels
1949	Levorsen	238	1500
1949	Weeks	161	1010
1953	MacNaughton	159	1000
1956	Hubbert	199	1250
1958	Weeks	238	1500
1959	Weeks	318	2000
1965	Hendricks (U.S.G.S.)	394	2480
1967	Ryman (Esso)	332	2090
1968	Shell	286	1800
1968	Weeks	350	2200
1969	Hubbert	215-334	1350-2100
1970	Moody (Mobil)	286	1800
1971	Warman (B.P.)	191-318	1200-2000
1971	Weeks	364	2290
1972	Warman	302	1900
1972	Bauquis, Brasseur & Masseron (I.F.P.)	310	1950

It is noticeable that these estimates tend to increase from about $160 \times 10^9 \text{ m}^3$ in the early 1950s to Hendricks' estimate of $400 \times 10^9 \text{ m}^3$ in 1965, and have subsequently settled at about $300 \times 10^9 \text{ m}^3$ (1900×10^9 barrels). The estimates have been made during a period of worldwide and intensive exploration activity using increasingly sophisticated exploration techniques. Knowledge of the extent and prospects of most major sedimentary basins, both onshore and offshore, has been gained from geophysical surveys and well information, and it is reasonable to assume that the later estimates have been influenced by this information. In view of the widespread of present-day knowledge and the increased number of sedimentary basins in which exploration activities have been carried out, it is also reasonable to assume that continued expansion of the estimates of ultimate recoverable reserves is less likely to occur than in the past.

All the figures quoted by the authorities listed refer to the total world ultimate recoverable reserves. The reserves of the U.S.S.R., Eastern Europe and China may amount to some $71 \times 10^9 \text{ m}^3$ (450×10^9 barrels). On the basis of this estimate ultimate recoverable reserves of

about $230 \times 10^9 \text{ m}^3$ (1450×10^9 barrels) is indicated for the rest of the world. Up to the end of 1972 it was estimated that $110 \times 10^9 \text{ m}^3$ (700×10^9 barrels) of oil, or nearly 50 % of the western world's ultimate recoverable reserves had been discovered. Of this total, $36 \times 10^9 \text{ m}^3$ (230×10^9 barrels) have been produced leaving present proved recoverable reserves of $75 \times 10^9 \text{ m}^3$ (470×10^9 barrels). This figure is lower than the reserves now quoted in industry journals, which are believed to include some over-optimistic figures. As it is likely that most of the more easily found reserves – those contained in the giant anticlines, the shallow structures easily detected by geophysical methods, the structures in shallow water – have already been discovered, the task of finding the remaining half of the ultimate recoverable reserves will obviously be more difficult.

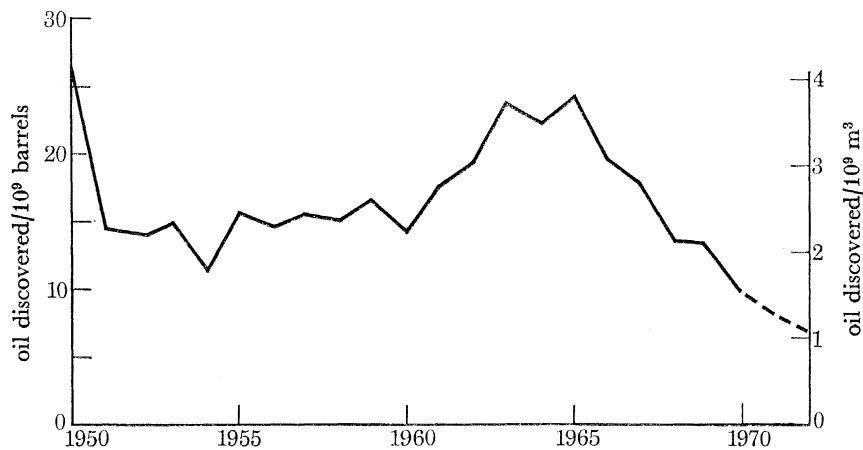


FIGURE 4. World oil discoveries, excluding U.S.S.R., Eastern Europe and China – 5-year running mean.

The problems that lie ahead can be seen from an examination of the historical discovery figures (figure 4). Annual discoveries vary widely from year to year and a five-year running average has been calculated in an attempt to indicate trends in discovery rates. Over the last 25 years, when much of the Middle East reserves were discovered, the average rate of discovery has been about $2.9 \times 10^9 \text{ m}^3$ (18×10^9 barrels) per annum. Although the figures for the last year or two are still subject to revision, they do extend the period in which discoveries have been below average and suggest that the previous discovery rate may not be maintained in the future.

The presently known reserves are extremely irregularly distributed, with 70 % of the total located in a comparatively small part of the Middle East, and the remaining 30 % divided fairly evenly between North America, Africa and the rest of the world (figure 5). The possible future discoveries may be more evenly distributed, with North America and the Middle East each containing about 20 % of the total and Africa about 10 %. The other countries of the world may contain 20 %, while the remaining 30 % may be in presently unforeseen areas and in deep-water prospects. As the technology to exploit the deep-water prospects is still under development, it is doubtful whether this portion of the reserves, if proved, can contribute to production within the period under review.

From 1959 to 1970 the annual crude oil production of the world, excluding the U.S.S.R., Eastern Europe and China, quadrupled from 0.57×10^9 to $2.25 \times 10^9 \text{ m}^3$ (3.6×10^9 to 14.2×10^9 barrels). Until 1968 annual additions to reserves generally exceeded production and the remaining proved reserves increased in this period from an estimated 48×10^9 to $78 \times 10^9 \text{ m}^3$ (300×10^9

to 490×10^9 barrels). Since that date production has exceeded the annual additions, which have been below the average rate of discovery over the last 25 years, and the proved reserves have now declined to $75 \times 10^9 \text{ m}^3$ (470×10^9 barrels). Throughout this period the reserves/production ratio has declined steadily, due to the exponential increase in production rates against a more uniform average rate of discovery of new reserves. The forecast demand for 1974 is $2.86 \times 10^9 \text{ m}^3$ (18×10^9 barrels), which is the 25-year average annual rate of discovery and it is therefore probable that future production will exceed additions to reserves and that the remaining proved recoverable reserves will decline continuously.

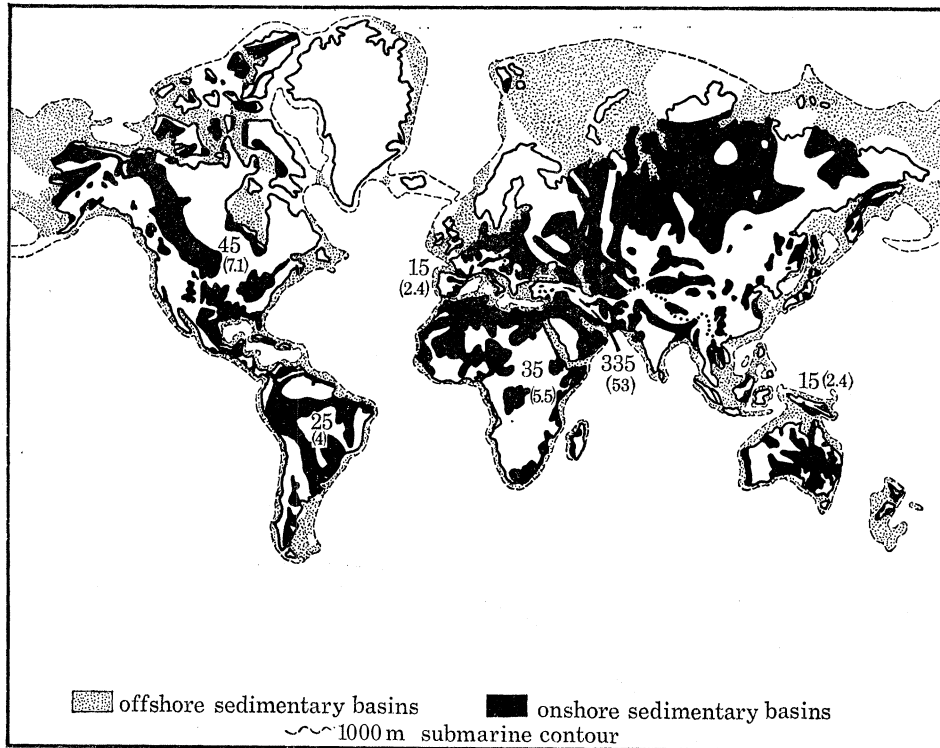


FIGURE 5. Distribution of remaining proved oil reserves – 10^9 barrels (10^9 m^3). Total remaining at end 1972 is estimated to be 470×10^9 barrels ($75 \times 10^9 \text{ m}^3$).

The proved reserves figures quoted above for 1950 to the present are substantially higher than the annually published figures for this period. The figures used here have been obtained by referring the reserves of major fields, that is fields with reserves of more than $80 \times 10^6 \text{ m}^3$ (0.5×10^9 barrels) back to the year of their discovery. As the reserves contained in major fields constitute about 75% of the proved reserves it is believed this procedure gives a realistic assessment of both the reserves and the reserves/production ratio.

The historical curves of annual production, remaining reserves and reserves/production ratio have been extended to 1985, showing both the potential demand and the production forecast (figure 6). The forecasts of production and demand over this period cover a range of values for both quantities. Mean values of supply and demand have been used to demonstrate the probability that demand, which is forecast to increase from $2.7 \times 10^9 \text{ m}^3$ (17×10^9 barrels) in 1973 to $5.25 \times 10^9 \text{ m}^3$ (33×10^9 barrels) in 1985, may be limited by supply after 1978.

In estimating the remaining reserves after 1973 it has been assumed that the increasingly

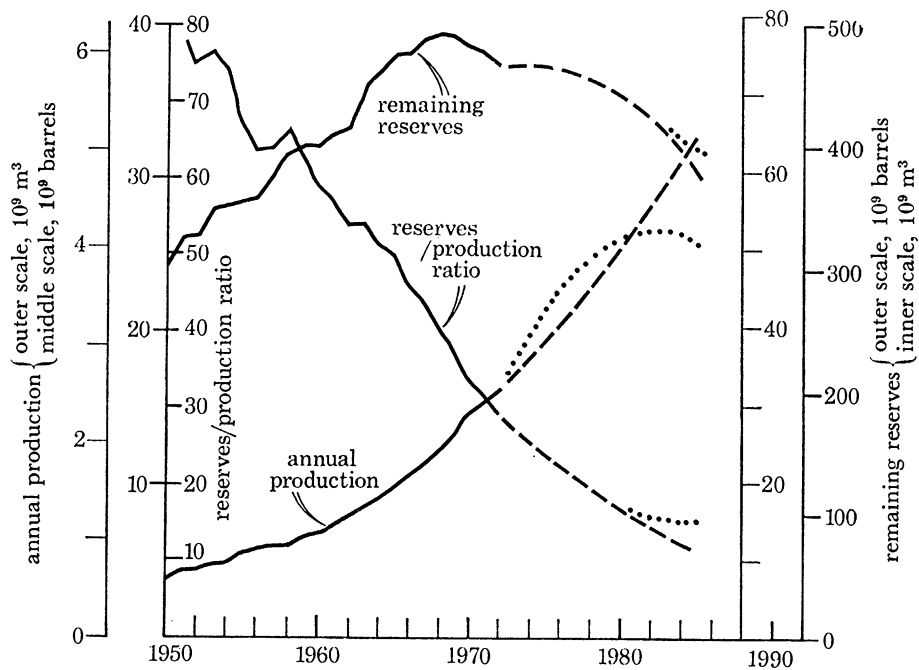


FIGURE 6. World production, reserves and reserves/production ratio, 1950-72 and forecasts for 1973-85, excluding U.S.S.R., Eastern Europe and China. — — —, forecast demand;, forecast availability.

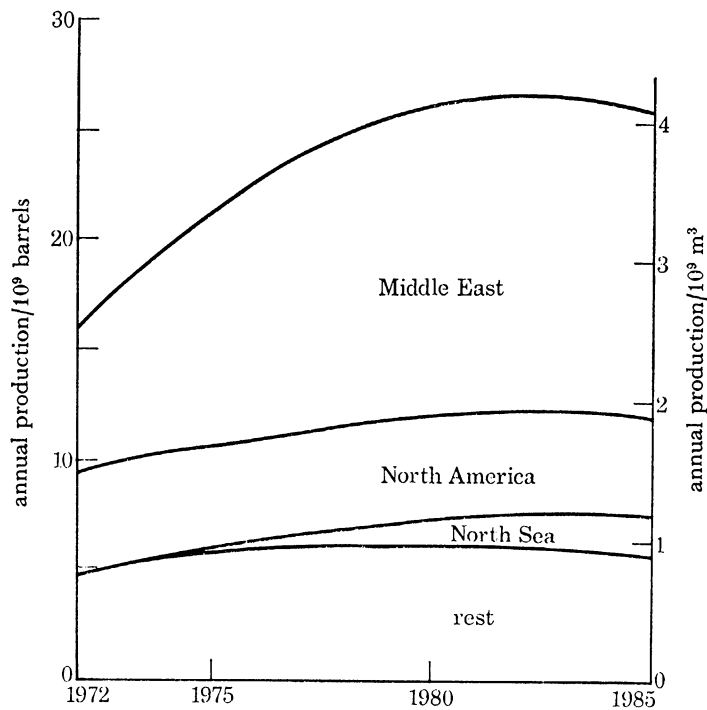


FIGURE 7. Forecast world crude oil production, 1973-85, excluding U.S.S.R., Eastern Europe and China.

sophisticated exploration techniques will maintain the 25-year average rate of discovery of $2.86 \times 10^9 \text{ m}^3$ throughout this period. In spite of this optimistic assumption, the reserves will decline to about $60 \times 10^9 \text{ m}^3$ (380×10^9 barrels) and the reserves/production ratio to 11 by 1985 if the demand forecasts are met. This ratio is considered to be too low and implies a reserve base that is too small to support the production required to meet the forecast demand. The limitation of annual production to $4.3 \times 10^9 \text{ m}^3$ (27×10^9 barrels) in 1982/83 followed by a slow decline of production will allow the reserves/production ratio to be maintained above 15, which is probably a more realistic level for worldwide operations.

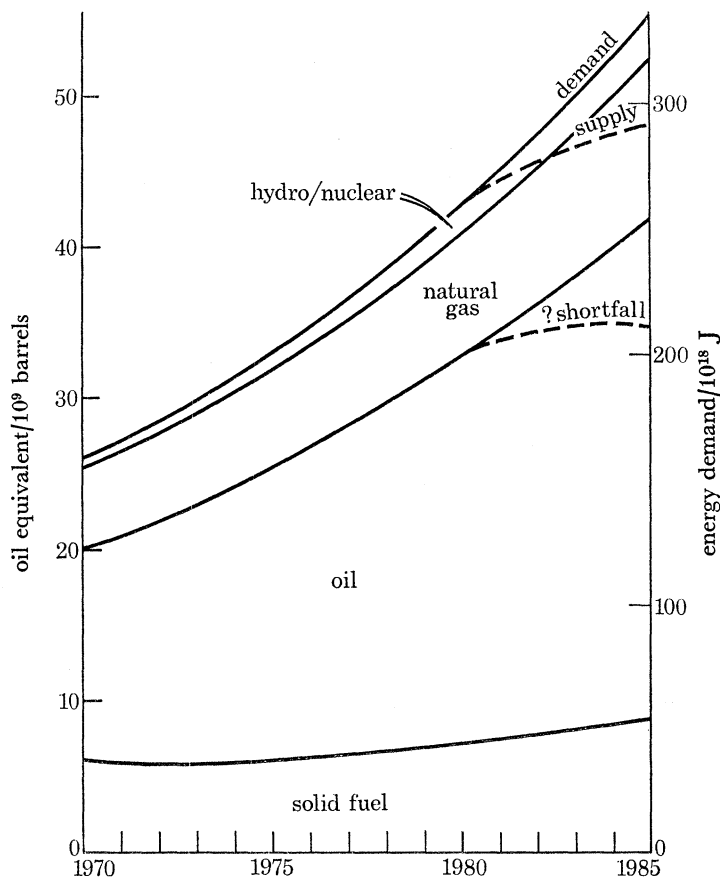


FIGURE 8. Forecast growth of world energy demand, 1973–85, excluding U.S.S.R., Eastern Europe and China, showing the effect of a possible oil shortage.

The production throughout this period will be heavily dependent on Middle East sources (figure 7). The contribution of this area to the total western world production is forecast to increase from 40% in 1973 to 53% in 1985. The North Sea production will amount to 7% of the world supply in 1985.

The possible limitations of demand by a shortage of crude oil has serious implications for the world energy demand. In the case of the mean values of the production and demand forecasts the shortfall would represent 15% of the total energy demand (figure 8) and the growth of energy available would be reduced from 5.3 to 2.4%. It is apparent that alternative energy sources must be developed rapidly if the world's economic growth is not to be restricted by a shortage of primary energy.

Note added in proof (March 1974)

Since this paper was prepared there has been an unprecedented rise in the world oil prices. If the increased prices are maintained it is likely that the medium and long term demand for oil will be less than had been forecast but it is too soon to predict the extent of this reduction. It is also likely that higher energy prices will encourage the production of coal and that solid fuels will regain some of their lost share of the world's primary energy consumption, thereby reducing the demand for oil. The combined effect of increased prices and increased competition from alternative fuels will defer the time at which the demand for oil will be limited by its availability.

Discussion

SIR PETER KENT (*Natural Environment Research Council*)

In a written contribution, Sir Peter Kent wished to emphasize that the discovery situation which had been described in Sir Eric Drake's paper was not likely to be fundamentally changed by new exploration. There are strict physical limits to the possible range of oil occurrences – particularly downwards, for raised temperature at depth precludes survival of liquid hydrocarbons, a depth ranging down to 6000 m under favourable circumstances, but commonly less than 4600 m and as shallow as 910 m in some sedimentary areas.

Not only are seismic survey methods now greatly sophisticated, with an accuracy and penetration far exceeding the standards of only 15 years ago, but virtually all the world's sedimentary basins except for some remote Arctic regions have been subject to at least reconnaissance survey. A good deal is now known also about the deep oceans, and the information is essentially unfavourable.

There are undoubtedly large numbers of small oil-fields awaiting discovery, and probably other areas comparable to the North Sea (of high regional importance) but it now seems quite unlikely that further reserves of the order of the Middle East will be found. Additions of this size would be necessary if the energy demand escalating at the present rate until the end of the 1980s was to be met from hydrocarbon sources.