Outlook for World Oil Into the 21st Century

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The Outlook for World Oil Into the 21st Century, with Emphasis on the Period to 1990

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ABSTRACT

This study attempts to forecast oil supply and demand in the non-Communist world for two periods: 1976-1990 and 1990-2005. Oil is treated as the energy supply of last resort, the balancing item, with special emphasis on oil from the Organization of Petroleum Exporting Countries (OPEC). We first project energy demand, based on forecast economic growths and energy/economic growth relationships. This demand is assumed to be met to the maximum feasible extent from non-oil energy supplies (coal, gas, nuclear power, hydro and geothermal power, and other sources). The resultant total oil demand is then met first from non-OPEC oil supplies, in order to test the demand for and adequacy of OPEC oil supplies under our different energy demand scenarios.

Our findings are that a gradual transition to non-oil sources of energy over the next 25-30 years is more likely than an extended oil shortage of crisis proportions.

EPRI PERSPECTIVE

PROJECT DESCRIPTION

The availability and price of foreign crude oil to the United States through the end of this century are discussed in this final report. It is one of many studies sponsored by the Energy Supply Program to gain a better understanding of the nation's future energy supplies.

PROJECT OBJECTIVES

The objective of this study is a carefully reasoned analysis of the world oil supply demand balance through the year 2000. Even though oil is not anticipated to be a major fuel for power generation by the electric utility industry through the end of this century, electricity will compete with oil imports in residential, commercial and industrial energy markets. Particularly important from EPRI's and the electric utility industry's standpoints, world oil prices will influence the level of permissible costs of energy supplies from new technologies.

CONCLUSIONS AND RECOMMENDATIONS

A major conclusion of this study is that an oil supply "crisis" is unlikely through the end of this century. This does not imply, though, that the nation can relax its efforts to expand oil and gas production or to develop synthetic liquid hydrocarbon production from oil shale and coal. Domestic oil and gas will continue to play a major role in the nation's energy supply through the year 2000. Synthetic liquid and gaseous hydrocarbons will probably be needed in large quantities by the early part of the 21st century from a resource depletion standpoint, and perhaps much sooner for economic and political reasons. Because many technical, environmental and socioeconomic problems are associated with these new liquid hydrocarbon sources, work must be begun to assure these resources will be available when needed. It is also possible that we will need these energy sources sooner than is anticipated in this study. The cost of developing these technologies before they are needed is less than the cost of not having them if the world oil supply demand situation proves to be worse than foreseen.

We commend John H. Lichtblau and Dr. Helmut Frank, principal investigators, for their research, and the others working under their direction, for the professional quality of the study.

As with other EPRI research, the results of these efforts are being made available to the public. And, as stated above, we believe this is a valuable report. As with all reports made available by the Energy Supply Program, publication does not necessarily imply EPRI endorsement of all views and analyses expressed therein.

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SUMMARY

The purpose of this study is to determine the trend of oil supply and demand for the Non-Communist World (NCW) as specifically as possible for the period 1976-1990. In addition, a more general forecast of the oil supply and demand situation for the period 1990-2005 is attempted.

Our analysis of both periods is based primarily on economic, technical and natural resource considerations; accordingly, it does not take account of purely political factors such as military interruptions or the use of oil as a political instrument. (These matters are, however, discussed in an appendix to this study). On this basis our overall findings are that an oil shortage before the late 1980's is unlikely, that an oil shortage before the end of the century is a possibility but not a probability, and that a gradual transition, accompanied by moderate real price increases, over the next 25-30 years from oil to non-oil sources to meet incremental world energy requirements is more likely than an extended oil shortage of crisis proportions.

Our conclusions are built on a number of considered assumptions. Thus we believe that world oil prices will, at a minimum, be maintained at their 1977 level in real terms (i.e., adjusted for world inflation). We also assumed that for economic and policy reasons, oil in general and OPEC oil in particular will only supply those incremental energy needs which cannot be met from other sources at prevailing prices. This is a basic change of oil's historic role in the period up to the early 1970's when the growth in its demand was due in part to its displacement and preemption of other fuels. We expect that the same economic and policy factors which will accelerate the availability of non-OPEC energy sources will bring about a more efficient utilization of oil and oil-competitive energy as well as increased conservation of all forms of energy by end-users. Some evidence of all of these developments is already visible and public policies to accelerate them have been proposed and/or adopted throughout the world. The impact of these policies should broaden over time.

The combined result of these developments will be a lower growth than in the past in total energy requirements per unit of growth in general economic activity (E/GNP ratio) and a lower growth in oil demand than in total energy demand. The latter would be a reversal from the postwar trend prior to 1974.

In forecasting these trends to 1990 we first projected total oil and other energy requirements in the NCW outside the U.S. From this total expected non oil energy production in this area was subtracted to provide an estimate of NCW oil requirements outside of the U.S. U.S. net oil import requirements were then added. Thus, our total oil demand projections are for the NCW (ex. U.S.) plus U.S. import needs. Our total oil supply projections consist of NCW (ex. U.S.) oil production plus whatever net communist exports may be available. Requirements for OPEC oil were derived by subtracting estimated future non-OPEC NCW (ex. U.S. production) oil production from total NCW oil requirements. The requirements for OPEC oil thus derived are then examined in light of estimates of future OPEC production capability to assess NCW oil demand/supply balances.

For the NCW (ex. U.S.) we have made alternate assumptions of projected economic growth rates and E/GNP ratios. Our combination of a high and a moderate GNP growth rate with a high and a low E/GNP ratio results in three different average annual growth rates in energy demand for the period 1976-90 since two of the cases are essentially the same:

Case A - 4.8 percent
Case B/C - 4.3 percent
Case D - 3.9 percent

We have also made three energy growth rate assumptions for the U.S. Combining these with the three cases for the NCW (ex. U.S.) yields total annual average NCW energy growth rates of 4.1 percent, 3.7 percent and 3.3 percent, respectively, to 1990 in Cases A, B/C and D. For comparison purposes, the pre-1974 long term postwar energy demand growth rate for the NCW was 4.7 percent.

It is important to note that our high GNP growth projection for the NCW is about in line with the average growth rate for the period 1960-76, while our moderate GNP growth projection is only slightly below it. Similarly, for the E/GNP ratio, the high case assumes a moderate improvement from the long term historic ratio while the low case is only somewhat more optimistic about future energy conservation and improvement in energy utilization. These assumptions reflect our intention to keep economic growth relatively high and energy efficiency improvements relatively modest, not because we believe this to be the most likely development

but because we want to test whether available energy supplies would permit the world economy to continue to grow at or near its recent historic growth rate.

We project that non-oil energy supplies outside the U.S. will grow from the equivalent of nearly 22 million barrels daily (MM B/D) in 1976 to nearly 46 MM B/D in 1990 in all three growth cases, under our assumption of maximization of non-oil energy sources for economic and policy reasons. The fastest growth will occur in nuclear power which will increase tenfold, followed by natural gas which will nearly triple during this period. Under our three cases the amount of oil required to balance total NCW (ex. U.S.) energy supply and demand would be as follows:

	1985	1990
	(million barrels daily)	
Case A	43.7	55.7
Case B/C	40.9	49.8
Case D	38.0	44.3

U.S. import requirements are projected to add the following volumes to the above requirements.

	1985	1990
	(million barrels daily)	
Case A	12.0	14.5
Case B/C	10.4	11.7
Case D	9.4	10.0

In meeting these requirements the Communist world will contribute only a very small amount: about 0.5 MM B/D, all of its from China. We believe that oil exports from the Soviet Bloc will have ceased by 1985 or will equal its import requirements.

Thus, the NCW (ex. U.S.) will have to supply 54, 61 or 70 MM B/D of oil by 1990 to meet the respective total oil requirements (including U.S. imports) in our three cases. We believe that strictly from the physical resource point of view all of these volumes can be made available. They would however, cause a moderate to significant decline in the reserve/production ratio* from the 1976 level, since cumulatively more oil is likely to be produced than will be found during this period in any of our cases.

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* A reserve/production ratio is equal to proved reserves in any given year divided by that year's volume of production.

Whether the required volumes will become actually available depends, however, not only on the resource but also on technical, economic and policy considerations. We assume that for economic and policy reasons non-OPEC oil production will be maximized under all our cases. Thus, for the NCW (ex. U.S.) we project supplies to increase from 7 to 18 MM B/D between 1976 and 1990, with the principal increases occurring in Latin America and Europe. The resulting requirements for OPEC oil to balance NCW supply and demand would be as follows:

	1985	1990
	(million barrels daily)	
Case A	41.1	51.7
Case B/C	36.6	43.1
Case D	32.8	35.8

Since OPEC's current productive capacity of 39 MM B/D is being increased by several of its members, primarily Saudi Arabia, there are no apparent constraints to meet the requirements for OPEC oil in all three cases by 1985. By 1990 the low case can still be met without any capacity expansion; the middle case can be met if all OPEC, other than Saudi Arabia, were to raise their output by 4-5 MM B/D, while Saudi Arabia raised its level to at least 16 MM B/D. These levels are considered achievable from a resource and technical point of view and, given the time span, we believe their attainment is unlikely to be blocked on policy grounds.

In Case A, all OPEC members other than Saudi Arabia would have to produce at maximum rates while Saudi Arabia would have to produce as much as 23 MM B/D. Both from a technical and policy viewpoint the Saudi Arabian figure cannot be expected to be attained or approached. Hence, the demand projection in Case A will not be met. Case A would therefore result in what is popularly referred to as an "energy crisis", a temporary situation during which world oil supplies are physically insufficient to meet the demand for them and no further short-term substitution of other energy sources is possible. Under these conditions oil prices would have to rise to reduce demand to the level of available supplies. In turn, this would tend to reduce the level of general economic activity and, possibly, cause political destabilization.

An "energy crisis" case, as defined above, could occur in the late 1980's if oil demand rose at an average annual rate of 4.0-4.5 percent from 1977 to 1990.

While this is realistically possible, a lower growth rate is much more likely, particularly because of strong indications of a significant structural decline in the future world economic growth rate from the 1960-76 period, with a corresponding decline in the energy growth rate. For this reason we consider Case A the least likely scenario and Case D perhaps somewhat more likely than Case B/C, although all three cases must be considered realistic.

Regarding future oil prices, we estimate very tentatively tha in Case A the real F.O.B. price of foreign oil might rise by up to 80 percent between 1977 and 1990, in Case B/C it might rise by up to 35 percent, and in Case D it might rise only marginally. Real landed prices would probably rise somewhat more in all cases because of expected higher real transportation costs.

During the 15-year period 1990-2005, we expect oil demand in all cases to grow at a lower rate than in the period 1976-90, because the lead times required to improve energy utilization and encourage oil conservation and substitution on a global scale are such that their impact will be much stronger in the 1990's than in the 1980's.

At the same time, the growth in NCW oil supply will start levelling off during the 1990's. We project non-OPEC oil production (ex. U.S.) to grow at less than half the growth rate of the 1980's to a peak of about 21 MM B/D. Total OPEC production is expected to peak at about 51 MM B/D, including a maximum of 19 MM B/D from Saudi Arabia.

When these production peaks will be reached depends on the policy of the producing countries and on NCW demand. Technically, we believe they cannot be reached before 1995-96. In Case A oil requirements would already be so close to these peaks by 1990 that the "energy crisis" would continue through the first half of the 1990's, with real oil prices rising sharply to hold demand down to available supplies. In Case B/C a trend continuation of the real price increases projected for the 1985-90 period would permit oil demand to grow at a sharply reduced level until near the end of the century. In Case D a moderate decline from the pre-1990 growth rate and a modest real price increase would permit continued growth until at least our end year of 2005. By that time sufficient other energy sources may be developed so that crude oil would no longer have to contribute to

incremental world energy requirements.

To summarize, the above post 1990 estimates, together with our earlier findings, show that if non-U.S. NCW oil demand (including U.S. import requirements) were to grow at an annual rate approaching 4.5 percent in the 1980's, severe supply constraints, preceded and accompanied by substantial price increases, would appear towards the end of that decade and could continue to the mid-1990's. If demand in the 1980's were to grow at 3.5 percent annually, no supply constraints would occur in the 1980's but moderate constraints and accelerating price increases of several years' duration could develop by the early 1990's. If demand in the 1980's grows at a rate of about 2.5 percent, no supply constriant is likely either in the 1980's or in the period 1990-2005, and no substantial real price increases would be required to balance supply and demand. A structural decline in the NCW's general economic growth rate, which we consider not at all unlikely, would enhance the probability of this last scenario.

Chapter 1

THE OUTLOOK FOR OIL TO 1990 AND AFTER: OVERVIEW AND FINDINGS

INTRODUCTION

This study attempts to forecast Non-Communist World (NCW) oil supply and demand for the periods 1976-1990 and 1990-2005, in an attempt to answer two related but distant questions:

- Will the NCW nations be able to produce the quantities of oil required to meet the levels of future oil demand?
- Will these nations, especially certain OPEC countries, want to produce these volumes?

We have in general not considered purely political factors in our analysis. However, they are discussed in an appendix to this study by Professor D.A. Rustow, a political scientist.*

Our findings are that an oil shortage before the late 1980's is unlikely, that an oil shortage thereafter is a possibility but not a probability and that a gradual transition, accompanied by moderate real price increases, over the next 25-30 years from oil to non-oil sources to meet incremental world energy requirements is more likely than an extended oil shortage of crisis proportions.

METHODOLOGY

The exceptional oil price increases of 1973 which sent a shock throughout the world economy, set in motion substantial economic, technological and regulatory forces whose purpose has been to dampen the incremental demand for oil. This is being accomplished both by conservation measures and by shifts from oil to other energy sources. Thus, oil which throughout the postwar period had increasingly displaced other fuels in the world energy markets, is in the process of becoming a "swing" fuel, to be used only where and when other fuels are not available.

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*Very briefly, Professor Rustow believes that the governments of the major oil exporting countries, regardless of political orientations, will find it expedient to sell oil to the NCW within the limits of their technical capacity and economic needs. Thus, in most situations purely political considerations are unlikely to determine the long term global availability and price of oil.

Given the relatively high current world price of oil and our conviction that it is likely to rise at least moderately in the longer run, the efforts described above are likely to succeed to some degree. Hence, they must be reflected in our forecast.

Our analysis begins with a determination of the total future energy requirements of the NCW; next, we determine the amount of energy that can be met fron non-oil sources; oil, in its role of a swing fuel, will then make up the balance. Such an approach may seem obvious today but it is a radical departure from typical pre-1973 forecasting of energy markets; then the proper question would have been: how much existing or potential use of other fuels could be displaced or preempted by oil in the future?

Our analysis of future oil and other energy supply and demand focuses primarily on the NCW outside the U.S. but includes that area's net energy trade position with the Communist world and with the U.S. Thus, U.S. oil import requirements are included in our NCW demand forecast while Communist oil exports, to the extent considered available, are included in our NCW supply forecast. The bases of both the Communist and U.S. net oil trade positions are developed in Chapter 5.

Any comprehensive analysis of world energy demand and supply must face certain key methodological issues. In particular, the investigator must take a choice between constructing a model, which utilizes econometric or other quantitative techniques, and any one of a number of simpler approaches which involve less sophisticated projections tempered with a good deal of judgment. Given the complexity of the components, subjectivity of inputs and availability of data, it is not clear that modelling will yield better results. Thus, we have chosen the latter option.

Even so, we have had to tackle a tricky problem resulting from the two-way relationship between energy and the economy. Future levels of energy demand reflecting an assumed set of economic growth rates and stipulated prices may not be met, because of supply constraints stemming from physical, technical or policy induced limitations. The result presumably would be pressures to drive prices up. Substantially higher energy prices, however, would tend to restrain economic growth, and hence energy demand. We have attempted to solve this dilemma by initially assuming that energy prices, more especially world oil prices, remain constant in real terms. Where this causes oil supplies to become inadequate to meet a projected level of demand, we have made estimates of the range of price increases likely to restore a supply-demand balance. Depending on the time available to achieve equilibrium,

this may entail different degrees of demand constraint and expansion of energy supplies.

The treatment of the supply and demand sides for the period to 1990 is asymmetrical in that we have developed alternative demand scenarios for different rates of economic growth and energy/economic growth coefficients but only a single supply scenario for energy sources other than oil from the members of the Organization of Petroleum Exporting Countries (OPEC). The latter reflects our assumption of maximum development of non-OPEC energy sources for policy reasons and the clear limits in their expansion potential over the time span of 13 years.

UNDERLYING ECONOMIC ASSUMPTIONS

In order to forecast total energy requirements it is necessary to make assumptions about future general economic growth and the relationship between economic growth and energy requirements. We have made alternative assumptions of projected economic growth rates and the "energy/economic growth coefficient" (E/GNP ratio) which relates movements in real Gross National Products (GNP) to movements in energy consumption.

Our combination of a high and a moderate GNP growth rate with a high and a low E/GNP ratio results in three different scenarios for the NCW (ex. U.S.) from 1976 to 1990:

- Case A combines high economic growth with high E/GNP ratios, yielding an average annual energy demand growth rate of 4.8 percent.
- Case B combines high economic growth with low E/GNP ratios, while Case C combines moderate economic growth with high E/GNP ratios. Since both cases yield an average annual energy demand growth rate of 4.3 percent, we are treating them in our study as a single case, referred to as Case B/C.
- Case D combines moderate economic growth with low E/GNP ratios, yielding an average annual energy demand growth rate of 3.9 percent.

Including the U.S. (under three separate assumptions discussed later in this chapter), the NCW energy growth rates to 1990 would be 4.1 percent in Case A, 3.7 percent in Case B/C, and 3.3 percent in Case D. Since these energy consumption growth rates are simply the product of our projected GNP growth rates and our projected energy/GNP growth coefficients, it is important to examine the assumptions underlying these two factors.

For both the NCW as a whole and for the NCW ex. U.S. our high GNP growth projection is approximately in line with average historic growth rates of 4.5 percent and 5.1 percent respectively, for the period 1960-76. The moderate growth projections are about 0.5 percent lower than the high ones.

We have not used the same growth rates for all areas. For Japan, for instance, whose historic economic growth rate was nearly 9 percent, we have assumed a reduction even in our High Growth Case. On the other hand, for Western Europe we have held the High Case rate above the historic (1960-76) rate of 3.8 percent and the Moderate Case rate only slightly below it. For the less developed countries, which include the rapidly growing OPEC members, we have assumed no significant change from the historic growth rate of 5.9 percent in the High Case, and little over a half percent below the historic rate in the Moderate Case.

These rates reflect our intention to keep economic growth assumptions relatively high, not because we believe this to be the most likely development, but because we want to test whether available energy supplies would permit the world economy to continue to grow in coming years (to 1990) at or near its recent historic growth rate (1960-76). We realize of course that our selected historic base period includes the two worst recession years (1974-5) since the end of World War II. But this is considerably outweighed by the soaring growth rate of the thirteen earlier years. These years belonged to the great postwar boom era in the industrialized Western world which was largely fuelled by ever increasing quantities of oil at declining real prices. Given the abrupt and, we assume, permanent increase in the cost of oil in 1973 and the truism that no economic system depending directly or indirectly on non-renewable resources can keep on growing at a fixed exponential rate, we believe strongly that the average economic growth rate in the period 1976-90 will be significantly below that of the 1960-76 historic period. Other reasons for this conclusion are the relative economic maturity, very slow population growth rate and increasing average age of the population in the industrial countries which account for over 80 percent of the NCW's gross economic product and energy consumption. Hence, our High Case is probably excessive and even our more Moderate one should be considered optimistic. Certainly, the evidence of the latest two years (1976-77) and most projections for 1978 indicate no return, or even approach, to the historic rate for the world's industrial countries other than the U.S. Nevertheless, our two chosen growth rates provide a useful test of the constraint of energy resources on economic growth.

For our other variable, the E/GNP ratio, the High Case assumes that future energy consumption per unit of output (and real income) will decline to 0.8-0.9:1.0, only moderately lower than the historic 1:1 ratio, i.e. that energy demand elasticities are quite low and tend to be nearly offset by rising real income and other opposite tendencies like accelerated electrification.

Our Low Case projects a more rapid decline in the energy/GNP growth coefficient--i.e. a faster improvement in the efficiency of energy utilization--especially in the 1980's, in response to rising energy prices, possible mandatory or publically encouraged conservation measures, and perhaps fear of shortages. For the NCW ex. U.S. our projected E/GNP ratio is about 0.75: 1.00, for the entire NCW it is slightly lower. Again, we were not attempting to determine the maximum achievable improvement in energy utilization but rather one that would seem readily achievable under mildly optimistic assumptions. In fact, a number of major industrial countries have reduced their E/GNP ratios in the period 1973-1977 by more than we have assumed in our Low Case. This case may therefore have a higher probability of being realized than our high one.

NON-OIL ENERGY SUPPLIES OUTSIDE THE U.S.

We project that non-oil energy supplies outside the U.S. will more than double between 1976 and 1990, equivalent to an average annual increase of 5.4 percent. This is substantially greater than the total energy demand growth rate in our highest case. It implies an increase in the relative importance of the sources other than oil, and, hence, a relative easing of the demand pressure on petroleum as the swing fuel.

It must be stressed, however, that this projection, like all others, is subject to a wide range of uncertainties stemming from future technological, economic and political developments. The world oil price increases in 1973 as well as the shift in decision-making from private Western oil companies to OPEC state agencies have stimulated consuming countries into accelerated energy supply diversification, both internally and externally. We assume that these measures will show increasing results as the 1980's progress, provided oil prices do not decline in real terms. Expectations of rising real oil prices and non-economic factors, such as government policies, will reinforce the tendency toward diversification.

Among the different non-oil energy sources, coal will show the least increase--less than 25 percent over the fourteen year period, or from 800 million to 1 billion

tons for the NCW ex. U.S. Its share in total energy supplies will therefore decline. Part of the reason lies in the fact that the great bulk (nearly 80 percent) of the world's economically recoverable coal reserves are located in the U.S., the Soviet Union and China, none of which is expected to increase steam coal exports greatly in global terms. Thus, unlike the U.S., the rest of the NCW will not experience a renaissance in coal between now and 1990 as part of the effort to limit reliance on oil.

For natural gas the situation is likely to be just the reverse. While U.S. gas supplies are declining, in the rest of the world we expect them to increase very substantially. Current NCW (ex. U.S.) proved reserves* are more than 1,100 trillion cubic feet. This is equal to 87 years of current annual production, or well over twice the comparable oil reserve/production ratio. Some 75-80 percent of these reserves are located in OPEC and other oil exporting countries. For technical reasons and because of very high capital and transportation costs, little of this gas has been exported to consuming countries so far. The increase in oil prices in the last five years, along with expected further increases and growing experience in the liquefaction and cryogenic transportaion of natural gas have significantly changed the outlook for future gas exports. Furthermore, most oil and gas exporting countries have started to install processing plants to strip the liquids from the gas and export these by tanker. We believe these factors will not only bring about commercial utilization of existing natural gas deposits, leading to an eventual sharp reduction in natural gas flaring, but will also encourage the search for non-associated natural gas reserves which in some major producing countries has never been undertaken.

It should be noted, however, that the high liquefaction and transportation cost may retard these developments since they may prevent the exporting countries from receiving the same price per unit Btu for gas as for oil. If the exporters should insist on such parity as some have said they would, development of some gas resources for export might be postponed. However, this consideration is likely to apply, if at all, only to the few countries whose potential oil producing capacity is substantially in excess of actual production. Countries producing at or near capacity, or expecting to do so by the early 1980's, will probably be more eager

*Proved reserves are defined as established reserves which can be produced under current economic and technological conditions.

to supplement their limited oil export earnings with revenues from gas exports. Algeria, OPEC's largest current and potential gas exporter, is a case in point.

Altogether, then, we see NCW (ex. U.S.) annual gas production rising from 12 to about 35 trillion cubic feet between 1976 and 1990. This would increase the share of gas in total NCW (ex. U.S.) energy supply from 11 percent to 16.5 percent. By no means all of this increase will come in the form of exports. Much of the North Sea gas will be utilized in the countries in which it was found. Similarly, we expect that slightly less than 40 percent of OPEC's total gas production of 15-16 trillion cubic feet by 1990 may be exported.

The other major growth in non-oil energy supplies will come from nuclear power. We expect NCW (ex. U.S.) nuclear generating capacity to grow from 35 to 290 gigawatts during our fourteen year period. The resulting power generation would increase from 0.8 million barrels per day oil equivalent (MM B/DOE) in 1976 to 8.0 MM B/DOE in 1990. While this represents a dramatic growth over a relatively short period, we have taken the lowest estimate of three authoritative forecasts and have reduced it slightly for 1990. For 1985 we have used the lowest of all available forecasts. Our selection is based on our view that while nuclear power construction will proceed throughout the world, it will continue to encounter significant political, technical and safety problems, all of which will cause further delays in reaching existing targets.

Hydroelectricity will expand primarily in the developing countries where it provides not only an economical source of energy but often also irrigation and flood control. We project total NCW (ex. U.S.) output to increase from about 850 million to 1.4 billion kilowatt hours (KWH) or from the oil equivalent of 4.3 to 7.0 MM B/D.

The following table is a summary of our supply projections of the various non-oil energy sources. We realize of course that for each source the supply could be higher or lower than our projection, depending on the magnitude of the economic incentive, government policies and other factors. However, we have limited ourselves to a single projection, based on the assumption of maintenance of existing world oil prices in real terms and a moderately active government policy. As pointed out, we do not think it likely that real oil prices will fall, and we do not think that a rise in oil prices could bring forth substantially higher volumes of these energy sources by 1990, given the time span required to develop them.

Table 1-1

NON-COMMUNIST WORLD SUPPLY OF NON-OIL ENERGY
OUTSIDE THE U.S., 1976 TO 1990

(million barrels per day
oil equivalent)

	1976 (preliminary)	1980	1985	1990
Coal	11.0	11.6	12.5	13.6
Gas	5.8	9.5	13.2	16.8
Nuclear	0.8	2.2	4.6	8.0
Hydro/Geothermal	4.3	4.9	5.9	7.0
Other	-	0.2	0.3	0.5
Total	21.9	28.4	36.5	45.9

WORLD OIL RESOURCES

We now turn to the availability of oil during the next 14 years. How much is left in the ground, where it is located and at what rate it can be produced are the key questions in the global energy debate underway for the past five years. The questions reflect the undisputable fact that all fossil fuels are finite and, hence, will eventually be exhausted. In the case of oil, however, the awareness of this ultimate resource limitation, and the accompanying fear that it might occur before other energy sources in sufficient volumes become available, did not arise because of evidence of an approaching resource constraint. Rather, it was the reaction to two events in 1973-74; one bore no relation to the question of physical resource availability and the other can actually be expected to expand recoverable resources and decelerate the rate of consumption. The first was the Arab oil export embargo; the second was the OPEC imposed four-fold price increase which did not reflect prevailing market conditions but rather the effect of economic and political monopoly power. It was this dramatic focus on the politics and economics of oil which raised the widespread concern about the conditions of its future physical availability.

The first and foremost thing to be said about this issue is that all projections of future recoverable oil supplies are speculative, since there is no way of

determining the size of the still undiscovered portion of the world's ultimate oil resources, nor how much of it will be found, and when and where, nor at what rate future finds will be recovered.

The current consensus estimate of geologists seems to fluctuate around two trillion barrels of ultimate recoverable total world oil reserves, i.e. the amount of oil originally in the ground which can be recovered with foreseeable technology. Only about 18 percent of this, or 360 billion barrels, had been withdrawn for consumption by the end of 1976; another 37 percent, or 750 billion barrels, consists of proved and prospective reserves in discovered fields; the remaining 45 percent, or 925-950 billion barrels, remains to be discovered.

It may be significant that the consensus estimates have not been substantially modified following the quantum price jumps of 1973-74, despite the fact that the recovery factor included in the estimates is in part a function of economics. The current world oil recovery rate is estimated at 25 percent or less of the resource in place. Most projections have assumed this will increase to 40 percent towards the end of the century. A few recent forecasts have projected a higher future recovery factor as a result of the oil price increases and, accordingly, have come up with a higher estimate for ultimate recoverable oil reserves than the consensus figure.

The geographic distribution in the most widely used estimate (by Moody and Esser) assigns one third of remaining recoverable reserves (proved, prospective and undiscovered) to the Middle East, one quarter to the Sino-Soviet Bloc, 13 percent to North America (U.S. and Canada) and the remaining 29 percent throughout the rest of the world.

Based on the consensus estimate of remaining recoverable reserves, it can be calculated that exhaustion at presently assumed recovery rates will occur in eighty years if world production were to remain fixed at the 1976 level of 21 billion barrels. However, since world oil demand and, hence, production are certain to rise through 1990 and beyond, exhaustion can be calculated to occur well before then, at least hypothetically.

More important than exhaustion is the peaking of world production which will of course take place much earlier. One expert (King Hubbert) expects this to occur

just after the mid-1990's at an annual production level of 100 MM B/D. This would permit an annual world growth rate of 2.9 percent over the next twenty years. Another widely accepted forecast (Moody-Esser) predicts the peaking in the late 1980's or early 1990's based on pre-1974 "normal" demand growth rates. Adjustment for both the experienced and the expected lower demand growth rates of the post-1973 period would postpone peaking until about the end of the century.

In sum, then, a continuation of the long term pre-1974 world oil demand growth rate of about 7.5 percent annually would cause world oil production to peak in the mid-1980's. A future demand growth of half that rate would postpone peaking to the mid-1990's. Thus, considering only physical resource availability and no other factors, an annual growth rate in world oil demand up to about 4 percent could be met at least through 1990 without creating a supply shortage. While this would be substantially below the average pre-1974 growth rate, it would be above the average rate of roughly 2.3 percent for the last five years (1973-1978, including an estimate for the current year).

It should be reiterated that these growth rates refer to the entire world, including the Sino-Soviet region and, thus, are not fully comparable with growth rates discussed in subsequent sections of this chapter.

NON-COMMUNIST WORLD OIL DEMAND

Having established our three growth rates for NCW (ex. U.S.) total energy demand over the period to 1990, and having estimated the likely availability of non-oil energy sources, the amounts of oil are determined by subtraction (see the following table). Two major adjustments must be made to obtain total supply of and demand for NCW oil (ex. U.S.): net U.S. oil import requirements must be added to the demand side and net Sino-Soviet oil exports added to the supply side.

U.S. Oil Import Requirements

In keeping with our three-case structure for NCW outside the U.S., we have developed three cases for future U.S. oil imports. Total U.S. energy requirements were determined under various assumptions of economic growth and energy/GNP growth ratios. We then estimated the amount of domestic energy, including oil, likely to become available over the period 1990. Oil imports represent the balance between total domestic energy supplies and total energy requirements.

Table 1-2

NON-COMMUNIST WORLD OIL DEMAND OUTSIDE THE U.S.,
1976 TO 1990

(million barrels per day
oil equivalent)

	1976	1980	1985	1990	1976 to 1990 Average Annual Rate of Growth (% per year)
Case A					
Energy Demand	53.0	63.5	80.2	101.6	4.8
Non-Oil Supplies	21.9	28.4	36.5	45.9	5.4
Oil Demand	31.1	35.1	43.7	55.7	4.3
Case B/C					
Energy Demand	53.0	62.8	77.4	95.7	4.3
Non-Oil Supplies	21.9	28.4	36.5	45.9	5.4
Oil Demand	31.1	34.4	40.9	49.8	3.4
Case D					
Energy Demand	53.0	61.8	74.5	90.2	3.9
Non-Oil Supplies	21.9	28.4	36.5	45.9	5.4
Oil Demand	31.1	33.4	38.0	44.3	2.6

Our high economic growth rate is slightly above the long term (1960-76) rate of 3.4 percent; our moderate growth is half a percentage point below it. (In judging these rates it may be of interest that a recent Congressional staff predicted a long-term full employment U.S. GNP growth rate of 3 percent by the mid-1980's)(1).

Our energy/GNP growth coefficients are slightly above 0.8 in the High Case and slightly above 0.7 in the Low Case. Both are below the historic rate of about 1.0 (The average ratio of the last two years, 1976-77, was below 0.70.) The three scenarios, representing different combinations of economic growth rates and E/GNP coefficients, result in the following annual energy growth rates:

U.S. ENERGY DEMAND GROWTH, 1976-90
(percent per year)

	1976-80	1980-90
Case A (High Case)	3.8	2.8
Case B/C (Mid Case)	3.4	2.4
Case D (Low Case)	3.0	2.1

For comparison purposes, the historic energy growth rate (1960-76) was 3.5 percent.

We project domestic energy production plus non-oil (mostly natural gas) imports to grow at a rate of 1.8 percent from 1976 to 1980 and 2.8 percent from 1980 to 1990. The faster growth in the latter period will be due primarily to expected increases in coal supplies and nuclear power and a modest increase in natural gas supplies through a combination of stabilized domestic production and rising imports. (Our gas import projection may be conservative, since we have assumed a decline in imports from Canada. Recent discoveries in Alberta and British Columbia may alter this outlook).

The balancing requirements for oil imports are as follows:

REQUIRED U.S. OIL IMPORTS
(million barrels per day)

	Case A	Case B/C	Case D
1976	7.3	7.3	7.3
1980	10.9	10.3	9.7
1985	12.0	10.4	9.4
1990	14.5	11.7	10.0

These amounts have to be added to the corresponding cases for NCW oil outside the U.S., shown in Table 1-2 of this chapter. We might add that even our lowest import projection for 1985 is well above the Administration's target of 6-7 MM B/D, as stated in its National Energy Plan. But we consider this an unachievable target, and there are indications that the Administration is beginning to do so, too.

Communist-NCW Oil Trade

The other adjustment, Sino-Soviet oil trade with the NCW, requires us to add 1.4 MM B/D to NCW oil supplies for 1976. Of these, 1.2 MM B/D come from the Soviet Union. We project a modest increase in Chinese exports to 0.5 MM B/D in the 1980's and a cessation of net Soviet Bloc exports by or before the mid-1980's. We do not see the Soviet Bloc becoming a significant net importer of oil within our time frame, as is predicted in some other studies. Our conclusion is based on the following considerations:

1) Substantial dependency by the Soviet Union or its satellites on oil imports would run counter to the basic economic and political strategy of the Soviet Bloc;

2) Most geologists believe the Soviet Union has a vast undeveloped and underdeveloped petroleum resource potential;

3) The logistical problems of bringing this oil to consuming areas are serious but not insurmountable and Soviet planners are now concentrating on overcoming them;

4) Soviet Bloc countries are in a much better position than Western countries to curb the growth in domestic oil demand and bring about a switch to coal and gas, both of which are abundant in the area;

5) We believe our view that Chinese oil exports will increase only modestly is distinctly conservative, in view of China's acknowledged need to earn increasing amounts of foreign exchange and the fact that oil represents one of its few readily marketable export commodities.

Adjusting our NCW (ex. U.S.) oil supply figures by both U.S. import requirements and net Sino-Soviet exports yields total NCW (ex. U.S.) oil requirements. In our three cases the resultant respective annual growth rates for the period 1976-90 are 4.6 percent, 3.6 percent and 2.7 percent as is shown in Table 1-3.

Table 1-3

REQUIRED NON-COMMUNIST WORLD OIL PRODUCTION
OUTSIDE THE U.S., 1976 TO 1990

(million barrels per day)

	1976 (preliminary)	1980	1985	1990	Average Annual Rate of Growth 1976 to 1990 (% per year)
Case A					
NCW (Ex. U.S.) Oil Demand	31.1	35.1	43.7	55.7	4.3
U.S. Oil Import Demand	7.3	10.9	12.0	14.5	
Sub Total	38.4	46.0	55.7	70.2	
Less: Sino-Soviet Net Exports	1.4	1.2	0.5	0.5	
Required NCW (Ex. U.S.) Oil Production	37.0	44.8	55.2	69.7	4.6
Case B/C					
NCW (Ex. U.S.) Oil Demand	31.1	34.3	40.8	49.9	3.4
U.S. Oil Import Demand	7.3	10.3	10.4	11.7	
Sub Total	38.4	44.6	51.2	61.6	
Less: Sino-Soviet Net Exports	1.4	1.2	0.5	0.5	
Required NCW (Ex. U.S.) Oil Production	37.0	43.4	50.7	61.1	3.6
Case D					
NCW (Ex. U.S.) Oil Demand	31.1	33.4	38.0	44.3	2.6
U.S. Oil Import Demand	7.3	9.7	9.4	10.0	
Sub Total	38.4	43.1	47.4	54.3	
Less: Sino-Soviet Net Exports	1.4	1.2	0.5	0.5	
Required NCW (Ex. U.S.) Oil Production	37.0	41.9	46.9	53.8	2.7

For comparison purposes, total NCW oil demand, including total U.S. oil demand, would be as follows:

NON-COMMUNIST WORLD OIL DEMAND
(million barrels per day)

	1976	1980	1985	1990	1976 to 1990 Average Annual Growth Rate
Case A	47.6	55.6	66.0	80.6	3.8%
Case B/C	47.6	54.2	61.6	72.0	3.0%
Case D	47.6	52.7	57.4	64.2	2.2%

PHYSICAL AVAILABILITY OF REQUIRED DEMAND

The next question is whether the 54-70 MM B/D of projected requirements for NCW (ex. U.S.) oil production by 1990, shown in Table 1-3, are likely to be physically available, given existing reserves and projected new discoveries. Over the fourteen years ending in 1976 annual gross reserve additions in the area amounted to 24 billion barrels. We have assumed, somewhat arbitrarily, that between 1977 and 1990 only two-thirds of this amount, or 16 billion barrels, will be discovered annually, notwithstanding the very sharp increase in oil prices (and oil exploration) compared to the previous period and the continuing improvements in the technology of drilling in offshore areas where most of the remaining discovered reserves are likely to be found. Our projected finding rate implies therefore only a modest response to the higher prices or a lower finding rate per unit of effort.

Combining this finding rate with our three required NCW (ex. U.S.) production rates shows that in all three cases more oil will be withdrawn than will be discovered; hence, the reserve/production (R/P) ratio will decline significantly from its end-1976 level of 38 in all cases, as is shown in the following summary table:

Table 1-4

RESERVE LIFE FOR THE NON-COMMUNIST WORLD OUTSIDE THE U.S. IN 1990
(billion barrels)

	CASE A	CASE B/C	CASE D
Proved Oil Reserves as of 1/1/77	515	515	515
Assumed Gross Reserve Additions (1977 to 1990)	224	224	224
Cumulative Production 1977 to 1990	270	250	231
Proved Reserves at Year-End 1990	469	489	508
Production in 1990	25.4	22.3	19.5
Reserve/Production Ratio, 12/31/90 (Yrs)	18	22	26

The question is, how much of a decline in the R/P ratio can be considered reasonable, given existing and prospective physical, technical, economic and political factors? None of these factors would preclude some reduction from the current ratio of 38, which exceeds that prevailing in many major producing countries by a wide margin.

Considering only the physical factors and leaving all other considerations, including the availability of oil after 1990, for later, it may be entirely possible to reduce the NCW (ex. U.S.) reserve/production ratio to 18, as required in our Case A. By comparison, the U.S. oil industry has operated for many years with R/P ratios as low as 10-12 years. Thus, strictly from a resource point of view, it appears possible for NCW (ex. U.S.) production to grow by up to 4.6 percent annually to 1990, reaching a volume of about 70 MM B/D in the latter year.

OIL SUPPLIES AND PRICES FROM OPEC AND NON-OPEC SOURCES

Assuming the physical resource base is adequate for our projected three levels of NCW oil demand to 1990, there remains the question of how much oil will actually be available throughout this period. The difference reflects technical, economic and political constraints on the maximum productive potential. Price of course plays an important part in these constraints.

Non-OPEC Oil Supplies

We have assumed that oil supplies from non-OPEC sources will be maximized in all cases, since they will come either from countries that want to reduce oil import costs and dependency, or from new entrants into world oil exports with substantial foreign exchange requirements or from new producers with readily available local and regional markets. We realize that our decision not to vary non-OPEC oil production to 1990 is open to some question. If the pressure for incremental oil supplies becomes strong enough and real prices rise sharply,some additional non-OPEC oil is likely to be forthcoming in spite of time constraints. Our scenarios in effect represent therefore a test of the availability of OPEC oil under the assumption that price increases would have no impact on non-OPEC production.

As before, our oil demand growth rates all assume, as a starting point, constant real prices throughout the period. Under this assumption, we project NCW non-OPEC production (ex. U.S.) to rise from about 7 MM B/D in 1976 to about 18 MM B/D in 1990 (Table 1-5). This implies an annual growth rate of over 7 percent, or 50 percent faster than our highest estimate of requirements for oil from NCW (ex. U.S.).

Table 1-5

NON-COMMUNIST WORLD CRUDE OIL PRODUCTION
OUTSIDE THE U.S. AND OPEC, 1976-1990

(million barrels per day)

	1976	1980	1985	1990
Western Hemisphere	3.5	4.7	5.8	7.6
Eastern Hemisphere				
Europe	0.9	3.4	4.5	5.9
Africa & Middle East	1.3	1.8	2.3	2.7
Asia-Pacific	1.2	1.3	1.5	1.8
Total Eastern Hemisphere	3.4	6.5	8.3	10.4
Total Above Areas	6.9	11.2	14.1	18.0

The principal increase in the Western Hemisphere is expected to come from Mexico whose output is projected to surpass 3.5 MM B/D by 1990. We have assumed Canadian production will continue to decline through 1985 and then increase moderately; in view of last year's performance and some very recent large discoveries, this may be a conservative assumption. In Europe we project total North Sea production to rise to over 5 MM B/D by 1990. In the Africa-Middle East area, we estimate Egyptian production to surpass 1.0 MM B/D by 1990. In Pacific Asia we foresee modest increases in India and other Southeast Asian countries.

Requirements for OPEC Crude Oil

The requirements for OPEC oil production are shown in Table 1-6.

Table 1-6

NON-COMMUNIST WORLD DEMAND FOR OPEC CRUDE OIL, 1976 TO 1990

(million barrels per day)

	1976 (preliminary)	1980	1985	1990	Average Annual Rate of Growth 1976 to 1990 (% per year)
Case A					
Required NCW Production (Ex. U.S.)	37.0	44.8	55.2	69.7	4.6
Non-OPEC Production (Ex. U.S.)	6.9	11.2	14.1	18.0	7.1
Required OPEC Production	30.1	33.6	41.1	51.7	3.9
Case B/C					
Required NCW Production (Ex. U.S.)	37.0	43.4	50.7	61.1	3.6
Non-OPEC Production (Ex. U.S.)	6.9	11.2	14.1	18.0	7.1
Required OPEC Production	30.1	32.2	36.6	43.1	2.6
Case D					
Required NCW Production (Ex. U.S.)	37.0	41.9	46.9	53.8	2.7
Non-OPEC Production (Ex. U.S.)	6.9	11.2	14.1	18.0	7.1
Required OPEC Production	30.1	30.7	32.8	35.8	1.2

We must now turn to the two key questions of the whole energy debate: Will OPEC be able to produce the quantities projected in our forecast, and will it want to produce them? If the answer to either question were "no" for any of our three cases, oil demand would be unable to grow at the projected rate. In such a situation, required demand reduction would have to be brought about through price increases and/or government consumption restrictions. Since non-OPEC energy supplies are assumed to be fully utilized in all of our scenarios, the decline or absence of incremental oil supplies could easily lead to a temporary contraction in general economic activity. Eventually, the higher oil prices would stimulate production of additional non-OPEC energy sources and more efficient energy utilization so that economic growth could resume at the previous rate. But the intervening period of reduced economic activity, if the reduction were substantial and lasted for a number of years, could create significant general economic dislocations and consequent political destabilization. It is this scenario which is popularly referred to in the media and elsewhere as the "energy crisis."

Is an energy crisis likely in any of our three cases? OPEC had a sustainable physical producing capacity of 39 MM B/D in 1977, or about 8 MM B/D above actual production. By 1985 we project required production of less than 2.0 MM B/D above the 1977 level in Case D, 5.5 MM B /D above in Case B/C, and 10 MM B/D above in Case A. Thus, in 1985 our low and middle cases can be met from currently existing or marginally increased OPEC productive capacity.

To allow for operating flexibility, our Case A would require a 6-7 MM B/D increase in capacity. Since Saudi Arabia is on record as planning to increase its productive capacity by nearly 2.5 MM B/D by the early 1980's, and since Iraq and the United Arab Emirates are also undertaking significant capacity increases, while small increases may be possible in some other OPEC members, it should be physically possible to meet the 41 MM B/D OPEC production requirement of our high case in 1985.

For 1990, the Case D OPEC requirement of 36 MM B/D could be met without any increase in existing capacity. The Case B/C requirement of 43 MM B/D could be met if the twelve members other than Saudi Arabia were to raise their production by about 4-5 MM B/D, or 18 percent, while Saudi Arabia raised its output to about 16-17 MM B/D. Given Saudi Arabia's vast oil reserves and the time span to 1990, such an increase should be physically entirely possible. In fact, under a plan, now

shelved, it was to be nearly reached before 1985. From a physical point of view, therefore, the Case B/C requirements appear to be attainable.

In Case A, if all member countries other than Saudi Arabia were to operate at their estimated maximum sustainable or allowable production rates, Saudi Arabia would have to raise its production to 23 MM B/D to meet the required production level of nearly 52 MM B/D. Again, Saudi Arabia's resource base would appear to be large enough to permit such an increase in productive capacity.

Technically, however, it may not be possible to install the facilities required for such a vast increase in productive capacity by 1990. Furthermore, according to some recent reports, expansion of capacity to or near the required figure would lead to declines in reservoir pressure and water encroachment, resulting in loss of ultimate recoverable reserves. Hence, our projected Case A OPEC oil requirements for 1990 would probably not be technically attainable, regardless of the resource base.

In sum, then, considering the resource base only, all our projections can be attained in both 1985 and 1990. From a technical point of view, the same holds true for 1985 but not for 1990 when only Case D, our low case, can be attained with reasonable certainty, our middle case can be attained with sufficient lead time and effort, and Case A, our high case, may not be achievable under any condition.

The answer to the question of whether OPEC members want to increase their production to meet our projected requirements is complex, since it requires assumptions about future oil prices, the ability of various OPEC members to absorb the additional income from the higher production levels, the long-term economic development plans of these countries and their perception of how long their oil will last or how long there will be a market for it. Above all, the complexities are multiplied by the interaction of OPEC production policies and world oil prices.

In analyzing these complexities we have made a number of assumptions:

1) All OPEC members will attempt, individually and collectively, as a minimum to maintain crude oil prices in real terms, i.e. in constant dollars.

2) Most oil importing countries will be willing to accept OPEC's minimum price policy but would oppose, although not necessarily successfully, any significant increase in the real price imposed by OPEC.

3) All OPEC members will want to expand their production at least moderately over time; those that cannot do so because of a declining resource base will attempt to keep their production as high as proper reservoir maintenance permits.

4) Internal demand for oil will rise rapidly in all OPEC countries, in some cases reducing the quantities available for exports.

In Case D, our low case, we conclude on the basis of these assumptions that OPEC will want to meet our projected requirement in both 1985 and 1990. Production would increase at an average rate of 1.2 percent annually and, in view of announced and indicated expansion projects, OPEC's collective excess producing capacity in 1990 will be higher than at present. Under these conditions all but three OPEC members (Saudi Arabia, Kuwait and U.A.E.) could be expected to have current accounts deficits in the absence of real price increases. Very likely therefore, they would seek higher real prices despite continuing market pressure in the opposite direction. Saudi Arabia, supported by the two other surplus countries, might be expected to oppose or moderate the quest for increases for the same reasons it has done so since 1975.

We believe the most probable price scenario resulting from these countervailing pressures will be approximate maintenance of the current price in real terms through 1990. Assuming a 5 percent inflation rate, the price of OPEC marker crude (Saudi Arabian Light) would rise from its end-1977 level of $12.70/barrel to roughly $23-25/barrel in current dollars by 1990.

The two principal facts in the Case D price scenario are 1) even under its very modest growth rate oil prices will not decline, and 2) a real price increase will only be prevented if Saudi Arabia actively opposes it.

In Case B/C the twelve OPEC members other than Saudi Arabia would have to raise their collective production by 4-5 MM B/D to 26-27 MM B/D between 1977 and 1990 while Saudi Arabia would have to move from 9 to about 16 MM B/D. For the twelve members this would be an annual average increase of approximately 1.5 percent and could be achieved by 1990 without reaching projected maximum sustainable capacity. Most members could be expected to welcome such an increase in view of

their growing revenue requirements. Saudi Arabia could achieve the required level if it can be assumed not to resist the moderate but steady output expansion over the next thirteen years required to avoid an oil shortage.

Such an assumption seems reasonable. It is true of course that Saudi Arabia can finance its entire ambitious social and industrial development program from the existing level of oil export earnings and still retain its current account surplus. Nevertheless, its rulers are unlikely to refuse higher export sales in the 1980's merely because of the resulting additional revenue. The higher cost of subsequent development programs, the growing momentum of rising expectations, as well as the desire to maintain and enhance its new role as an economic super power can all be expected to blunt opposition to moderate real increases in oil revenue. Refusal to increase potentially available production when the rest of the world needs it would create economic and political risks which the Saudis give every indication of being anxious to avoid.

Prices under this scenario are likely to remain fairly constant in real terms until 1983/84. After that a number of OPEC countries will be producing at their physical or chosen capacity while Saudi Arabia's excess capacity will be insufficient to exert a strong moderating influence on their price policies. Under these circumstances our best guess is a real OPEC marker crude price of $15-17/barrel by 1990 which would cause a slight drop in actual demand from that projected under stable price conditions. Assuming an inflation rate of 5.5 percent, somewhat faster than in Case D, the monetary price in 1990 would be $30-34/barrel. Market forces will play some part in determining price but the principal factor will be OPEC's continuing price-setting ability which will be stronger than in Case D.

In Case A, our projected 52 MM B/D OPEC production requirement by 1990 would call for sustained production of 23 MM B/D from Saudi Arabia. There is considerable doubt whether such a level could be technically achieved. In any case, it is likely to be strongly resisted by the government and must therefore be considered as practicably unattainable. If we assume that, say, 17 MM B/D is Saudi Arabia's maximum attainable, acceptable production level by 1990, prices would have to rise sufficiently to reduce projected demand by about 6 MM B/D. We believe this will be accomplished less by OPEC's price-setting power than by market forces. Depending on when full awareness of the insufficiency of oil supplies is registered,

prices could either take a quantum jump in the second half of the 1980's or move up more gradually from the early 1980's on. Our best guess in the latter case is a real price of $16-18 per barrel by 1985 and $21-23 by 1990. Assuming a 6 percent inflation, the monetary price would be $26-29 and $45-49, respectively. Obviously, these as well as our other price forecasts are more indicative of trends than of precise numerical values. Furthermore, landed real prices will rise somewhat faster due to increased tanker rates.

THE RELATIVE LIKELIHOOD OF OUR SCENARIOS

In evaluating the probability of our three scenarios, it is important to recall that all are based on relatively high global (NCW) economic growth assumptions. Even our "moderate" growth rate is only 0.5 percent below the historic (1960-76) rate.

An increasing number of recent economic forecasts show significant reductions in future economic growth rates from the historic level, suggesting that the general economic slowdown of the last five years may not be a short term phase of a cyclical trend but rather the beginning of a long term structural change.

There are a number of reasons that such a development is likely. One is of course the substantially higher cost of energy. Since low-cost energy was an important factor in fuelling the economic boom of the 1950's and 1960's, it stands to reason that high cost energy will act as a retardant to growth.

A more basic reason,as we have mentioned, is that no system based directly or indirectly on finite resources can keep growing indefinitely at a fixed exponential rate, since eventually the magnitudes of the increases become literally unmanageable. Inasmuch as the period 1960-76, for various reasons, had an exceptionally rapid average growth rate, a slowdown from this high base could still keep the world economy expanding at a tolerable rate.

Other considerations are the very slow population growth -- 0.9 percent annually -- in the industrial nations which account for over 80 percent of the NCW's energy consumption, their economic maturity and emerging saturation in some sectors, the rising average age of their population which can be expected to act as an eventual corrective to excessive unemployment, and the likely impact of these factors on the rate of investments.

Allowing for a faster growth in the developing countries -- particularly the quickly expanding OPEC nations -- than in the industrial ones, the resulting NCW growth rates of 3.4-3.5 percent per year to 1990 would seem both economically reasonable and politically tolerable, since it permits significant per capita economic growth in all groups of countries.

With a moderate improvement in energy efficiency such an economic growth rate would require an NCW energy growth rate of slightly below 3 percent. NCW oil requirements would grow to 1990 at an annual rate about in line with our Case D forecast, even if non-oil energy supplies were to increase somewhat more slowly than we have projected, due to a slower growth in the GNP.

Thus, while we consider all three of our 1990 scenarios within the range of reality, present indications are that Case D may be somewhat more likely than Case B/C, and much more so than Case A.

OIL SUPPLY AND DEMAND, 1990-2005

Two unequivocal statements can be made about the post-1990 period: 1) the ultimate amount of recoverable conventional oil still in the ground will be substantially less at the beginning of the new period (1990) than it was at the beginning of the previous one (1977); and 2) the global economic, political and technological forces set into motion since 1974 to conserve scarce forms of energy and develop alternate sources for them, both with special emphasis on oil, will reduce the growth in NCW oil demand in the 1990's below the rate prevailing in the 1980's.

The question is, will oil demand eventually stop growing because more efficient utilization and the availability of alternate sources will reduce the need for more oil; or will the declining available resource dictate a temporary reduction in demand through the imposition of prices high enough to eliminate unmet demand. The first can be described as an adjustment process, the second as an energy "crisis" which would tend to depress prevailing economic growth.

To analyze which of these is the more likely eventuality we make two assumptions: NCW oil production outside OPEC and the U.S., after rising by over 7 percent annually to 18 MM B/D in 1990, will begin to taper off, reaching a peak of 21 MM B/D by about 1995. This would reflect declining production in the North Sea

and some other areas as well as a lower overall finding rate. The projection may appear pessimistic since over half the undiscovered recoverable NCW oil reserves outside the U.S. are believed to be located outside OPEC and since recovery rates can be expected to improve over time. On the other hand, considerable amounts of oil will have to be found in the 1990's just to maintain production levels.

Our other assumption concerns post-1990 OPEC production. For 1990 we projected a maximum sustainable output of about 46 MM B/D, if Saudi Arabia can and will produce 17 MM B/D. If Saudi Arabia can reach a peak production of 19 MM B/D from the mid-1990's on, and if there will be post-1990 output increases in Kuwait, the U.A.E. and Iraq, partly offsetting declines in other OPEC members, we arrive at a hypothetical OPEC peak output figure of about 51 MM B/D from the mid-1990's on.

The key question, as in everything concerning OPEC, is how realistic our Saudi projection is. Counted from 1977 on, the growth rate of 3.7-4.0 percent to reach peak production by the mid or late 1990's (depending on demand growth) does not seem excessive. Certainly, the reserves are big enough for an eventual 19 MM B/D production rate and the time span from the early 1980's (when capacity is scheduled to reach 14 MM B/D) is long enough to permit very gradual further expansion, with pauses for consolidation.

Adding our projected OPEC and non-OPEC production gives us a maximum NCW (ex. U.S.) production level of 72 MM B/D, to be attained by 1995/96 at the earliest. Precisely when this level will actually be required depends both on the production reached by 1990 and the subsequent growth rate. If the previous growth rate were to be maintained beyond 1990, the maximum production level would be reached almost immediately in Case A, by 1995 in Case B/C, and by about 2002 in Case D. It is, however, much more likely that in each Case the growth rate in the post-1990 period will be below that of the pre-1990 period. The reason is that the efforts to improve energy utilization, encourage petroleum conservation and develop substitutes all require long lead times so that their impact will increase over time.

Thus, by the mid or late 1990's NCW synthetic oil and gas production may amount to the equivalent of 3.5-4.0 MM B/D, compared to probably under 1.0 MM B/D by the mid-1980's. Exports of liquefied natural gas (LNG) will also be substantially higher in the 1990's partly because of the long lead time required to build the

transformation and transportation facilities, and partly because higher real oil prices will make the LNG trade more attractive, given the high cost of these facilities.

The slower oil demand growth rate after 1990, resulting from these factors, would be of little help in Case A, since 1990 production would already be very close to the attainable maximum. Thus, Case A continues to be an "energy crisis" case, at least through the early 1990's, with sharply rising real prices exerting downward pressure on general economic growth rates. In Case B/C, assuming a substantially slower demand growth rate after 1990, maximum production might not be reached until about 2000. However, the required drop in the growth rate would have to be such that some further real price increases (on top of those projected for the second half of the 1980's) would be necessary to balance supply and demand. In Case D a moderate decline from the pre-1990 growth rate could well permit continued growth beyond our end year of 2005.

The above estimates, together with our earlier findings, show that if non-U.S. NCW oil demand (including U.S. import requirements) were to grow at an annual rate approaching 4.5 percent in the 1980's, severe supply constraints, preceded and accompanied by substantial price increases, would appear towards the end of that decade and could continue to the mid-1990's. If demand in the 1980's were to grow at 3.5 percent annually, no supply constraints would occur in the 1980's but moderate constraints of several years' duration could develop by the early 1990's. If demand in the 1980's grows at a rate of about 2.5 percent, no supply constraint is likely either in the 1980's or in the period 1990-2005, and no substantial real price increases would be required to balance supply and demand. A structural decline in the NCW's general economic growth rate, which we consider not at all unlikely, would enhance the probability of this last scenario.

REFERENCES

1. U.S. Long Term Economic Growth Prospects: Entering a New Era. A Staff Study for the Joint Economic Committee of the Congress of the U.S. January 25, 1978.

Chapter 2

ENERGY DEMAND PROSPECTS

World energy demand prospects and their determinants have recently been examined in detail in a number of studies, including those of the Edison Electric Institute (EEI) (1), the Workshop on Alternative Energy Strategies (WAES) (2) and Resources for the Future (RFF) (3) under contracts with the Electric Power Research Institute (EPRI). Also, the topic of modeling the interrelationship between energy and economic growth has been the subject of a number of recent conferences sponsored by EPRI and others (4). Although the present study does not attempt to duplicate these efforts, let alone try still other approaches, it is useful to summarize the results of these and other investigations in order to see where our own projections lie, relative to the range of published forecasts.

In conformity with the general approach of this study, the review of energy demand forecasts will focus on the range of recent demand estimates, their underlying assumptions, and the major uncertainties inherent in these.

RECENT ESTIMATES OF GROWTH IN ENERGY DEMAND

Table 2-1 illustrates the range of energy demand growth rates to 1985 or 1990 included in recent studies from a variety of official and private sources. It shows two things at a first glance: 1) except for some of the high-case projections which are purposely set above expected growth rates, all projections are perceptibly below the long-term pre-1973 historic trend; and 2) most projections with sequential time periods exhibit declining rates over time. Both these assumptions are based on the apparently firm belief of the forecasters that the rise in real energy prices in the 1973-74 period is irreversible for the forecast period (up to 1990) and will have a progressively retarding impact on energy growth rates.

For the world as a whole (including the Sino-Soviet Bloc) the U.S. Department of the Interior (DOI) (5) projects average annual increases on the order of 3 percent -- lower during the late 1970's and slightly higher but declining in the 1980's.

Table 2-1

PROJECTIONS OF PRIMARY ENERGY DEMAND GROWTH

(percent per year growth)

Source[a]	Cases	Historic 1955/1973	1975/1985	1975/1990
			Total World	
CEI	High		5.1	5.1
	Medium		4.1	4.1
	Low		3.1	3.1
RFF	High	5.1	NA	3.7[b]
	Low		NA	2.6[b]
DOI	-		2.7[c]	2.9[c]
			Non-Communist World (NCW)	
Exxon	-		-	3.9
Walter J. Levy Assoc.	-		4.1	3.7
Morgan Stanley	-	4.7	3.5	3.2
DOI	-		2.8[c]	2.8[c]
Caltex Petroleum	-		NA	3.6[b]
			Industrialized Countries	
CIA	Historical		5.7[d]	NA
	Reduced Growth		4.2[d]	NA
	Conservation		3.5-3.8[d]	NA
OECD	High		4.0[e]	NA
	Reference		3.6[e]	NA
	Low		3.1[e]	NA
WAES	A	4.4	2.6[f]	NA
	B		1.6[f]	NA
	C		2.9[f]	NA
	D		2.5[f]	NA
	E		3.8[f]	NA
Texaco[g]	-		NA	3.5
Royal Dutch/Shell[h]	A		NA	3.9
	B		NA	2.6
Sherman Clark Assoc.	-		NA	2.6

(cont'd)

Table 2-1 (Cont'd)

PROJECTIONS OF PRIMARY ENERGY DEMAND GROWTH

(percent per year growth)

Source[a]	Cases	Historic 1955/1973	1975/1985	1975/1990
			Western Europe	
OECD	Reference	4.4	3.6[e]	NA
FEA	High		5.3[e]	NA
	Reference		4.5[e]	NA
	Low		3.2[e]	NA
CIA	Historical		5.4[d]	NA
	Reduced Growth		3.4[d]	NA
	Conservation		3.2-3.6[d]	NA
DOI	-		3.1[c]	3.1[c]
WAES	A		2.4[f]	NA
	C		2.8[f]	NA
	E		3.6[f]	NA
Texaco			NA	3.5
Royal Dutch/Shell	A		NA	4.0
	B		NA	2.7
Sherman Clark Assoc.	-		NA	2.5

Note: Historic growth rates from World Energy Supplies 1950-1974, United Nations, New York, 1976. NA: not available.

[a]Forecasting Organizations:

EEI - Edison Electric Institute
RFF - Resources for the Future
DOI - U.S. Department of the Interior
CIA - U.S. Central Intelligence Agency
OECD - Organization for Economic Cooperation and Development
WAES - Workshop on Alternative Energy Strategies
FEA - U.S. Federal Energy Administration

[b]1980 to 2000.

[c]1973 base year.

[d]1976 base year.

[e]1974 base year.

[f]1972 base year.

[g]Includes Western Europe, U.S. and Japan only.

[h]Includes Wetern Europe, U.S., Canada and Japan only.

A recent estimate by RFF (3) projects a range of 2.6 to 3.7 percent per year for 1980-2000, depending on alternative assumptions of increases in population and economic activity. Finally, the EEI study uses alternative growth scenarios ranging between 3 and 5 percent annually. EEI's high figure represents a simple extrapolation of historical growth which the report argues is unlikely to prevail in the future because world resources of energy, food and other raw materials would be exhaused if past growth rates do not begin to taper off soon. The low growth rate is inadequate, the report holds, because it would doom large segments of the world's population to permanent poverty, starvation and war. EEI thus considers an intermediate growth rate on the order of 4 percent per year as the only sustainable, and therefore realistic, one.

The difference between the DOI figure of 3 percent (which is virtually identical with the RFF base case*) and EEI's median rate of 4 percent is not trivial. Over a 15-year period, a 4 percent growth totals to 90 percent while a 3 percent figure accumulates to only 56 percent. Assuming a base level of gross energy input of 250 quadrillion Btu (quads) in 1975, the difference by 1990 would be 60 quads, more than total current consumption of Western Europe.

For the NCW, a series of recent energy demand estimates are available from major oil companies, a consulting firm and an investment banking firm. They show a range of outcomes similar to the world total: from above 4 percent per annum to below 3 percent.

(In evaluating the significance of these and the following numbers, a basic distinction should be drawn between single point forecasts and those giving a range of possible outcomes. The single figures represent, in fact, the forecaster's judgment of the most likely outcome. By contrast, a forecast providing a range or array of numbers represents alternative outcomes corresponding to alternative sets of assumptions).

A still wider array of estimates exists for the industrialized countries (corresponding, roughly, to the members of the Organization for Economic Cooperation

*The RFF base case assumes a medium rate of population growth, low productivity, high oil prices, free trade and a continuation of the present trend in environmental policies.

and Development [OECD]) though most run to only 1985. These include the recent projections by the OECD Secretariat itself (3.1 to 4.0 percent) (6) and those of the WAES study (1.6 to 3.8 percent). The OECD numbers, it should be noted, represent an arbitrarily assumed deviation, in both directions, from a Reference Case of 3.6 percent. The wide WAES range results from a series of five scenarios depicting alternative assumptions of energy prices and economic growth rates (see below). The recent U.S. Central Intelligence Agency (CIA) estimate, which ranges between 3.5 and 4.2 percent (7), indicates the reduction in energy consumption from a recent historical trend because of expected lower economic growth (high figure) plus additional savings from conservation efforts (low figure). For 1990, two alternative cases by Royal Dutch/Shell represent high and low growth cases (3.9 and 2.6 percent, respectively) (8).

Estimates to 1985 for Western Europe alone show a similar divergent pattern from a low of 2.4 to a high of 5.3 percent per year. Projections to 1990 (generally from 1975) range from less than 3 to 4 percent annually. Most of these estimates can be evaluated by reference to rates of economic growth or energy-economic growth coefficients. (For the purpose of clarity, the ratio of energy growth to real economic growth will be referred to as the E/GNP growth coefficient). In most cases, assumptions concerning the size of the E/GNP growth coefficients were explicated. For a few which used a disaggregated approach to energy demand estimation, we derived the implicit E/GNP growth coefficients, shown in Table 2-3, to permit a broader set of comparisons.

ECONOMIC GROWTH ASSUMPTIONS

Estimates of economic growth rates associated with specific energy demand forecasts, for the most part, are made only for the industrialized countries, or some major grouping of them. One exception is a recent RFF study (3). It assumes total world economic growth rates of 3 to 4.2 percent per year for the last two decades of the century. For the NCW, Caltex Petroleum projects a single figure in the middle of this range (3.6 percent for 1975-2000) and for 1976-1985 WAES projects a range of 3.4-5.2 percent (see Table 2-2).

For the industrialized countries, OECD and the U.S. Federal Energy Administration (FEA) show a Reference Case of 4.3 percent for 1975-1980. OECD varies this by 0.5 percentage points up and down, for sensitivity purposes, while FEA's variation is one percent around the Base Case.

Table 2-2

ECONOMIC GROWTH ASSUMPTIONS

(Percent Per Year)

Source	Case	1975/1985	1975/1990
		Total World	
RFF[a]	Low	NA	3.0
	High	NA	4.2
		Non-Communist World	
Caltex Petroleum[a]		NA	3.6
WAES[b]	Low	3.4	NA
	High	5.2	NA
		Industrialized Countries	
OECD[c]	Slow	3.7	NA
	Reference	4.2	NA
	Fast	4.7	NA
FEA[c]	Low	3.2	NA
	Reference	4.2	NA
	Fast	5.2	NA
CIA		4.6	NA
Morgan Stanley		4.6	4.0
Texaco[d]		NA	4.0
Sherman Clark Assoc.[d]		NA	4.3
Royal Dutch/Shell[e]	B		2.7
	A		4.5
WAES[b]	Low	3.1	NA
	High	4.9	NA
		Western Europe	
OECD[c]	Reference	3.8	NA
FEA[c]	Low	2.8	NA
	Reference	3.8	NA
	High	4.8	NA
WAES[b]	Low	2.7	NA
	High	4.6	NA
CIA		3.4	NA
Texaco		NA	3.5
Sherman Clark Assoc.		NA	3.9
Royal Dutch/Shell[e]	B	NA	2.5
	A	NA	4.1

Table 2-2 (Cont'd)

ECONOMIC GROWTH ASSUMPTIONS
(Percent Per Year)

Source	Case	1975/1985	1975/1990
		Japan	
OECD[c]	Reference	5.8	NA
FEA[c]	Reference	5.8	NA
CIA[b]		6.1	NA
WAES[b]	Low	4.8	NA
	High	7.9	NA
Texaco		NA	5.5
Sherman Clark Assoc.		NA	5.1
Royal Dutch/Shell[e]	B	NA	4.0
	A	NA	7.0

Note: NA: not available.

[a]1980-2000.

[b]1976 Base Year.

[c]1974 Base Year.

[d]U.S., Western Europe and Japan only.

[e]All Shell figures are 1980-1990. "Industrialized Countries" are U.S., Western Europe, Japan and Canada only.

For the 1980's, the single number forecasts and the Reference Cases of OECD and FEA show close agreement. A wider divergence is found only where high and low growth cases are deliberately shown to illustrate the energy impact of alternative growth assumptions.

Base estimates and single number forecasts for Western Europe after 1980 fall into a relatively narrow range (3.5 to 4.1 percent). For Japan, the range of estimates, including high and low growth assumptions, runs from 4 to 8 percent (the low is Shell's low growth case, the high is the WAES high case). For both Europe and Japan, virtually all estimates fall well short of historical growth rates.

In attempting to assess the validity of these economic growth estimates, it may be well to dwell briefly on the impact of the world oil price trend discontinuity in 1973/74 on world economic growth. The great postwar boom in the industrialized western world which lasted, with brief and mild interruptions, from the late 1940's to the early 1970's was highly energy intensive. To a large extent it was therefore fuelled, as it were, by the ever growing availability of low cost oil and the expectations that this would continue. Hence, it is not surprising that the radical and abrupt change in this situation four years ago brought about a slow-down in general economic growth throughout the world. But the magnitude and duration of the economic slow-down, at least in Europe and Japan, is probably due to the coincidence of the oil price increase with other growth-retarding factors emerging at about the same time, such as rising inflation, balance of payments distortions, saturation levels in some growth areas and declining population growth rates. In the absence of the sudden oil price increase these would have caused gradual secular reductions in growth rates. There is evidence that the shock effect of the oil price increase has telescoped the growth-retarding impact of these developments into a much shorter period. The continued near-stagnation in many industrial countries four years after the price increase provides some preliminary indication of this.

Given our assumptions, shared by most forecasters, that energy prices will remain high in real terms, that inflation is a more intractable problem than had been earlier assumed by economic planners and that the low population growth rates in the industrial countries will not be reversed in the foreseeable future, we lean to the view that the lower estimates of economic growth (e.g., the low cases of EEI, WAES, the CIA, and even the Shell B cases) are more likely to be on target than the more optimistic projections of OECD, FEA and most of the oil companies,

let alone the high growth cases of various industry forecasts. We differ with some of these latter forecasts. We believe that at least in the economically developed nations, which account for about 84 percent of NCW energy consumption, the slow economic growth rates (by pre-1974 standards) will be accepted. Population increases in these countries average now below 1 percent per annum and gains in real per capita income can be achieved without reversion to high historical rates of economic growth. The European and Japanese experience of the last four years provides support for this thesis.

ENERGY-ECONOMIC GROWTH RELATIONSHIPS

There is no question that, broadly speaking, the level of energy consumption per capita has been closely correlated with per capita real income. Also, long-term increases in real income for individual countries have been accompanied by similar increases in energy consumption,* and changes in GNP growth rates have been mirrored by similar changes in energy usage. The relationship has not always been one to one, but the E/GNP growth coefficient has been a useful and widely used tool for deriving energy consumption forecasts from projections of economic growth.

This simple approach has been questioned by some analysts (9) but it provided reasonable results in the past because economies, by and large, were growing at stable or at least predictable rates, real energy prices were constant or falling, energy supplies were freely available, and government policies toward energy consumption were stimulative or at least neutral. These conditions no longer prevail since the quadrupling of world oil prices and the 1973-74 embargo. As pointed out, the higher energy prices have set in motion complex adaptation processes, the full extent of which have not yet been manifested; moreover, uncertainties as to magnitude and timing of future energy price increases complicate consumption

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*The recent CIA study found that the formula

$$ED = ED(-1)(x((SGNP/SGNP(-1))-1)+1)$$

provided a very close historical fit, with r^2 values of at least .99. ED represents energy demand and SNGP a smoothed time series of GNP for each of the four regional groups, using a 4-year moving average. See The International Energy Situation: Outlook to 1985, April 1977, p.4.

forecasts. Fear of future supply constraints and/or sudden interruptions are causing defensive actions by consumers and governments. And national and international policies are emphasizing a wide range of conservation measures, the full impact of which is difficult to anticipate. One must therefore ask to what extent the traditional link between energy consumption and economic growth must be modified, or even whether its usefulness has not been largely impaired in the new energy environment.

Earlier studies were derived from an era of rapidly rising real incomes and constant or falling real costs of energy. Few serious students are willing to assume that the past relationship between energy consumption, prices and incomes provides reliable indications of the future when increases in real incomes are uncertain and real energy prices are sharply rising.

More recent data (since 1973) reflect an unclear mixture of response to economic downturns, sudden, sharp price increases, and conservation appeals, even though the direction of the trend is no doubt correct. On a priori grounds, one would expect energy consumption per unit of GNP to fall but for the full adjustments to require considerable time, since this requires the replacement of existing capital stock by more energy-efficient equipment as well as more or less basic changes in consumer outlook and habits in response to higher energy prices and conservation policies.

A survey of recent energy forecasts indicates that most if not all forecasters are attempting to build these new factors into their projections. In most cases, however, the adjustments appear to reflect the subjective evaluation of the forecasters, rather than an objectively verifiable technique. Most oil company forecasters, for example, have reduced the E/GNP growth coefficient to a range of 0.8 to 0.9 from the widely used historical ratio of 1.0 (See Table 2-3). Several other recent studies agree with this assessment, including the OECD and the RFF studies.

However, both the Caltex forecast and the CIA report stay with the historical ratio of around 1.0, the latter because the base (1975) from which future changes are measured already reflects a significant drop from the historical energy consumption trend.* Still others employ E/GNP growth ratios which show a really

*Between 1973 and 1975, energy consumption decreased by 4.5 percent in the U.S., 5.5 percent in Western Europe and 2.7 percent in Japan. See BP Statistical Review of the World Oil Industry (annual).

Table 2-3

ENERGY-ECONOMIC GROWTH COEFFICIENTS

Source	Cases	1975/1985	1975/1990	1980/2000
			Total World	
RFF	High	NA	NA	.88
	Low	NA	NA	.87
			Non-Communist World	
Caltex Petroleum		NA	NA	1.00
WAES		NA	NA	0.82-0.87[a]
Morgan Stanley		NA	0.80	NA
			Industrialized Countries	
Texaco[b]		NA	0.86	NA
Sherman Clark Assoc.		NA	0.60	NA
Royal Dutch/Shell[c]	A	NA	0.82	NA
	B	NA	0.81	NA
OECD	Reference	0.84[d]	NA	NA
			Western Europe	
OECD		0.93[a]	NA	NA
Texaco		NA	1.01	NA
Royal Dutch/Shell	A	NA	.88	NA
	B	NA	.88	NA
Sherman Clark Assoc.		NA	0.64	NA
CIA	Reduced Growth	1.03	NA	NA
	Conservation	0.97-1.13	NA	NA
			Japan	
OECD		0.94	NA	NA

Note: NA: not available.

[a] 1972-2000.

[b] U.S., Western Europe and Japan only.

[c] U.S., Western Europe, Japan, and Canada, for 1980-1990 only.

[d] 1974 Base Year.

dramatic drop from those prevailing in the past. Sherman Clark Associates is one (0.6 for 1975-1990 and even lower for the 1980's alone).

The present state of knowledge permits only limited light to be shed on these and related divergences. E/GNP growth ratios are composites reflecting many factors other than the level of income and energy prices. Included among these are the structure of a country's (or region's) economy at a particular point or period in time, its climate, population density, life styles, energy efficiency and others. Some recent findings illustrate the range of possible outcomes:

1. The EEI study (1) found that similar levels of real income have been associated with quite different levels of per capita energy consumption. This suggests that existing E/GNP growth ratios might be sharply modified, given enough time and appropriate policies.

2. The RFF study of comparative energy consumption patterns in 1972 (10) determined that much of the difference between per capita energy consumption in the U.S. and major European countries was accounted for by the transportation sector. Industrial usage per unit of output differed relatively little.

3. The same RFF study (10), which compared per capita energy consumption and per capita real income for a large number of countries, concluded that the energy/income ratio becomes steeper as a country industrializes (stressing energy-intensive activities) but that the ratio tends to flatten as the importance of the service sector increases in advanced development states.

POSSIBLE ENERGY DEMAND GROWTH TO 1990

The preceding discussion has surveyed the range of energy demand forecasts for the ten to fifteen-year period beginning in 1975 and found wide divergences among various reputable sources. Also, the range of alternative scenarios for given forecasts adds to the dispersion of the resulting energy demand growth rates and volumes. These different outcomes result from alternative views of the future growth rates of economic activity plus differences in the relationship between energy consumption and economic activity (in turn determined by a host of technological conditions, policies pursued, and consumer decisions).

The principal aim of our analysis is to determine whether energy supplies, especially supplies of oil, will be adequate to meet world energy demands during the next 13-15 years and, if so, at what prices the requisite supplies are likely to be available. We have expressed the view that economic growth in the future is likely to fall well below the post-World War II historic rate, which for a variety of reasons, was exceptionally high. Although this may be the most likely outcome among the various possible alternatives, it is not the most useful for

purposes of this analysis. An assumption of relatively slow rates of economic growth, as long as they are not directly caused by energy shortages, does not permit an assessment of the capacity of the energy industries to meet future energy demands; in fact, such a premise may automatically assume the problem away. Thus, our scenarios include only cases of high and moderate economic growth rates. Our exclusion of low growth cases tends of course to bias the range of projections upward. A higher case would probably be unreasonable, but a lower one could be well within the realm of possibilities. However, such a case would not add to our endeavor to determine whether and when reasonably optimistic economic growth rates will be affected by energy supply constraints.

As to E/GNP growth coefficients, the uncertainties are such that it appears unwise to build a narrow range of assumptions into an energy demand projection at this time. There are strong reasons for expecting energy demand to increase less rapidly, relative to economic activity, than in the past. These include conservation measures already adopted and those about to be added and energy price increases which have already occurred but whose effects (and certain responses) have not been fully manifested in consumption levels. We believe, in particular, that the ability and willingness of energy users to adapt to high and rising energy prices, given sufficient time, tends to be seriously underestimated by many forecasters: a slow but steady trend away from demand for energy-intensive to other types of goods and services is likely.

On the other hand, measurements of economic activity (as expressed in real GNP or similar concepts) may understate associated increases in energy consumption because these output measures fail to give sufficient weight to processes necessary to improve the quality of environment (air and water). These technologies tend to be highly energy intensive in many cases, and thus raise the E/GNP growth ratio over time as their relative importance increases. In addition, an accelerated shift toward electricity tends to increase growth rates of primary energy consumption for any given increase in net energy used, because of high conversion losses.

For the NCW excluding the U.S., we include two alternative sets of E/GNP growth coefficients. One set assumes that energy consumption per unit of output (and real income) will be only slightly lower than in the past, i.e., that energy demand elasticities are quite low and tend to be nearly offset by rising real incomes and other opposite tendencies like accelerated electrification. The

other case shows a more rapid decline in the E/GNP growth coefficient, especially in later years, in response to rising energy prices, possible mandatory conservation measures, and perhaps fear of shortages. However, we do not foresee that the coefficients will fall as drastically as is assumed in some forecasts, particularly for the developing countries whose scope for energy conservation is more limited than it is in some major industrialized nations.

The alternative economic growth and E/GNP growth assumptions are incorporated in two pairs of projections, as follows:

HG: a high economic growth case, which is somewhat above the Reference or Base Cases of recent official forecasts (OECD, FEA and others) but well within the range of private projections and, for most regions, somewhat lower than historic growth rates.

MG: a moderate economic growth case, which resembles the Base or Reference Cases of recent government forecasts.

HEC: a high E/GNP growth coefficient, in line with consensus estimates (OECD, FEA and most oil companies) but not as high as the CIA's.

LEC: a low E/GNP growth coefficient, assuming strict conservation policies, continued increases in energy prices, and strong consumer responses to them (high price elasticities).

The assumed economic growth rates and E/GNP growth coefficients for the periods 1976-1980 and 1980-90 are shown in Table 2-4. Alternative combinations of these assumptions result in four energy demand cases for the NCW excluding U.S., follows:

- Case A combines high economic growth with high E/GNP growth ratios, yielding an energy demand growth rate of 4.8 percent per year from 1976-1990:
- Case B combines high economic growth with low E/GNP growth ratios, yielding an energy demand growth rate of 4.3 percent per year from 1976-1990;
- Case C combines moderate economic growth with high E/GNP growth ratios, yielding an energy demand growth rate of 4.3 percent per year from 1976-1990;
- Case D combines moderate economic growth with low E/GNP growth ratios, yielding an energy demand growth rate of 3.9 percent per year from 1976-1990.

These rates compare with an historic (1955-73) rate of 5.6 percent annually for the NCW (ex. U.S.).

Table 2-4

ASSUMPTIONS UNDERLYING PIRINC[a] PROJECTIONS

(Non-Communist World, Ex. U.S.)

	Economic Growth Rates (%/Year)			
	High (HG)		Moderate (MG)	
	1976-80	1980-90	1976-80	1980-90
Western Europe	3.75	4.25	3.25	3.75
Japan	6.3	5.9	5.8	5.4
Other Industrialized Countries	4.7	4.5	4.2	4.0
Others[b]	5.5	6.0	5.0	5.5

	Energy/GNP Growth Coefficients			
	High (HEC)		Low (LEC)	
Western Europe	.85	.8	.8	.7
Japan	.95	.9	.9	.8
Other Industrialized Countries	.85	.8	.8	.7
Others[b]	1.15	1.1	1.05	1.0

	Growth In Primary Energy Demand (%/Year)			
	Case A (HG-HEC)	Case B (HG-LEC)	Case C (MG-HEC)	Case D (MG-LEC)
1976-1980				
Western Europe	3.2	3.0	2.8	2.6
Japan	6.0	5.7	5.5	5.2
Other Industrialized Countries	4.0	3.8	3.6	3.4
Others[b]	6.3	5.8	5.8	5.3
1980-1990				
Western Europe	3.4	3.0	3.0	2.6
Japan	5.3	4.7	4.9	4.3
Other Industrialized Countries	3.6	3.2	3.2	2.8
Others[b]	6.6	6.0	6.1	5.5
1976-1990				
Total, Above Areas[c]	4.8	4.3	4.3	3.9

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[a]Petroleum Industry Research Foundation, Inc.

[b]Includes oil-exporting countries.

[c]Inclusion of the U.S. (see Table 5-2) yields the following energy demand growth rates for non-Communist world:

1976-90 NCW	Case A	Case B	Case C	Case D
	4.1%	3.7%	3.7%	3.3%

The resulting energy demand volumes are shown for Western Europe, Japan, other industrialized countries, and "others"(largely developing nations including for this purpose, the oil-exporting countries) in Table 2-5. As mentioned, U.S. and Communist energy demands are omitted because their energy trade with the rest of the world will be treated only on a net flow basis (net imports or exports) in Chapter 5.

The growth rates (and levels) of energy consumption depend heavily, as should be expected, on the particular combinations of assumptions. As compared to the other forecasts, reviewed previously in this chapter, the following observations stand out:

For Case A, the overall growth rate (4.8 percent) would result in almost doubling energy consumption over the 14-year period. But it should be noted that the overall rate of increase in Case A is high not because of rapid energy demand increases by the industrialized nations: these, except for Japan, are quite moderate, and all are well in line with other projections. The prime mover is the very rapid growth of energy consumption by the developing countries. This reflects, in part, the inclusion of the OPEC countries, whose economic growth rates and energy demand increases are expected to continue at a very high rate throughout the period. In addition, it is assumed that the E/GNP growth coefficient for the developing countries will have to stay above 1.0 if these countries are to continue to build an economic base essential for successful development. In sum, Case A depicts a scenario which is admittedly optimistic in its implications for future economic prosperity but falls well within the publicly aspired goals of economic policy planners in many countries.

Cases B and C will be treated as one, Case B/C, because they yield virtually identical results: in Case B energy demand increases are moderated by strong responses to price increases and/or other conservation measures; in Case C reduced economic growth results in slower energy demand increases (even though E/GNP growth coefficients remain relatively high). The overall rate of energy demand increase falls into the mid-range of other forecasts if the U.S. is included. In both cases, the demand increases for the industrialized nations (3.1 percent including the U.S.) are on the low side of the range of other projections. For Western Europe, our estimates exceed only the slow growth cases of WAES and Shell, plus the quite low forecast of Sherman Clark Associates. Again, except for the special case of Japan, the major reason for the relatively high overall

Table 2-5

ENERGY DEMAND PROJECTIONS, 1976-1990

(Non-Communist World, Ex. U.S.)

(Quadrillion Btu)

	1976[a]	1980	1985	1990	%/Year Increase 1976-90
Case A: HG-HEC[b]					
Western Europe	51.7	58.6	69.3	81.9	3.3
Japan	15.0	18.9	24.5	31.7	5.5
Other Industrialized Countries[c]	11.7	13.7	16.3	19.5	3.7
Others[d]	33.9	43.3	59.6	82.0	6.5
Total	112.3	134.5	169.7	215.1	4.8
Case B: HG-LEC[b]					
Western Europe	51.7	58.2	67.5	78.2	3.0
Japan	15.0	18.7	23.6	29.6	5.0
Other Industrialized Countries[c]	11.7	13.6	15.9	18.6	3.3
Others[d]	33.9	42.5	56.8	76.1	5.9
Total	112.3	133.0	163.8	202.5	4.3
Case C: MG-HEC[b]					
Western Europe	51.7	57.7	66.9	77.6	2.9
Japan	15.0	18.6	23.6	30.0	5.1
Other Industrialized Countries[c]	11.7	13.5	15.8	18.5	3.3
Others[d]	33.9	42.5	57.1	76.8	6.0
Total	112.3	132.3	163.4	202.9	4.3
Case D: MG-LEC[b]					
Western Europe	51.7	57.3	65.1	74.1	2.6
Japan	15.0	18.4	22.7	28.0	4.5
Other Industrialized Countries[c]	11.7	13.4	15.4	17.6	2.9
Others[d]	33.9	41.7	54.5	71.2	5.4
Total	112.3	130.8	157.7	190.9	3.9

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[a] Preliminary data, taken from BP Statistical Review of the World Oil Industry, 1976.

[b] HG - High Economic Growth
HEC - High Energy Consumption
LEC - Low Energy Consumption
MG - Moderate Economic Growth

[c] Includes Canada and Australasia.

[d] Includes oil-exporting countries.

growth rate is the rapid increase in energy demand by the developing nations (about 6 percent per year). In sum, Case B/C assumes that neither strong energy conservation measures nor moderately reduced economic growth rates alone would reduce energy demand increases substantially from historic rates. NCW energy demand outside the U.S. in 1990 would exceed the 1976 level by over 80 percent.

Case D, which combines moderate economic growth with strong conservation response, brings the annual energy demand growth to below 4 percent, and the overall increase for the 14-year period to 70 percent. This is well within the range of other recent forecasts. The annual increases for the industrialized countries, other than Japan and the U.S. (2.6-2.8 percent), are quite low, falling below the "Low" estimates of OECD, WAES and the CIA projections. As in the other cases, the overall increases are heavily influenced by the growth of energy demand of the developing countries. However, in this scenario these countries' annual growth rate (5.4 percent) is relatively low when viewed against the fact that it includes the OPEC countries with their very ambitious plans for economic expansion.

As discussed earlier, in our view there remain a number of serious economic problems in both the industrialized and developing regions (and between these two) so that future economic growth rates are more likely to be lower than assumed in our moderate scenarios than higher. However, the purpose here is to assess whether future energy demand increases can be met, and on what terms, under a variety of somewhat more optimistic growth assumptions than may prevail in the real world.

REFERENCES

1. Edison Electric Institute. Economic Growth in the Future. New York: McGraw Hill Book Co., 1976.

2. Wilson et al. Energy Demand Studies: Major Consuming Countries, First Technical Report of the Workshop on Alternative Energy Strategies. Cambridge, Ma.: MIT Press, 1976. See also Wilson et al. Energy: Global Energy Prospects 1985-2000. Report of the Workshop on Alternative Energy Strategies. New York: McGraw Hill Book Co., 1977.

3. R. Ridker and W. Watson. Energy and the Environment in the United States, 1975-2025. Baltimore: Johns Hopkins University Press (forthcoming), Ch. 2.

4. Proceedings of the Workshop on Modeling the Interrelationships between the Energy Sector and the General Economy. EPRI SR-45. Palo Alto, Ca.: Electric Power Research Institute, July 1976.

5. U.S. Department of the Interior. Energy Perspectives 2. Washington, D.C., June 1976.

6. Organization for Economic Cooperation and Development. World Energy Outlook, A Report by the Secretary General. Paris, 1977.

7. U.S. Central Intelligence Agency. "The International Energy Situation: Outlook to 1985." Washington, D.C., April 1977.

8. Cited in National Petroleum Council, Committee on Future Energy Prospects. Topic No. 18: International Oil and Gas Supply. (Draft). Washington, D.C., 1977

9. See S.H. Schurr and B.C. Netschert. Energy in the American Economy, 1850-1975. Baltimore: Johns Hopkins University Press, 1960.

10. J. Darmstadter, et al. How Industrial Societies Use Energy: A Comparative Analysis. For Resources for the Future. Baltimore: Johns Hopkins University Press, 1977

Chapter 3

NON-OIL ENERGY SUPPLIES OUTSIDE THE U.S. AND THE SINO-SOVIET BLOC

The approach we follow in this study is to determine the demand for OPEC oil by deduction; i.e., we subtract from total energy demand all supplies other than OPEC oil. This chapter develops the supply projections for sources other than oil. Chapter 6 will cover oil supplies both from OPEC and non-OPEC producers.

In line with the procedures established for total energy demand, both the non-oil and non-OPEC oil discussion will focus on the NCW outside the United States. From both the U.S. and the Sino-Soviet Bloc, we consider here only the net contribution to the energy supply of the rest of the world, positive or negative, although this cannot be considered in complete isolation from developments within these areas, of course.

In our view, the deduction method represents a logical framework for arriving, in a series of steps, at the demand for OPEC crude. It corresponds to the economic and political realities of world energy, since oil in general, and OPEC oil specifically, are typically treated as "balance wheels" in satisfying energy requirements which other sources (non-oil energy supplies and indigenous oil) are unable to meet. It would be difficult to construct an alternative model of demand for OPEC crude oil which was both manageable and realistic under conditions where strict economic criteria (relative costs) frequently are not permitted to govern policy decisions.

This chapter considers the future supplies of coal, nuclear power, natural gas (including liquefied natural gas), hydro and geothermal power, and other sources. The last of these will not be discussed in detail, since the time span to 1990 is too short to permit any (or all) of them to have a significant impact on world energy markets. Some of them are likely to emerge toward the end of the forecast period and to become increasingly important thereafter.

COAL

World recoverable reserves of coal of all types (including anthracite, bituminous and lignite) are sufficient to last for well over 200 years at recent rates of production, based on a highly conservative concept, i.e., those reserves known to be recoverable with current technology and under economic conditions prior to the sharp 1973-1974 energy price increases (see Table 3-1). If a looser concept such as total resources (including inferred deposits and recoverability under likely future conditions) is used, the numbers could probably grow by several magnitudes.

Geographically coal reserves are highly concentrated: the U.S. plus the Sino-Soviet Bloc account for over three quarters of the world total; they plus Western Europe hold nearly 90 percent of all recoverable reserves. In contrast to oil, however, which is highly concentrated as well, coal reserves are located in countries which are either industrialized already or are determined to become so (China). As a result of this fact plus high transport costs, the total volume of international trade in coal has thus far remained comparatively modest, about 150-170 million tons annually in the last several years or no more than 5-6 percent of total world coal production (see Table 3-2). Furthermore, about 70 percent of this trade is not in coal used as an energy source (steam coal) but in metallurgical coking coal used as an ingredient in the manufacture of steel.

The great bulk of world coal exports come from two areas: the U.S. and the Soviet Bloc (mainly Poland). Exports from these two sources can be expected to increase moderately during the next 13 years. But both areas will require most of the coal they can produce for internal purposes, since in both, but particularly in the U.S., coal has been assigned a major role in government plans to reduce dependency on oil. Consequently, Western Europe, the principal recipient of U.S. and Soviet Bloc coal, will only obtain relatively small increases in shipment from these areas. According to a recent United Nations study (1), by 1985 European net coal imports will be 43 million tons above the 1973 level. During the same period indigenous European production is projected to increase by 27 million tons. This would be a reversal of the long-term postwar decline in European coal production because of rising production costs, as seams became thinner and more difficult to exploit, which made coal increasingly uncompetitive with imported oil.

Table 3-1

WORLD COAL RESERVES AND PRODUCTION

	Recoverable Reserves[a] (billion short tons)	Production[b] (million short tons)	Reserve To Production Ratio (years)
United States	218[c]	656	332
Western Europe	72	321	224
Other Non-Communist Countries	72	464	155
Total Non-Communist World	362	1,441	251
Sino-Soviet Bloc	307	1,508	203
Total World	669	2,949	227

Sources: Recoverable Reserves: Department of the Interior, Energy Perspectives 2, June 1976. Production: PIRINC estimates.

[a]1974 data.

[b]Estimated 1976 data.

[c]Assumes 50 percent recovery of 437 billion tons of coal in place.

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Table 3-2

WORLD COAL PRODUCTION AND TRADE IN 1976

(million short tons)

	Production (est.)	Net Imports	Consumption
United States	656	-59	597
Canada	20	3	23
Western Europe	321	64	385
Other Non-Communist Countries	444	34	478
Total Non-Communist World	1,441	42	1,483
Sino-Soviet Bloc	1,508	-41	1,467
Total World	2,949		2,950

Sources: U.S. Bureau of Mines and BP Statistical Review of the World Oil Industry, 1976.

Note: Sum of the parts may not equal total due to rounding.

Altogether, then, European coal consumption is projected to rise by about 65 million tons, or 16 percent between 1973 and 1985, after adjustment for stock changes, according to the UN study. This would of course be substantially less than any of the projected total energy growth rates for the area. Consequently, coal's share in Europe's energy supply pattern would continue to decline.

Most other forecasts are in general agreement with the UN forecast but are somewhat less optimistic about European production. Of the six projections shown in Table 3-3, only one is significantly more optimistic than the UN study while four are significantly less so. Furthermore, the British National Coal Board, by far the largest European coal producer, expects only to maintain its current production level for the next 6-8 years.

In the period 1985-90, coal imports from the U.S. may increase somewhat but imports from the Soviet Bloc will at best remain flat but are more likely to decline. Thus, coal's share in European energy requirements in 1990 will probably be less than in 1985.

In Japan indigenous coal production is, and will remain, insignificant. Most coal imports up to now have consisted of metallurgical coal for the iron and steel industry and, thus, are not a substitute for other energy sources. However, steam coal imports are expected to rise substantially, mostly from the Pacific area (Australia and Indonesia) where major increases in coal production are projected. By 1990, according to recent preliminary forecasts by several Japanese research organizations, steam coal imports will range from 20-40 million tons, compared to 0.5 million in 1975 (2). The higher of the two figures would contribute about 3.5-4.0 percent of Japanese energy requirements in 1990.

In viewing these various trends it seems clear that in sharp contrast to its expected role in the U.S., coal's position in the energy requirements of the rest of the NCW will continue to decline, though the volume of production and consumption will increase somewhat. We would view an increase in production from about 710 million metric tons in 1976 to 840 million in 1990 and an increase in net imports into the area from about 90 million metric tons last year to 150-170 million in 1990 as a reasonable projection. Together, this would be equivalent to an increase in oil supplies from 11.0 MM B/D last year to 13.6 MM B/D in 1990 (see Table 3-12).

Table 3-3

PROJECTIONS OF NON-COMMUNIST WORLD
COAL PRODUCTION OUTSIDE THE U.S.

(million metric tons coal)

Source	Base Year	1980	1985	1990
			Western Europe	
OECD	309[a]	321	323	NA
WAES	288[b]	NA	314-328	NA
Exxon	325[c]	331	325	305
DOI	335[d]	331	356	360
FEA	291[c]	287	287	291
UN	340[d]	NA	367	NA
			Canada	
OECD	19[a]	32	44	NA
WAES	NA	NA	30-37	NA
FEA	27[c]	36	64	100
			Australia-New Zealand	
OECD	65[a]	87	110	NA
WAES[e]	109[b]	NA	180-200	NA
FEA[f]	66[c]	95	114	136
UN	65[d]	NA	104	NA
			Other	
OECD	217[a]	304	352	NA
WAES	152[b]	NA	213-253	NA
			Total Non-Communist World, Ex. U.S.	
OECD	610[a]	744	829	NA
WAES	NA	NA	737-818	NA
Exxon	614[c]	737	866	981

Notes: NA: not available.

Base Years: [a]1974; [b]1972; [c]1975; [d]1973

[e]Includes South Africa.

[f]Excludes New Zealand

Conversion factors:

1 million tons oil equivalent = 1.5 million metric tons coal = 1.65 million short tons coal = 20,000 barrels daily oil equivalent

1 billion short tons coal = 25 quads.

1 billion metric tons coal = 27.5 quads.

NATURAL GAS

Proved reserves of natural gas worldwide are the smallest of the fossil fuel reserves. Only U.S. and Canadian published reserves separate the dry gas from the liquids contained in it. Hence the gas reserves shown in Table 3-4 for the rest of the world include undetermined volumes of natural gas liquids. On this basis world gas reserves amount to about 2,300 trillion cubic feet (TCF), equivalent to about two-thirds of the world's oil reserves (Table 3-4) (3). However, with the major exceptions of North America and more recently Western Europe, gas has been utilized far below its potential. In fact in the OPEC nations the bulk of the gas--4.0-4.5 TCF/year, equivalent to 2 MM B/D of oil--is being flared for lack of a market.

Also with very few exceptions, oil companies have not actively searched for gas per se in areas which did not have adequate local or nearby markets. Thus in most OPEC nations existing gas reserves consist mainly of "associated" gas found jointly with oil deposits. The potential for "non-associated" gas has not really been tapped in most of these countries. On purely resource grounds, therefore, a considerable expansion of world gas supplies is feasible between now and 1990, and to an extent this is likely to occur. But there are a number of geographic-logistical, economic-technical and policy considerations which may retard this development, or at least create considerable uncertainties over the pace of supply increases between now and 1990.

Over 40 percent of world gas reserves are located in the Sino-Soviet Bloc, with the heaviest concentrations in Siberia. In the NCW areas, the United States accounts for 16 percent of reserves and Western Europe (chiefly the North Sea) for another 11 percent. The major industrialized countries (including the Soviet Union) thus have significant quantities of gas reserves, although not all in locations which are readily accessible or inexpensive to produce and transport. The remaining deposits, largely in OPEC countries, require movement by water to reach major markets.* For gas, this imposes a serious handicap, since it must be liquefied, shipped in special cryogenic tankers at near-absolute zero temperatures, and regasified at its destination. Assuming the delivered price is

*Exceptions are pipeline shipments from Iran and Afghanistan to the Soviet Union and a planned trans-Mediterranean pipeline from Algeria to Italy.

Table 3-4

WORLD NATURAL GAS RESERVES AND PRODUCTION

	1/1/77 Proved Reserves[a]	1976 Production[b]	Reserve to Production Ratio
	(trillion cubic feet)		(years)
United States	216	19.0	11.4
Canada	56	2.6	21.5
Western Europe	142	5.8	24.5
OPEC	778	2.6	299.2
Others	154	2.0	77.0
Total Non-Communist World	1,346	32.0	42.1
Non-Communist World, Ex. U.S.	1,130	13.0	86.9
Sino-Soviet Bloc	953	15.0	63.5
Total World	2,299	47.0	48.9

Sources: U.S. reserves are those of the American Gas Association, other areas were taken from Oil & Gas Journal, December 27, 1976. Production data for 1976 are PIRINC estimates.

[a]May include some natural gas liquids (NGLs) outside the U.S. and Canada which would cause the R/P ratio shown to be somewhat too high.

[b]Estimated production exclusive of NGLs.

related to the Btu-equivalent of alternative fuels such as fuel oil, the net realization per Btu from gas exports falls considerably below that from exports of crude oil. This may be a consideration in policy decisions by potential gas exporting countries.* (Future increases in real oil prices would of course improve the attractiveness of gas exports).

In addition to gas reserves considered proved, because they are known to exist and can be produced with available technology and under current economic conditions, there are estimates of total gas resources. These represent the total volumes of gas which the earth's crust is believed to contain and may ultimately yield. Such estimates, of course, are highly conjectural since they are based on inferences drawn from known to unknown geological structures, frequently by application of statistical techniques. (For details see Chapter 4.) Not surprisingly, the numbers vary a good deal and can only serve to indicate orders of magnitude at best. Recent estimates range between 10,500 and 26,100 TCF for the total NCW, or 8 to 20 times the level of proved reserves (4). Even the lowest of these estimates is very large compared with recent levels of production (32 TCF in 1976 for NCW).

Recent estimates of future NCW gas production outside the U.S. vary over a considerable range. Projections to 1985 range between 24 and 31 TCF, as compared with about 13 TCF currently (Table 3-4). The critical importance of judgment is indicated by the fact that both numbers were published within about six months of each other and both are from governmental organizations (DOI and OECD). Estimates for 1990 range between 27 and 32 TCF.

Analysis of regional breakdowns indicates significant differences for each major producing area. For Western Europe, 1985 estimates range between 7.3 TCF (WAES) and 10.9 (DOI). Moreover, there is disagreement as to whether output can be further expanded beyond that date, since North Sea discoveries might be fully developed by then and some older fields (especially Groningen in the Netherlands --Europe's only major onshore field) will be declining; new finds, which are quite

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*Paradoxically, the maintenance of low price ceilings on interstate gas in the U.S. has encouraged the development of high cost sources, such as LNG imports, since conventional supplies are becoming increasingly inadequate to support existing pipeline systems and to meet high priority requirements.

Table 3-5

PROJECTIONS OF NON-COMMUNIST WORLD
PRODUCTION OF NATURAL GAS OUTSIDE THE U.S.
(trillion cubic feet)

Source	Base Year	1980	1985	1990
			Western Europe	
FEA	NA	6.9-8.0	8.3-9.2	8.2-10.0
OECD	5.5[a]	8.1	8.2-9.3	NA
WAES	4.4[b]	NA	7.3	NA
DOI	5.2[c]	9.1	10.9	10.8
Exxon	5.6[d]	7.8	8.3	8.1
			Canada	
FEA	NA	2.8-2.9	2.8-3.3	2.5-3.3
OECD	2.4[a]	2.9	3.5	NA
WAES	3.3[d]	NA	2.3-2.7	NA
Exxon	2.7[d]	2.8	3.9	5.2
			Other OECD[e]	
FEA	NA	0.5-0.6	0.6-0.9	0.7-1.0
OECD	0.3[a]	0.6	1.5	NA
			Other	
OECD	3.7[a]	8.9	16.9	NA
		Total Non-Communist World, Ex. U.S.		
OECD	11.9[a]	20.5	30.1-31.2	NA
DOI	12.8[c]	19.3	24.4	27.3
Exxon	12.0[d]	18.7	27.0	31.5

Note: NA not available.

Base Years: [a]1974; [b]1972; [c]1973; [d]1975

[e]Includes Japan, Australia, and New Zealand.

likely but whose size and timing cannot be anticipated, would thus be required.

Disagreements over the future Canadian gas production centers in part on the trend of discoveries in established producing areas, which has recently turned significantly more favorable in response to higher field prices, On the other hand, there is no solid basis on which to judge the timing (or exact size) of a contribution from the various frontier regions. The largest finds to date have been in the Arctic Islands, but they are still short of the minimum required for building a pipeline over extremely difficult terrain.* Discoveries in the MacKenzie Delta also are too small to support a separate pipeline. However, it currently seems likely that the U.S. and Canadian governments will approve the application of companies which would carry Canadian Delta as well as North Slope gas to markets.

Projections for other OECD countries, chiefly Australia, envisage increases of significance regionally but not globally. The major disagreement is over the rate of production increase in non-OECD countries, primarily OPEC but also including some non-members in Latin America and the Far East. To some extent, this reflects the inevitable resource discovery uncertainties. But predominantly, the questions concern policy decisions by major Middle East and African producing countries. As in the case of oil, these countries face the broad question of how rapidly to develop their major exhaustible resources, and what the optimum price-volume combinations should be in light of their expectations and individual circumstances. In addition, however, the relatively low net realizations (as compared with oil) obtainable on gas, plus the very large capital requirements to obtain minimum scale economies in long distance tanker movement introduce additional elements into any decision to develop gas for export. Accordingly, some major producers are deliberately moving slowly into the gas export trade. Thus, Iran, which has the largest reserves of non-associated gas outside the Soviet Union, has indicated that it expects to keep most of its uncommitted gas reserves for domestic consumption or for reinjection into the ground to maintain its oil production. However, more recently it has announced to build its first liquefied natural gas (LNG) export facility. Kuwait, which is currently building LNG export facilities

* Discoveries in the Islands are reported to total about 15 TCF, perhaps one-half of those needed to support a pipeline to southern markets.

with a capacity of 600 billion cubic feet annually has stated that by 1980 it could have internal markets for this entire amount. Whether such a policy is likely to prove optimal in the future depends on developments in both gas and oil, which will be reviewed in a later chapter.

For present purposes, it appears preferable to utilize a conservative set of assumptions within our time frame with respect to these and other exports of gas, dependent on complex policy decisions by both exporting and importing countries and subject to cost escalation and prolonged delays in completion. We assume, therefore, that 1985 gas exports will be limited to quantities already committed or highly probable (i.e., where planning and negotiations are far advanced). For 1990, we assume that only a portion of potential projects will be completed, specifically those from areas where transportation costs to major markets are relatively low (e.g., North and West Africa to Europe and the U.S. East Coast, and the Far East to Japan and the U.S. West Coast). We are also projecting Mexican pipeline exports to the U.S. on the order of only 0.7 TCF annually by 1990 (Table 3-7), although this level is likely to be reached before 1985, on the basis of tentative current projects.

Even under our conservative export assumptions, NCW (ex. U.S.) gas consumption is forecast to increase from 12.1 TCF in 1976 to 34.8 TCF in 1990, almost a tripling in volume (Table 3-6). Some 40 percent of this increase in consumption will occur in OPEC countries; Western Europe will account for over 20 percent of the increase. NCW (ex. U.S.) gas production is expected, in general, to increase more rapidly than consumption in order to supply increasing U.S. gas imports requirements (Table 3-7). Net gas exports from the Sino-Soviet Bloc are expected to increase to 0.4 TCF in 1980 and remain at this level through 1990.*

NUCLEAR POWER

This section discusses the future availability of nuclear power as it will affect the demand for fossil fuels generally, and for oil specifically. The nuclear fuel cycle is complex and problems exist at virtually every stage. We will point out areas of agreement as well as existing uncertainties which bear on the prospects for nuclear power.

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*Scheduled increases in shipments from the USSR to Europe will be largely offset by increased Iranian exports to the Soviet Union.

Table 3-6

NON-COMMUNIST WORLD NATURAL GAS
SUPPLY/DEMAND BALANCE OUTSIDE THE U.S.
1976 TO 1990

(trillion cubic feet per year)

Local Consumption[a]	1976	1980	1985	1990
Western Europe	6.5	8.9	10.4	12.4
Canada	1.6	2.2	2.6	3.0
Other OECD	0.6	1.6	2.7	3.8
OPEC	1.9	4.4	7.7	9.6
Others	1.5	2.6	4.0	6.0
Total NCW (Ex. U.S.)	12.1	19.7	27.4	34.8
Net Exports				
Western Europe	-0.7	-1.2	-1.7	-3.8
Canada	1.0	0.8	0.7	0.7
Other OECD	-0.6	-0.9	-1.0	-1.8
OPEC	0.7	1.4	2.7	6.0
Others	0.5	0.7	1.4	1.6
Total NCW (Ex. U.S.)	0.9[b]	0.8	2.1	2.7
Production				
Western Europe	5.8	7.7	8.7	8.6
Canada	2.6	3.0	3.2	3.7
Other OECD	0	0.7	1.7	2.0
OPEC	2.6	5.8	10.4	15.6
Others	2.0	3.3	5.5	7.6
Total NCW (Ex. U.S.)	13.0	20.5	29.5	37.5

Source: PIRINC estimates.

[a] Includes reinjection into oil reservoirs.

[b] Does not equate with U.S. gas imports due to rounding. See Table 3-7.

Table 3-7

U.S. AND SINO-SOVIET BLOC
NATURAL GAS TRADE, 1976 TO 1990
(trillion cubic feet per year)

	1976	1980	1985	1990
U.S. Imports				
Pipeline				
Canada	1.0	0.8	0.7	0.7
Mexico	-	-	0.6	0.7
	1.0	0.8	1.3	1.4
LNG	-	0.4	1.2	1.7
Total	1.0	1.2	2.5	3.1
Sino-Soviet Bloc Trade				
Exports	0.4	0.8	1.2	1.2
Imports	0.4	0.4	0.8	0.8
Net Exports	-	0.4	0.4	0.4

Source: U.S. Bureau of Mines and PIRINC estimates.

For the period to 1990, known reserves of uranium ore, both in the United States and abroad, are believed to be adequate to meet the requirements of all nuclear plants expected to come into operation. Since 1973, sharp increases in yellowcake (U_3O_8) prices and growing scarcities of oil and gas have stimulated efforts at improved resource mapping and exploration. In time, additional volumes of uranium are likely to shift from probable, possible and even speculative reserves to the firm category. There exists a high degree of ore concentration outside the U.S., with Canada, Australia and South Africa accounting for the bulk of foreign reserves (5). Normal market forces, which would cause uranium prices to increase further in the face of rapid demand increases, may be reinforced by national or even collaborative policies on the part of producing countries. For example, it would be logical for these countries to place limits on exports to assure adequate supplies for domestic needs over the long term, as Canada has already done.* Whether such policies materialize depends on the pressures on uranium supplies in later years.

The nuclear energy industry, as is widely known, faces a number of serious unresolved problems, including permanent disposal of nuclear waste, security of radioactive material being transported for reprocessing, and the potential misuse of nuclear fuel for military or terrorist purposes. And even though remote, the possibility of a serious accident at a nuclear installation raises inordinate fears among the general public. As a result, public opposition to increased reliance on nuclear power has recently been growing in Europe and Japan. In Sweden, the future development of nuclear power has been jeopardized by recent political changes; in Germany, a moratorium has been declared on future nuclear plants except those currently under construction; elsewhere, public sentiment has contributed to increasing delays and rising costs, if not to outright plant cancellations. These effects are not easily separable from such factors as slower power demand growth projections and financial stringencies, which have likewise caused a scaling down of nuclear expansion. For whatever reasons, there have been several sharp downward revisions in estimates of nuclear capacity and production.** It does not appear that all recent forecasts have fully adjusted for these slippages.

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*As with natural gas (and oil), Canadian policy has been to ensure adequate supplies for the requirements of domestic markets (for as much as 30 years ahead) before granting any export permits.

**Between 1975 and early 1977, the OECD's projections for nuclear power production in 1985 have been reduced from a range of 650 - 748 MMTOE to 464 MMTOE. Similarly, the International Atomic Energy Agency's estimates of free world nuclear power capacity for 1990 have been lowered from 875-1,000 GW to 550-750 GW.

Available estimates of nuclear capacity (Table 3-8) show a wide range of growth for 1985 (only one forecast is available for 1990). Both the OECD and WAES ranges reflect alternative growth assumptions plus rising oil prices. The high OECD number reflects accelerated policies to reduce oil imports. It is noteworthy that, except for Canada, the most recent set of projections, that by FEA, falls near the low end of the range, even though FEA used a single (presumably "most likely") set of assumptions.

The great uncertainties concerning nuclear availability also show up strikingly in projections of nuclear power production, although all forecasts utilize more or less standard operating rate assumptions.* Thus, the range of comparable estimates for NCW (ex. U.S.) nuclear power production in 1985 runs from FEA's 920 billion kilowatt hours (KWH) to 1,557 billion KWH (Interior Department). See Table 3-9. Some of these differences are accounted for by the date of the estimates; Interior's is one of the oldest and the FEA's one of the most recent. The CIA gives a range for 1985 of 456-795 billion KWH for the OECD countries, exclusive of the U.S., Australia, and New Zealand. For 1990, where fewer estimates are available, the range is from 1,782 billion KWH (FEA) to 3,011 billion KWH (DOI).

In our view, the odds that further delays in nuclear plant completions will occur during the forecast period are greater than that completions will accelerate. Some projects now included in the 1985 tabulation are unlikely to be available by that date and should be moved to the 1990 column. As a result, total nuclear output outside the U.S. and Sino-Soviet Bloc is likely to be no greater than the lowest estimate in Table 3-9, or possibly slightly less -- say, 1,600 billion KWH. This would be equal to about 8 MM B/DOE, compared to not quite 1 MM B/DOE in 1976 (see Table 3-10 and -12).

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*The 1977 National Energy Outlook, for example, assumes a 65 percent capacity factor for all years for the U.S., 60 percent for foreign plants in 1980 and 65 percent for foreign plants in 1985-1990.

Table 3-8

PROJECTIONS OF NON-COMMUNIST WORLD
NUCLEAR POWER CAPACITY OUTSIDE THE U.S.
(Gigawatts)

Source	Base Year	1980	1985	1990
			Western Europe	
FEA	21.0[a]	61.0	112.0	196.0
OECD	NA	55.0	114.6-138.9	NA
WAES	18.9[b]	NA	106.9-147.5	NA
			Canada	
FEA	2.4[a]	7.0	10.0	18.0
OECD	NA	NA	6.2- 12.8	NA
WAES	2.5[b]	NA	8.0- 12.0	NA
			Japan	
FEA	5.3[a]	15.0	23.0	43.0
OECD	NA	NA	35.1	NA
WAES	3.9[b]	NA	25.0- 40.0	NA
			Others	
FEA	1.1[a]	6.0	25.0	70.0
WAES	1.2[b]	NA	24.0- 47.0	NA
			Total Non-Communist World, Ex. U.S.	
FEA	29.8[a]	89.0	170.0	327.0
WAES	26.5[b]	NA	163.9-246.5	NA

Note: NA: not available.

[a] 1975

[b] 1974

Table 3-9

PROJECTIONS OF NON-COMMUNIST WORLD
NUCLEAR POWER PRODUCTION OUTSIDE THE U.S.
(billion kilowatt hours)

Source	Base Year	1980	1985	1990
			Western Europe	
FEA	111.6[a]	301	609	1,071
OECD	79.4[b]	341	702- 850	NA
CIA	119[c]	238-317	357- 596	NA
Exxon	131.1[a]	262	655	1,148
DOI	65.7[d]	422	1,135	1,923
			Japan	
FEA	16.7[a]	74	126	233
OECD	19.7[b]	86	199- 297	NA
CIA	39.7[c]	60- 79	79- 139	NA
Exxon	27.8[a]	79	199	338
DOI	9.4[d]	122	281	516
			Canada	
FEA	13.2[a]	33	52	100
OECD	14.8[b]	35	52	NA
CIA	19.9[c]	20- 40	20- 60	NA
			Others	
FEA	5.5[a]	27	133	378
Exxon[e]	23.9[a]	79	218	405
DOI[e]	9.4[d]	47	141	572
			Total	
FEA	147[a]	435	920	1,782
OECD[f]	113.9[b]	462	953-1,181	NA
CIA[g]	178.7[c]	318- 436	456- 795	NA
Exxon	182.8[a]	420	1,072	1,891
DOI	84.5[d]	591	1,557	3,011

Note: NA: not available.

Base Years: [a]1975; [b]1974; [c]1976; [d]1973

[e]Includes Canada.

[f]OECD (Ex. U.S.) only.

[g]OECD (Ex. U.S., Australia and New Zealand) only.

Conversion factors:

1 billion kilowatt hours = 5,035 barrels per day oil equivalent = .25175 million tons oil equivalent

1 quad = 93.8 billion kilowatt hours

Table 3-10

NON-COMMUNIST WORLD NUCLEAR GENERATING
CAPACITY AND PRODUCTION OUTSIDE THE U.S., 1976 TO 1990

	End Year Capacity	Average Yearly Production
	(gigawatts)	(billion kilowatt hours)
1976 (Est.)	35	160
1980	89	435
1985	170	920
1990	290	1,600

Source: PIRINC estimates.

HYDRO AND GEOTHERMAL POWER

The construction of hydroelectric generating plants is subject to especially long lead times. Projects likely to be completed by 1985 thus are fairly well known and those for 1990 well along in the planning stage. The OECD's 1975 projections for Western Europe are based largely on official forecasts and represent an increase of 29 percent over the base year, 1974. Perhaps another 10 percent may be completed later in the decade. Larger increases are believed to be precluded by adverse environmental impact (6) and, of course, by the fact that the best sites have already been developed in the industrialized countries. Sizeable increases are also projected for Canada, Japan and Australia, although the OECD reduced the expansion in Canada below that forecast by the Canadian government by about 10 percent (see Table 3-11).

The bulk of the NCW's hydroelectric potential (outside the U.S.) is in the developing countries which, according to the WAES report, account for 44 percent of potential capacity but have developed only 4 percent of the total to date (7). The WAES report states that, by the year 2000, output in the developing countries could go as high as 4.4 MM B/DOE, or about 870 billion KWH, not much below current total foreign output outside the Sino-Soviet Bloc. This would represent a more than four-fold increase from the current rate, or an increase of some 675 billion KWH. The Department of the Interior projects hydro/geothermal power production for NCW (ex. U.S.) of 1,013 billion KWH in 1990.

Table 3-11

PROJECTIONS OF NON-COMMUNIST WORLD
HYDRO/GEOTHERMAL POWER PRODUCTION OUTSIDE THE U.S.
(billion kilowatt hours)

Source	Base Year	1980	1985	1990
			Western Europe	
OECD	366.3[a]	421.7	474.0	NA
CIA	317.8[b]	417.1	476.7	NA
DOI	337.7[c]	384.6	431.5	469
			Canada	
OECD	212.5[a]	242.4	299	NA
CIA	198.6[b]	238.3	297.9	NA
			Japan	
OECD	84.8[a]	89	117	NA
CIA	79.4[b]	79.4	119.2	NA
DOI	65.7[c]	93.8	103.2	112.6
			Others	
DOI[d]	375.2[c]	384.6	403.3	431.5
			Total Non-Communist World, Ex. U.S.	
OECD[e]	642.3[a]	702.7	788.5-968.0	NA
DOI	778.6[c]	863.0	938.0	1,013.1

Note: NA: not available.

Base Years: [a]1974; [b]1976; [c]1973

[d]Includes Canada.

[e]OECD (Ex. U.S.) only.

Conversion factors:

1 billion kilowatt hours = 5,035 barrels per day oil equivalent = .25175 million tons oil equivalent.

1 quad = 93.8 billion kilowatt hours.

In our view, hydroelectric development in the developing countries will go forward during the 1980's, since it represents in many cases a key to agricultural and industrial development. It provides not only an economical source of energy but necessary irrigation and flood control; these can support the development of export commodities which generate foreign exchange earnings in excess of loan services. On the other hand, if our somewhat pessimistic assumptions regarding economic growth and balance of payments problems prove correct, the financing of highly capital intensive projects may well have to be stretched out over longer periods, and not all projects presently contemplated can be completed within the planned time frames. We project NCW (ex. U.S.) output in 1990 to be about 1,390 billion KWH or about 7.0 MM B/DOE compared to 4.3 MM B/DOE in 1976.

Efforts to explore and develop the NCW's geothermal potential outside the U.S. have thus far been on a modest scale. Except for the utilization of natural steam, the presence of which appears to be extremely rare, major technical problems remain to be resolved before commercial scale electricity generation (utilizing hot rocks or hot water) can be undertaken. Accordingly, we do not foresee more than a fractional contribution abroad from this source by 1990.

OTHER SOURCES

The United States is likely to see the emergence of several new forms of energy on a commercial scale during the 1980's, including solar water and space heating, coal-based synthetic oil and gas and shale oil. Elsewhere in the NCW, these sources are unlikely to progress at the same pace. In the case of solar power the reason in the developed countries is partly climatological and partly that the share of single dwelling units (which are much more appropriate for solar space heating than multiple dwelling units) in residential construction is significantly less than in the U.S. In the developing countries space heating requirements are usually modest and the equipment primitive. The market for relatively expensive solar space heating equipment would therefore be quite limited in these countries.

Synthetic fuels from coal and shale will not become significant outside the U.S. in the foreseeable future because most other non-Communist countries do not have the necessary resource base. Those that do are likely to wait for the U.S. to prove out technical and commercial feasibility of these processes. An exception is the case of Canadian tar sands, where at least one major plant is scheduled to

be added before 1980. Also, some coal gasification projects may well be undertaken in Canada (and possibly in Europe) before 1990. In sum, however, all of these sources are not expected to add much more than 0.5 MM B/DOE to the total foreign energy supply (excluding the Sino-Soviet Bloc) by that year, at least half of which will be produced in Canada.

SUMMARY

Table 3-12 presents a summary of our projections for energy supplies other than oil available to NCW consumers outside the U.S. It will be noted that virtually all sources are shown as expanding significantly with nuclear power and gas increasing by the largest volumes. Total non-oil supplies are projected to more than double over the 14 year period to 1990. This is equivalent to an annual rate of increase of 5.4 percent, which is substantially greater than even the highest total energy demand growth rates currently thought to be realistic. Our projections indicate, therefore, that the relative importance of the sources other than oil will increase in future years, thus easing the demand growth pressure on petroleum, the "swing" fuel in our world energy demand balance.

It cannot be stressed too often that this projection, like all others, is subject to a wide range of uncertainties stemming from future technological, economic and political developments. Throughout, it has been assumed that the events since 1973 have stimulated consuming countries into accelerated energy supply diversification both internally and externally, which will show increasing results as the 1980's progress.

Certain limitations inherent in our approach must also be pointed out. In particular, we have not examined in detail the complex substitution possibilities, and their constraints, in the various energy sectors. For example, it may be physically possible to accelerate the production of both coal and uranium, but outside the U.S. incremental utilization of these sources as fuel is predominantly or exclusively in electricity generation for the foreseeable future. Thus, these two fuels are essentially completing in one single market so that a faster increase in the availability of one could mean a decrease in additional requirements for the other. Thus, unless electrification in the non-Communist world outside the U.S. continues to proceed at a much more rapid rate than total energy demand, one of these two fuels (uranium or coal) could become demand limited during the period under study. We have assumed in our forecast that the growth in electrification will be such as to render this unlikely.

Table 3-12

NON-COMMUNIST WORLD CONSUMPTION OF NON-OIL ENERGY OUTSIDE THE U.S., 1976 TO 1990

(million barrels per day oil equivalent)

	1976[a] (preliminary)	1980	1985	1990
Coal[b]	11.0	11.6	12.5	13.6
Gas[c]	5.8	9.5	13.2	16.8
Nuclear	0.8	2.2	4.6	8.0
Hydro/Geothermal	4.3	4.9	5.9	7.0
Other	-	0.2	0.3	0.5
Total	21.9	28.4	36.5	45.9

Sources: Data for 1976 were taken from BP Statistical Review of the World Oil Industry (see note below). Projections are by PIRINC.

[a]The BP data have been adjusted to reflect a heat content of 5.8 million Btu/barrel of oil equivalent.

[b]Includes shipments from U.S. and Sino-Soviet Bloc.

[c]Includes natural gas liquids.

REFERENCES

1. United Nations Economic and Social Council. Economic Commission For Europe, Coal Committee. Perspectives of the Coal Industry in the ECE Region: Part 5, May, 1977.

2. Unpublished preliminary data submitted by the Institute for Energy Economics, Tokyo. Choice for a Long Term Energy Strategy. National Institute for Research Advancement, January 1977, p. 9.

3. The Oil & Gas Journal, December 27, 1976, pp. 104-5. Other recent estimates, such as those of World Oil (August 14, 1976), differ only in detail.

4. National Petroleum Council, Committee on Future Energy Prospects. Topic No. 18: International Oil and Gas Supply.(Draft). Washington, D.C., p. 24. Estimates cited are by Hendricks (1965), Institute of Gas Technology (1976) and U.S. Geological Survey (1973).

5. U.S. Federal Energy Administration. 1977 National Energy Outlook. Draft Version. Washington, D.C., Ch. III, Table III-23.

6. Organization for Economic Cooperation and Development. World Energy Outlook. Report by the Secretary General. Paris, 1977, p. 53.

7. C.L. Wilson, et al. Energy: Global Prospects, 1985-2000. Report of the Workshop on Alternative Energy Strategies. New York: McGraw Hill Book Co., 1977, p. 221.

Chapter 4

WORLD OIL RESOURCES

All major commercial fuels in current use (with the exception of water power) are finite resources. This means the total amount in existence is fixed and is irreplacably diminished by each unit produced and consumed. Another aspect of finiteness is that production costs are subject to the law of diminishing returns, i.e., as the more accessible deposits begin to be exhausted, additional production must come from progressively less accessible ones which, other things being equal, require higher effort per unit of output. In turn, this tends to be reflected in rising real prices of the resource, unless offset by technological improvements.

In the case of oil the prospects of ultimate resource constraint were, with some notable exceptions, treated up to about 1970 as academic exercises, somewhat irrelevant for the present generation of consumers. Globally, the amount of oil found during most of the postwar period had been so large that no matter how fast production increased, at the end of each period proved reserves in the ground were always higher than at the beginning. Thus, between 1950 and 1972 world oil production, excluding the Sino-Soviet Bloc, increased from 10 MM B/D to over 44 MM B/D, a cumulative withdrawal from finite deposits of 192 billion barrels. Yet, at the end of this period known reserves were 493 billion barrels higher than at the beginning, and prices, in real terms, were lower.

The sudden awareness of the ultimate resource limitation of oil and the accompanying fear that its exhaustion might occur before the availability of other energy sources in offsetting volumes did not come about because of evidence of an approaching resource constraint. Rather, it was the reaction to two events in 1973-74, one of which bore no relation to the question of physical resource availability and the other should more logically have raised hopes for an expansion of the resource base. The first was the Arab oil export embargo, a political action which demonstrated the power of those who have ultimate control over the bulk of the world's oil resources. The second was OPEC's imposed

300 percent price rise between the fall of 1973 and the spring of 1974 which was bound to increase the commercial supply of the resource, decrease its demand growth and make substitute sources more competitive, thus reducing the probability of future resource constraints.

This is not to say that the question of ultimate resource exhaustion and, even more, of the preceding phase of a terminal decline in productive capacity need not concern the present generation. But the events which have ushered in the worldwide preoccupation with these matters are by themselves not indicative that we are about to enter this phase. Rather, what has happened is that the dramatic focus on the politics and economics of oil in the last four years has also raised the very legitimate question of how much oil is really still left in the ground, where it is located and at what rate it can be produced. This chapter will deal with these questions.

Unfortunately, despite the importance of the subject and the attention given it of late, there have been no systematic and thorough attempts to estimate world oil resources on a uniform and comparable basis. For the U.S. and a few other countries a considerable amount of information has been available for some years, but for many other major oil producing countries the available data are very scanty and incomplete.

Because of this deficiency, the emphasis in this section will be on the limitations of present knowledge of world oil resources, and on the uncertainties which this weakness introduces into any estimates of future oil supplies and prices.

CONSENSUS ESTIMATES

Historical Summary

Information on the history of major estimates of world oil resources or ultimate recovery which have been made in the past two decades or so has been presented in several publications by M. King Hubbert, formerly geophysicist for Shell and subsequently for the U.S. Geological Survey (USGS). According to this source, one of the earliest systematic attempts to estimate world oil resources was that of L. G. Weeks, then a geologist for Standard Oil of New Jersey and subsequently an independent consultant.

In 1948 Weeks reported what he called "Ultimate Potential Reserves" to be 610 billion barrels for the world and 110 billion for the U.S. (1). Weeks' 1948 estimate for the U.S. was close to the most recent estimates by the USGS (2) and the Committee on Mineral Resources and the Environment (COMRATE) of the National Academy of Sciences (3), which are considered among the best currently available. However, Weeks' original world figure was patently far too low. In fact, Weeks himself made several upward revisions in his world figures. In 1950 he amplified his earlier estimates to account for continental shelves and estimated world recovery at 1,000 billion barrels. Six years later, Hubbert added to Weeks' work and arrived at figures of 1,250 billion barrels for the world and 150 billion for the U.S. (1).

More recently Hubbert summarized the more important estimates of world ultimate recovery of various experts made in the 1960's and early 1970's. He expressed the opinion that worldwide exploration is by now sufficiently advanced that recent estimates by various international oil companies and petroleum geologists of the ultimate amount of crude oil the world will produce have become reasonably consistent (4). The tabulations indicated a convergence towards an estimate of close to 2,000 billion barrels or slightly less, including offshore to a water depth of 6,000 feet (5, 6). (See Table 4-1.) A recent survey of 28 recognized experts, using a "Delphic technique", arrived at a very similar figure (260 billion tons or 1.9 trillion barrels) for conventional oil resources, but including offshore only to a depth of 660 feet (7).

Significance of Consensus Figure

To make the consensus estimate more meaningful, it may be related to the current level of production. For this purpose, we use the Moody-Esser estimates (8), which are widely accepted as the most carefully based recent numbers and which provide substantial geographical detail. Adjusting these for production in 1975 and 1976 (41 billion barrels excluding natural gas liquids, according to the Oil & Gas Journal) yields total cumulative production at the beginning of 1977 of 360 billion barrels of crude oil. This amounts to 18 percent of the consensus estimate of ultimate recovery. The remaining 82 percent, or 1,670 billion barrels, are equivalent to about an 80-year supply at the 1976 rate of production. In other words, if production could be held to present levels, the resource would presumably last until around the year 2057.

Table 4-1

RECENT ESTIMATES OF WORLD ULTIMATE
CRUDE OIL RECOVERY

Date of Estimate	Estimator	Organization	Billion Barrels
1962	L. G. Weeks	Consultant	2,000
1965	T. A. Hendricks	USGS	2,480
1967	W. P. Ryman	Esso (Exxon)	2,090
1968	-	Shell	1,800
1969	M. King Hubbert	National Academy of Sciences	1,350-2,100
1969	L. G. Weeks	Consultant	2,200
1970	J. D. Moody	Mobil	1,800
1971	H. R. Warman	BP	1,200-2,000
1972	J. D. Moody and H.H. Emmerick	Mobil	1,800-1,900
1972	Richard L. Jodry	Sun	1,952
1975	J. D. Moody and R. W. Esser	Mobil	2,030
1975	Not Available[a]	Exxon	1,945
1977	M. King Hubbert	Congressional Research Service	2,000[b]

[a] As reported by Oil & Gas Journal, May 26, 1975, p. 63.

[b] Approximate number.

This is of course merely a hypothetical calculation. In practice, the life cycle of production from any oil reserve base (global or a single reservoir) follows a pattern of ascending to a peak and then progressively declining to ultimate exhaustion. Thus, actual production from the world's ultimate recoverable reserves would last much longer but at a progressively declining rate, following attainment of peak producibility.

This life cycle pattern is reflected in Hubbert's estimates of resource exhaustion. Noting the convergence of estimates toward a figure of about 2,000 billion barrels, he regards the range of 1,350 to 2,100 billion barrels as encompassing the most reasonable estimates. By fitting symmetric bell-shaped curves to production data he determines that world production will peak about the year 1990, if the bottom of the range is correct, and about the year 2000, if the top proves correct (5). He also concludes from his curve fitting procedures that the middle 80 percent of the world's ultimate production will be produced in a span of 58-64 years (half on either side of the peak years). The most recent Hubbert curve, fitted to ultimate recovery of 2,000 billion barrels, yields a peak in the mid-1990's at a maximum production of about 37 billion barrels (101 MM B/D). Moody and Esser, using a similar technique, arrive at a peak in the late 1980's or early 1990's (8).

Hubbert's approach is open to the obvious criticism that the assumption of symmetry may not hold, i.e., that world production may not fall from the peak in the same pattern as it rose to the peak. Predicting the precise pattern of production increases to the peak and decreases thereafter is a matter of considerable difficulty. Hubbert's procedure, which is that of mathematical projection based on curve fitting and extrapolation of historical data, rests on the premise that the basic conditions affecting the data (economic, technological, social, and political) will follow the same trends in the future as in the past. For some historical periods this may be a fairly reasonable assumption. For others it may not be true. The OPEC price increases of 1973-1974 and the shift in production decision-making from private industry to the governments of producing countries have altered some of the basic conditions affecting the oil industry. In the oil importing nations, policies designed to stimulate conservation, plus the quadrupled oil prices since 1973, have affected and will continue to affect the growth of energy demand. Higher oil prices also accelerate development of substitute energy sources. These and other basic and

pervasive changes in the economics of the oil industry make it more than ordinarily difficult to estimate the shape of future petroleum production. So will actions of the OPEC members in the area of prices and conservation.

Another criticism of the Hubbert curves relates to the level of assumed production in the assumed peak years. A reasonable argument could probably be made for a flatter peak, because of production limitations or conservation policies, followed by a more gradual tapering off as prices continue to rise. Hubbert, in his most recent work (6), attempts to allow for this weakness by providing an alternative projection on the assumption that production will remain at recent levels (about 20 billion barrels per year). In that event, no decline would occur before the third decade of the 21st century, and the middle 80 percent of resources would not be exhausted until 2049.

However, any such departure from the normal bell-shaped curve causes the loss of a major advantage claimed by proponents of the Hubbert methodology, that their results rest on purely objective facts and avoid the introduction of arbitrary policy issues. This position is certainly open to question both on technical grounds and for policy reasons; the latter may impose constraints long before these would arise from resource limitations (9). After all is said and done, however, there remains the fact that Hubbert, using the same techniques, in 1956 accurately predicted the peaking of domestic U.S. production in 1970, which is no mean achievement.

Geographical Distribution

Details of the 1975 Moody and Esser estimates are shown in Table 4-2. Of the total ultimately recoverable resources of 2,030 billion barrels, 1,105 billion or about 54 percent come from fields already discovered, and the remaining 925 billion (or about 46 percent) from fields yet to be found (including offshore areas to water depths of 6,000 feet). In other words, almost half the world's oil remains to be discovered.

In arriving at reserves from discovered fields, Moody and Esser include cumulative production (319 billion barrels to January 1, 1975) plus "proved and prospective" reserves. The latter comprises, in addition to proved reserves, quantities which have a reasonable probability of being recovered with foreseeable technology and something like current cost/profit relationships. They may be regarded as approximately equivalent to "indicated" and "inferred" reserves, or as the excess of

Table 4-2

MOODY AND ESSER ESTIMATES OF RECOVERABLE WORLD CRUDE OIL RESOURCES AS OF 1/1/75

(billion barrels)

	From Discovered Fields			From	
	Production to 1975	Proved and Prospective	Total	Undiscovered Fields	Ultimate Recovery
Communist Countries	50	128	178	300	478
North America:					
U.S.	106	51	157	85	242
Canada	7	9	16	70	86
Total North America	113	60	173	155	328
Middle East	78	435	513	150	663
Other:					
North Sea	1	22	23	45	68
Other Western Europe	2	2	4	12	16
North Africa	14	40	54	33	87
Gulf of Guinea	5	30	35	30	65
Other Africa	-	-	-	8	8
Northwest South America	36	25	61	32	93
Other Latin America	9	14	23	50	73
Southeast Asia	9	23	32	32	64
Other Far East	2	7	9	58	67
Antarctica	-	-	-	20	20
Total Other	78	163	241	320	561
Total World	319	786	1,105	925	2,030

Source: World Oil, September 1975, p. 49.

UPDATED ESTIMATES OF RECOVERABLE WORLD CRUDE OIL RESOURCES AS OF 1/1/77

	Production to 1977				
Communist Countries	59	119	178	300	478
U.S.	112	45	157	85	242
Middle East	93	420	513	150	663
North Africa	16	38	54	33	87
Northwest South America	38	23	61	32	93
Other	42	100	142	325	467
Total World	360	745	1,105	925	2,030

"probable" over "proved." Volumes in this classification may be estimated by deducting Oil & Gas Journal's proved reserves as of January 1, 1975 (555 billion barrels) from Moody and Esser's 786 billion barrel total. This would imply that prospective reserves were 231 billion barrels, or 42 percent or current proved reserves.

In the lower portion of Table 4-2, we have updated the Moody-Esser figures by adding 1975 and 1976 production to cumulative production and subtracting the same volumes from proved and prospective reserves. This assumes that gross reserve additions during the last two years came from fields which had been discovered by 1975 and not from undiscovered fields, an assumption that is reasonable for the most part.

The results can be summarized as follows:

- World cumulative production to the beginning of 1977 totaled 350 billion, or 18 percent,of estimated world ultimate recovery of 2,030 billion barrels.
- Proved and prospective reserves amounted to about 745 billion, and ultimate recovery from undiscovered fields to about 925 billion, totalling 1,670 billion barrels remaining to be recovered. Since current production totals nearly 21 billion barrels annually, this is equivalent to about 80 years of production at current levels.
- The Middle East and the Communist countries are the most favored with oil resources. The Middle East has 33 percent of the world's ultimately recoverable oil, the Communist countries 24 percent. The U.S. has only 12 percent and other major producing areas even less.
- On the basis of the remaining recoverable resources in the ground, the Middle East has 34 percent, the Communist countries 25 percent, and the U.S. only 8 percent. The reason for this low U.S. share is that the U.S. has already produced a larger portion of its ultimately recoverable oil than any other major producing area, about 46 percent of its ultimately recoverable oil as of the beginning of 1977. By contrast, the Communist countries had only produced about 12 percent of theirs. The next most exhausted area following the U.S. is Northwest South America (mainly Venezuela) which has produced nearly 41 percent of its ultimate. North Africa has produced 18 percent of its ultimate, the Middle East 14 percent and Southeast Asia also 14 percent. In fact, the U.S. and Northwest South America (mainly Venezuela) are the only producing areas in the world which have already produced more oil than they are expected ultimately to recover from as yet undiscovered oil fields. By all tests these two areas are at present the most depleted.

- Other areas such as the North Sea, the Gulf of Guinea, the Far East, and Antarctica offer sizable prospects but nothing sufficiently major to alter the situation as it presently appears. If these estimates are right, the undrilled areas of Latin America, Africa, and the Far East definitely merit further exploration, but none affords any real hope of finding another Middle East.

Moody also presented data as to the offshore-onshore distribution of oil believed recoverable from undiscovered fields (Table 4-3). As the table indicates, for the world as a whole some 41 percent of the oil ultimately recoverable from as yet undiscovered fields is expected to come from offshore areas. For the U.S. the percentage is somewhat greater, i.e., around 65 percent,for the Middle East 13 percent, for North Africa 21 percent, and for the Communist Bloc countries, only 8 percent.

Estimates of recovery from undiscovered fields are obviously subject to greater uncertainty than estimates of recovery from already discovered fields. Moody and Esser recognize this by expressing estimates of ultimate recovery from undiscovered fields as not only a single point estimate, e.g., the 925 billion shown in the table above, but as a range of 600 to 1,400 billion barrels (8). Moody and Geiger give a range of 280 billion barrels (90 percentile) to 2,200 billion barrels (10 percentile) (10) for total ultimately recoverable resources.

Uncertainties

These numbers, and others based on quite different geological concepts, raise the question of whether the consensus figure of 2,000 billion barrels, which has been so widely accepted, rests on solid ground. If serious doubts over its validity arise, is the error more likely to be on the low or on the high side? Examination of this question requires at least some reference to methodologies, assumptions and data bases employed by the various estimators.

The simplest classification of commonly used methodologies is a three-way system of the USGS (2). It divides recent estimates (most of them limited to the United States) into three basic categories: 1) performance or behavioristic extrapolation, 2) volumetric-yield methods, and 3) combined methods-geological and statistical models. Hubbert's work, which has already been discussed, is a prime example of the first approach, which employs mathematical-statistical curve fitting and projection.

Table 4-3

UNDISCOVERED RECOVERABLE CRUDE OIL
(billion barrels)

	Onshore	Offshore	Total	Percent Offshore
Communist Countries	275	25	300	8
North America:				
U.S.	30	55	85	65
Canada	13	57	70	81
Total North America	43	112	155	72
Middle East	130	20	150	13
Other:				
North Sea	-	45	45	100
Other Western Europe	3	9	12	75
North Africa	26	7	33	21
Gulf of Guinea	6	24	30	80
Other Africa	2	6	8	75
Northwest South America	23	9	32	28
Other Latin America	16	34	50	68
Southeast Asia	4	28	32	88
Other Far East	15	43	58	74
Antarctica	-	20	20	100
Total Other	95	225	320	70
Total World	543	382	925	41

Source: World Oil, September 1975, p. 48.

The 1965 Hendricks estimate is an illustration of the second method. This involves examination of available data on world sedimentary basins, estimating volumes of sedimentary rock, and comparison with known basins in the U.S. By reference to pore space and other factors, Hendricks arrived at an estimate of original oil in place of 10,000 billion barrels (11). He then assumed that 3/8 of this oil would never be discovered, i.e., he applied a discovery factor of 5/8, and obtained a figure of about 6,200 billion barrels of discoverable oil in the world. Finally, he applied a recovery factor of 40 percent to arrive at his estimated world recovery of 2,480 billion barrels.

All three elements in the estimating procedures are critical to the final answer. Thus, Hendrick's discovery factor of 5/8 is subject to wide variation. Various estimators have used ratios ranging from as low as 0.1 to as high as 1.0. Obviously, a very different final estimate will result.

The 40 percent recovery factor used by Hendricks is relatively optimistic and explains largely why ultimate recoverable resources estimates exceed the consensus figure by some 25 percent. If one relates the latter (2,000 billion barrels) to the Henricks's estimate of discoverable oil (6,200 billion barrels), the implied recovery factor is 32 percent. This is in line with the current U.S. figure but well above that for the world (25 percent or less), though the latter is an estimate not based on solid data.

In support of the optimistic view, one may refer to the long-term trend in estimates of recoverable reserves, to eliminate excessive reliance on time constrained estimation (12). A review of recoverable oil estimates made during the past three decades is revealing: the range of numbers in the late 1940's was 400-600 billion barrels; in 1950's it was 1,000-1,500 billion barrels, and since 1960, the numbers converged toward the current consensus of about 2,000 billion barrels. Long-term increases in the recovery ratio, resulting from technological advances, are an important explanatory factor in the optimists' assessment. The historic trend, it is argued, should be expected to continue, and in fact be reinforced by the sharp rise in oil prices which has already occurred, and by further increases that may be expected as supply conditions continue to tighten. A recovery factor of 40 percent is frequently cited as a realistic achievement in the 1990-2000 period.* With

*For instance, the World Energy Conference's Delphic Survey, referred to earlier, assumes such a recovery rate will be attained globally by the end of the century.

"substantially higher" prices, the rate could rise further; a recent RFF study uses an alternative estimate of about 2,600 billion barrels, 30 percent above the base figures (13). Odell (14) even believes the volume of ultimate recoverable oil will increase to as much as 3,500 billion barrels by the year 2000 because of higher prices which will cause previously sub-marginal deposits to shift into the commercial category.

In assessing this viewpoint, it should be stressed that the current recovery factor already reflects widespread application of secondary recovery techniques, mainly water injection. Additional increases thus would have to come in part from tertiary recovery techniques such as thermal stimulation, chemical flooding, or carbon dioxide injection. These are much more difficult to apply successfully, for both technical and economic reasons, and may not add large volumes to reserves until prices have climbed significantly higher and stayed there for some time, or substantial subsidies for such operations are provided.

An additional factor arguing against an overly optimistic recoverable resource estimate is the location of the most promising remaining areas in the Arctic, eastern Siberia, and various offshore regions, where operations are much more difficult than in most established areas, and hence availability likely to be delayed. Finally, the upward trend of recoverable resource estimates is by no means universal: figures for the U.S. recently were sharply reduced and the Canadian Arctic appears not to have lived up to expectations, to cite but two examples. On the other hand, most estimates of the resource base, including that of Hendricks, cover only offshore shelves up to a water depth of 200 meters. Advancing technology has already extended this figure and will no doubt increase it farther as experience with offshore operations accumulates.

The third method combines geological estimates and probabilistic concepts. It involves processing large amounts of geologic and petroleum engineering data by mathematical and computer procedures to make estimates for each play in each basin in each petroleum province, and then subjects these to probability analysis. Crucial parameters such as the size of prospective areas, the thickness of potential pay, the percentages expected to be productive, and recovery per acre foot, are analyzed in probability terms to arrive at a probability distribution of potential recovery for a given area.

The most sophisticated example of this approach is the most recent estimate of U.S. resources of oil, natural gas liquids and natural gas published by the USGS

in 1975 (2). One of its advantages is the replacement of largely arbitrary discovery ratios, which had varied widely in earlier studies, with more sophisticated estimates based on probability concepts. Thus, USGS Circular 725 put U.S. undiscovered recoverable crude oil resources with a 90 percent certainty, at 50 to 127 billion barrels, i.e., there is a 5 percent chance that the undiscovered recoverable amount of crude oil is less than 50 billion barrels and a 5 percent chance that the amount is greater than 127 billion barrels. These estimates are based on pre-1974 oil prices.

Recent world oil resource estimates also have been couched in terms of ranges; for instance the Delphic Survey previously referred to showed a range from 1,300 billion barrels for 10 percent of the responses to 2,600 billion barrels for 25 percent.

DISSENTING VIEWS

At least one dissent warrants special consideration, that of Bernardo F. Grossling, a senior geologist with the USGS specializing in Latin America. Grossling's estimates, which are considerably more optimistic than the industry consensus, first appeared in several USGS publications (15, 16), and have since been incorporated in book form (17).

In a set of estimates published in 1975, Grossling pointed out that drilling density varies greatly throughout the prospective oil areas of the world. The co-terminous U.S. is by far the best drilled area. The U.S.S.R. is next but lags appreciably. Other areas have even fewer wells per square mile. Grossling presents the following data on wells per square mile of prospective area (15).

Co-terminous U.S.	1.17 wells per square mile
U.S.S.R.	.15
Argentina, Mexico, Venezuela	.05
Other Latin America	.01
Middle East	.01
South and Southeast Asia, Indonesia	.01
Africa and Madagascar	.003

Grossling's premise is that areas such as Latin America and Africa, if adequately drilled, could well turn out to be about as productive as the U.S. Another Middle East is not expected, but greater resources than have so far been found are anticipated in other world prospective areas, particularly Latin America and Africa. Exploratory wells are more to the point than production wells, but Grossling

elsewhere points out that the disparities between the areas in exploratory drilling present much the same kind of picture.

Like other petroleum geologists, Grossling estimates the size of prospective areas in various parts of the world, including continental shelf areas to a depth of 600 feet, and comes up with a figure of approximately 26,000,000 square miles of prospective area for the world at large (16). Of this about 4,900,000 or 19 percent is estimated to be in Latin America, about 4,700,000 or 18 percent in Africa/Madagascar, about 3,500,000 or 13 percent in the U.S.S.R, and about 3,000,000 or 11 percent in South and Southeast Asia (presumably including island areas). In this connection Grossling points out that Latin America, which has around 19 percent of the world's prospective area, has been producing only about 9 percent of the world output (16). Similarly, Africa with 18 percent of the world's prospective area has been producing only around 8 to 9 percent of the output. Grossling believes substantial opportunities for further petroleum development exist in both these continents (15).

By examination of certain benchmark areas, particularly the U.S. and U.S.S.R., Grossling concludes that continential size regions can be expected to yield 100,000 to 250,000 barrels of estimated ultimate recovery (EUR) per square mile of prospective area (15). Based on this and on the size of world prospective areas, Grossling estimates world EUR to be between 2,600 and 6,500 billion barrels (15). Grossling's minimum figure is thus some 30 percent above the consensus estimate. His maximum is more than three times as large.

Grossling's EUR for Latin America is in the range of 490 to 1,225 billion barrels, and for Africa and Madagascar in the range of 470 to 1,200 billion (15). The disparity between the Grossling and Moody estimates for Latin America and Africa is rather striking. Moody's ultimate recovery figure for Latin America is 166 billion and for Africa 160 billion barrels.

Grossling refers to a 1973 estimate of recoverable resources (presumably excluding cumulative production) by K.O. Emery, said to be based on Mobil data and contained in an unpublished report to the U.S. National Research Council, of 1,365 billion barrels. He comments that if world demand were to increase at a 5 percent cumulative rate, such resources would be exhausted by the year 2008, and adds that if resources were five times greater (about equivalent to his own

maximum estimate), the depletion date would be postponed only to the year 2045 (16). A telling illustration of the limits to exponential growth.

CONCLUDING OBSERVATIONS

The early sections of this chapter indicated that world resource estimates by industry experts in recent years seem to converge around a figure of roughly 2,000 billion barrels for world ultimate recovery. Of this amount cumulative production to the beginning of 1977 totals around 360 billion barrels, or 18 percent, which leaves 82 percent still to be produced as of that date. World production in 1976 totalled nearly 21 billion barrels, or about 1.3 percent of remaining reserves. This implies that, at current levels of production, remaining resources are equivalent to nearly 80 years' supply. If crude oil demand continues to increase (a more reasonable expectation) the theoretical "life index", based on current resource estimates, would of course be much lower because of the effect of cumulative production increases, especially if these should be at constant annual growth rates.

More significant for the determination of oil supply and price than ultimate resource exhaustion is the shape of the cumulative production function, especially the location and height of peak production. Using his mathematical trend fitting technique, Hubbert predicted that world production will peak and start declining around the year 1990 if ultimate recovery is at the level of 1,350 billion barrels, and around the year 2000 if ultimate recovery is at the 2,100 billion barrel level. One of his curves fitted to ultimate recovery of 2,000 billion barrels implies world peak production of roughly 37 billion barrels annually by 1996/7 and production of the middle 80 percent of resources in the 56-year period of 1967 to 2023. The peak production would imply a 2.9 percent annual growth rate from last year's figure of about 21 billion barrels. This is consistent with our middle projection of a 3.0 percent rate for the NCW to 1990 and slightly below several other recent forecasts.

Moody and Esser, using their estimate of 2,030 billion barrels of world ultimate recovery, predict the peaking of world production in the late 1980's or early 1990's based on pre-1974 "normal" demand growth rates. Applying the much smaller long-term growth rates currently projected would postpone their peak by 10-12 years. Unfortunately, Grossling has not provided an estimate of the shape and peak production for his higher resource estimates, but peak production would

presumably be substantially greater and the peak year much later than with the consensus estimate.

In sum, then, if the long term postwar growth rate which prevailed up to 1974 were to continue, world oil production could peak in 9-10 years under the more pessimistic of these estimates and in 12-14 years under more optimistic ones. A future growth of about half the historic rate would postpone both these dates by about 10 years under the same resource assumption.

These conclusions, however, should be considered highly tentative. The major reason is that all current resource estimates are based on some very speculative assumptions, regardless of the technique used. The geological approach assumes an analogy, with respect to the volumes of oil contained in prospective rock formations, between explored and unexplored regions. Subsequent adjustments made i.e., using lower discovery factors, are essentially arbitrary; it is impossible to judge which of a wide range of such factors has objective merit. But the difference between a discovery factor of 0.1 and 1.0 is obviously crucial to the final estimate.

Similar qualifications apply to the determination of peak production, both as to the level and its timing. Available estimates rest on the arbitrary assumption that discovery and cumulative production are symmetrical on both sides of the peak, i.e., that the distribution shows no tendency to be skewed. Yet, the actual shape of the function will be influenced by geological factors and supply elasticities, both of which are unevenly distributed over time.

In the final analysis, the actual volumes of oil that may be found and recovered depend not only on the resource in the ground and on price-cost relationships but on the institutional-political environment. Oil resources will be neither found nor developed if barriers are erected against access to potential oil-bearing regions by those with the "right" combinations of ingredients -- technical knowledge, managerial know-how, plus economic incentives. Moreover, resource availability offers no assurance that potential supplies will become actual supplies. These depend on policy decisions of those controlling the resource and on the luck, skill and technology of those searching for it.

It is the varying combination of all these factors which will determine the resource availability of oil at any given moment prior to the approach of ultimate

exhaustion. A case can be made, from a policy point of view, for preferring a conservative estimate over an optimistic one. The Project Interdependence report states it cogently:

> If we plan on the basis of the consensus view of the Nation's leading geologists, the Nation will be better prepared if the decline sets in by the mid-1990's as projected by Hubbert. If, on the other hand, substantial discoveries are made in the regions which...have been underestimated in terms of their oil and gas potential, the world will be pleasantly surprised....(6)

The issue here, however, is not the policy consequences which may or may not ensue but the objective validity of the numbers themselves. After all, deliberate underestimation can have adverse repercussions as well, e.g., failure to explore in potential oil bearing areas, premature and excessive investment in alternative energy sources, accepting excessive price increases from producing countries, to name a few.

From a strictly objective perspective, it is clear that for the next several years the resource availability will rise more rapidly than demand. In the more distant future the relationship is likely to reverse itself.

To estimate even approximately the decade when oil resources may actually approach exhaustion is beyond our ability and, we earnestly believe, that of most other forecasters, given the vast interplay of factors on both the supply and the demand side which will determine this. To estimate the approximate peaking date of world oil production is somewhat less hazardous, if only because it will occur much sooner. Combining all the information discussed herein with our best judgment, we believe that considering only physical resource availability and no other factors, production peaking is most improbable until after 1990 under any reasonably realistic current assumption of growth for NCW oil production over the next 14 years. How the growth assumptions in our three scenarios will affect NCW oil production by 1990 will be discussed in the next chapter.

REFERENCES

1. M. King Hubbert. Energy Resources. National Academy of Sciences, National Research Council. Washington, D.C., 1962, pp. 44-5.

2. Betty M. Miller, et al. Geological Estimates of Undiscovered Recoverable Oil and Gas Resources in the United States. Geological Survey Circular 725, U.S. Department of the Interior, Geological Survey, 1975.

3. Report of the Committee on Mineral Resources and the Environment. National Academy of Sciences. Washington, D.C., 1975, Ch. V.

4. M. King Hubbert. "U.S. Energy Resources. A Review of 1972." Background Paper for the Committee on Interior and Insular Affairs. U.S. Senate, 93rd Congress, 2nd Session. Serial No. 93-40 (92075). Washington, D.C. 1974, p. 181.

5. M. King Hubbert. "Survey of World Energy Resources." Canadian Mining and Metallurgical Bulletin. Vol. 66. July 1973, p. 48.

6. Congressional Research Service, Library of Congress. Project Interdependence: U.S. and World Energy Outlook through 1990. Summary Report for the Committees on Energy and Natural Resources and on Commerce, Science and Transportation, U.S. Senate, and the Committee on Interstate and Foreign Commerce, U.S. House of Representatives. Publication No. 95-31. June 1977, pp. 53-56.

7. Report on Oil Resources, 1985-2000. Conservation Commission, World Energy Conference. Istanbul, August 1977.

8. J.D. Moody and Robert W. Esser. "World Crude Resource May Exceed 1,500 Billion Barrels." World Oil. September 1975, pp. 47-56.

9. DeVerle P. Harris. "Conventional Crude Oil Resources of the United States." Materials and Society. December 1977, pp. 1-24.

10. J.D. Moody and R. Geiger. "Petroleum Resources: How Much Oil and Where." Technology Review. March/April 1975, p. 40.

11. T.A. Hendricks. Resources of Oil,Gas, and Natural Liquids in the U.S. and the World. Geological Survey Circular 522. U.S. Department of the Interior, U.S. Geological Survey. Washington, D.C., 1965, p. 17.

12. UNITAR-IIASA. "The Future Supply of Nature-made Oil and Gas." A Summary Report on the Conference held July 1976 at Schloss Laxenburg, Austria, 1977, pp. 6-7.

13. R. Ridker and W. Watson. Energy and the Environment in the United States, 1975-2025. Baltimore: Johns Hopkins Press (forthcoming), Ch. 2.

14. Cited by J.D. Parent and H.R. Linden. "A Survey of United States and Total World Production, Proved Reserves and Remaining Recoverable Resources of Fossil Fuels and Uranium as of December 31, 1975." Institute of Gas Technology. January 1977, p. 13.

15. B.F. Grossling. In Search of a Statistical Probability Model for Petroleum Reserve Assessment. Geological Survey Circular 724. U.S. Department of the Interior, Geological Survey. Washington, D.C.,1975.

16. B.F. Grossling. Latin America's Petroleum Prospects in the Energy Crisis, Geological Survey Bulletin 1411. U.S. Department of the Interior, Geological Survey. Washington, D.C., 1975.

17. B.F. Grossling. Window on Oil -- A Survey of World Petroleum Resources. London: Financial Times Ltd., 1976.

18. B.F. Grossling. "The Petroleum Exploration Challenge with Respect to the Developing Nations." UNITAR-IIASA Conference on the Future Supply of Nature-made Petroleum and Gas. Schloss Laxenburg, Austria, July 1976, pp. 8-10.

Chapter 5

NON-COMMUNIST WORLD OIL DEMAND AND POTENTIAL SUPPLIES

On the basis of our projections of world energy demand (Table 2-5) and non-oil energy supplies (Table 3-12), one can derive NCW oil demand under our three alternative energy demand growth scenarios. Consistent with our approach the U.S. is initially excluded from this computation (see Table 5-1).

As should be expected, the relatively moderate differences in the growth of total energy demand are magnified in terms of the growth of oil demand because of the assumption that increases in non-oil supplies are unaffected by the differences in total energy demand increases. Thus, the oil demand growth rate in Case D (2.6 percent) is somewhat over half that of Case A (4.3 percent), with Case B/C averaging 3.4 percent. Even the Case A growth rate, however, is less than half the pre-1973 growth rate of non-Communist foreign oil demand (10 percent annually during 1960-73).

To determine total demand for oil from non-U.S. NCW sources, two additional oil flows must be added to the above numbers: U.S. oil imports and net flows between the Sino-Soviet Bloc and the NCW countries.

U.S. OIL IMPORTS

The approach used in the determination of U.S. oil imports parallels that for the rest of the world, i.e., we have developed three scenarios combining high and moderate economic growth assumptions with high and low energy consumptions to determine total energy demand. Domestic energy supplies and gas imports are then deducted from total consumption to arrive at required imports of petroleum. Because of long lead times for developing new supplies, domestic production is not likely to vary significantly with total energy demand by 1990. Imports thus act as a swing fuel to fill the gap between total energy requirements and domestic supplies. Specifically, the following assumptions have been used.

For the high economic growth cases, annual average increases in real GNP are 4.5 percent for 1976-80 and 3.5 percent for 1980-90. For the moderate growth cases the increases are about 0.5 percentage points lower. The high growth rates are in line with 1976

Table 5-1

NON-COMMUNIST WORLD OIL DEMAND
OUTSIDE THE U.S., 1976 TO 1990

(million barrels per day
oil equivalent)

	1976	1980	1985	1990	Average Annual Rate of Growth 1976 To 1990 (% per year)
Case A					
Energy Demand	53.0	63.5	80.2	101.6	4.8
Non-Oil Supplies	21.9	28.4	36.5	45.9	5.4
Oil Demand	31.1	35.1	43.7	55.7	4.3
Case B/C					
Energy Demand	53.0	62.7	77.3	95.8	4.3
Non-Oil Supplies	21.9	28.4	36.5	45.9	5.4
Oil Demand	31.1	34.3	40.8	49.9	3.4
Case D					
Energy Demand	53.0	61.8	74.5	90.2	3.9
Non-Oil Supplies	21.9	28.4	36.5	45.9	5.4
Oil Demand	31.1	33.4	38.0	44.3	2.6

Sources: Data for 1976 taken from BP Statistical Review of the World Oil Industry, adjusted so that Btu content of a barrel of oil equivalent is 5.8 million Btu. Data for future years are PIRINC projections. See also Tables 2-5 and 3-12.

OECD estimates but below the U.S. Administration's target of about 5 percent to 1985, which we consider too optimistic, since it is substantially above the long term (1960-76) GNP growth rate of 3.4 percent. Our high rate projection, by contrast, is only somewhat above the historic rate for the entire period, 1976-90, while our low rate projection is somewhat below the historic level.

- Energy/GNP growth coefficients of 0.85 for 1975-80 and 0.80 for 1980-85 for the high energy consumption cases, and 0.75 and 0.70 for the low energy consumption. Both sets of coefficients reflect relatively moderate declines from the long term energy/GNP growth ratio (0.97 for the period 1960-76), in response to increased real energy costs. The low coefficients also assume adoption and implementation of a widespread conservation program similar to that now being considered by Congress.

The resulting levels and growth rates of energy demand are shown in Table 5-2. In all cases the forecast growth rates are lower in the later period (1980-90) than in the earlier one (1976-80). In the later period they are also substantially below the long term (1960-76) historic rate of about 3.4 percent.

In comparing our projections to the historic rate it should be pointed out that the particular selected historic period was heavily influenced by the exceptional decline in energy demand in 1974 and 1975. Had we selected the period 1960-73 the growth rate would have been over 4 percent. Since the decline in 1974-75 reflects the unprecedented energy price increase which ushered in the new period of lower energy demand growth, our projections are perhaps more meaningful when compared with the historic growth rate in the period preceding the OPEC oil price revolution in late 1973 and its impact on other energy prices.

We recognize that all but the lowest of our projected energy demand growth rates are significantly higher than the 2.3 percent target rate set by the Administration in its National Energy Plan for the period 1976-85. However, this is in line with our general approach in this study of testing the availability of oil under intermediate and somewhat higher growth assumptions rather than minimum ones.

Projected domestic energy production to 1990 is shown in Table 5-3. Total supply increases from about 57 to 79 quadrillion Btu's or 40 percent, equivalent to an average of 2.3 percent/year. The bulk of this increase comes from nuclear power and coal. Petroleum liquids production rises only slightly and does not quite offset the decline in the production of gas (including synthetic gas).

Because domestic supplies expand more slowly than demand in all cases, increased imports are required under all three scenarios (Table 5-4). Gas imports,

Table 5-2

ALTERNATIVE LEVELS OF U.S. ENERGY CONSUMPTION
1976 TO 1990

(quadrillion Btu)

Growth Assumptions:

GNP	Energy/GNP Growth Coefficient	1960	1976	1980	1985	1990
High	High	44.6	74.0	85.9	98.6	113.2
High	Low	44.6	74.0	84.6	95.3	107.2
Moderate	High					
Moderate	Low	44.6	74.0	83.3	92.4	102.5

(Average Annual Growth Rates)

Growth Assumptions:

GNP	Energy/GNP Growth Coefficient	1960-76	1976-80	1980-90
High	High	3.5	3.8	2.8
High	Low	3.5	3.4	2.4
Moderate	High			
Moderate	Low	3.5	3.0	2.2

Sources: Historical data are from U.S. Bureau of Mines; projections are by PIRINC.

Table 5-3

U.S. DOMESTIC ENERGY PRODUCTION, 1976 TO 1990
(quadrillion Btu)

Source	1976 (Preliminary)	1980	1985	1990
Natural Gas[a]	19.1	17.2	16.5	16.1
Hydrocarbon Liquids[b]	19.5	20.5	21.9	22.1
Coal[c]	13.8	16.9	21.4	25.8
Nuclear	2.0	3.9	7.5	11.9
Other	3.1	3.1	3.3	3.4
Total	57.5	61.6	70.6	79.3

Sources: Data for 1976 are from U.S. Bureau of Mines; projections are by PIRINC.

Note: Exports and stocks additions have been subtracted from production.

[a]Includes synthetic natural gas (SNG) production.

[b]Crude oil and NGL.

[c]Coal for domestic consumption only. Also SNG feedstock use is excluded.

Table 5-4

U.S. ENERGY IMPORT REQUIREMENTS UNDER ALTERNATIVE ASSUMPTIONS, 1976 TO 1990

	1976 (Preliminary)	1980	1985	1990
		(quadrillion Btu)		
Case A				
Demand	74.0	85.9	98.6	113.2
Domestic Supply	57.5	61.6	70.6	79.3
Total Energy Imports	16.5	24.3	28.0	33.9
Case B/C				
Demand	74.0	84.6	95.3	107.2
Domestic Supply	57.5	61.6	70.6	79.3
Total Energy Imports	16.5	23.0	24.7	27.9
Case D				
Demand	74.0	83.3	93.0	103.6
Domestic Supply	57.5	61.6	70.6	79.3
Total Energy Imports	16.5	21.7	22.4	24.3
Gas Imports				
All Cases	1.0	1.2	2.6	3.2
Oil Imports				
Case A	15.5	23.1	25.4	30.7
Case B/C	15.5	21.8	22.1	24.7
Case D	15.5	20.5	19.8	21.1
		(million barrels per day)		
Oil Imports				
Case A	7.3	10.9	12.0	14.5
Case B/C	7.3	10.3	10.4	11.7
Case D	7.3	9.7	9.4	10.0

Sources: Data for 1976 are from U.S. Bureau of Mines; projections are by PIRINC.

Conversion Factor:

1 barrel = 5.8 million Btu.

including pipeline shipments and LNG, are projected to rise from 1 TCF in 1975 to 2.6 TCF in 1985 and 3.2 TCF in 1990. The balance constitutes imports of petroleum. Under Case A assumptions (high economic growth and high energy/GNP growth ratios, the latter implying minimal progress in energy conservation), these would go as high as 14.5 MM B/D by 1990. Under assumptions of moderate economic growth and low energy/GNP growth ratios (Case D), imports would be nearly 9.5 MM B/D in 1985 and 10 MM B/D in 1990. For the intermediate Case (B/C), imports would rise from 10.4 MM B/D in 1985 to 11.7 MM B/D in 1990.

These import levels are in every case significantly higher than the Administration's announced target of 6-7 MM B/D by 1985 and implied further declines by 1990. The reason for the difference lies partly in our higher energy growth projections and partly in our lower growth projections for domestic coal demand and supply. The latter reflects our belief that the Administration's plan for large scale conversions of industrial plants from oil and gas to coal will fall considerably short of its target and that environmental and other constraints will also reduce coal's growth, particularly in the industrial sector, below the Administration's current expectations (1). Our view is in general agreement with the findings of several Congressional agencies which have analyzed the Administration's National Energy Plan (2, 3, 4).

ROLE OF SINO-SOVIET BLOC

Since 1974 the Soviet Union has been the world's largest oil producer; production in 1976 exceeded 10 MM B/D (17 percent of world total). In addition to supplying its rapidly expanding domestic oil consumption (growing at 7 percent/year over the past decade) and the bulk of Eastern European requirements, the U.S.S.R. has exported significant quantities of crude oil and finished products to Western countries -- about 1.4 MM B/D in 1976. The Peoples Republic of China also has begun to export crude oil, though on a much smaller scale thus far (less than 200,000 barrels daily to Japan in 1976). The future trend of the Communist countries' oil position is of potential importance to the availability of foreign oil to the United States. Significantly greater exports by the U.S.S.R. and/or China would tend to ease supply conditions in the West, while a reversal of the East-West oil flow would add to the strain on non-Communist oil supplies.

The CIA in a recent report has taken the latter position, forecasting a sharp turn-around of Soviet oil trade with the West (5). The agency foresees that instead

of making a net contribution to Western oil supplies, the Soviet Bloc (U.S.S.R. plus Eastern Europe) will require a small net inflow of oil by 1980. For 1985 it projects a very large deficit (3.5 to 4.5 MM B/D). This implies a total turn-around of 4.7 to 5.7 MM B/D from the recent position and would represent an addition to non-U.S. NCW oil demand of 13-16 percent by the mid-80's. For China, the agency estimates that exports will fall after 1980 (when they may reach 0.5 MM B/D) to a negligible level by 1985.

The agency supports these conclusions by detailed analysis of the resource position and production prospects for both countries (6). It finds that while the Soviet Union's resources may be large, proved reserves are no larger than those of the U.S.; major producing fields are close to their peak and will soon decline; there has been serious water encroachment in the largest field because production has been pushed above long term optimum rates; Soviet drilling technology and efficiency lag seriously behind those of the West; the turbodrill, on which the U.S.S.R. relies heavily, is not effective at depths below 2,300 meters or in soft formations; and that the most promising resource potential is in regions (Eastern Siberia and the Arctic) where operating conditions are very difficult and lead times long.

As a result, the CIA believes, new discoveries are unlikely to fully offset the impending decline of production from established areas, so that total production would decline by the early 1980's if not sooner. When this occurs, the U.S.S.R. will no longer be able to meet the oil requirements of its own economy, the bulk of Eastern European needs (currently it supplies some 75-80 percent), plus generate sizable exports for shipments to the West.

The CIA acknowledges that the results have serious implications for the Soviet economy and its relations with its Communist allies. Internally, increasing oil supplies are required to supply the transportation sector, many industrial uses (such as petrochemicals) and military demand. The Eastern European countries, except for Rumania which does not rely on Soviet oil, would encounter great difficulty in shifting their imports from the U.S.S.R. to hard currency sources. And the U.S.S.R. itself has used the proceeds from oil exports to the West to help finance imports of badly needed industrial equipment (and, at times, grain); recently oil has represented some 40 percent of its total hard currency earnings.

Well informed private analysts find little reason to quarrel with the CIA over the present position of the Soviet oil industry, with the exception of its estimate of proved reserves, about which there is considerable uncertainty. In contrast to natural gas, official oil reserve data are not published by the U.S.S.R. Recent estimates by Western sources, including proved and probable reserves, range between 38 and 103 billion barrels (6). On questions of recent overproduction of the largest field, lagging technology and low productivity, there is also no basic disagreement.

There is, however, considerable controversy over the implications of these conditions for the future, and over the options open to the U.S.S.R. if the pessimistic predictions should turn out to be correct. (The CIA, for example, estimates that production will fall 1.0-1.8 MM B/D short of the target.) Some observers, however, feel that Western sources have repeatedly underestimated Soviet ability to expand output rapidly, and that the Russian target of 12.8 MM B/D in 1980 is quite realistic. As reasons, they cite the existence of numerous smaller fields in accessible areas which are being developed, the willingness of Soviet personnel to operate under quite primitive frontier conditions, and an apparent decision to draw on Western technology to improve drilling performance in lower formations and offshore areas (7, 8).

A second question concerns the Russians' ability to substitute other energy sources for oil. Again the CIA is pessimistic, citing locational and transportation problems impeding more rapid development of natural gas and coal (despite the existence of huge reserves), and shortages of skilled labor and equipment which limit accelerated expansion of these sources as well as nuclear power. This view may seriously underestimate a command economy's capability for overcoming shortages by concentrating resources on one industrial sector, especially if the entire decade of the 1980's is considered. In addition, the Soviets can, if they feel it sufficiently important, hold down energy demand increases at home and in neighboring countries, although this may entail some curtailment of economic growth. In the case of automobile production, they have already taken this course (7).

We feel that the Soviet Union will be most reluctant to cut back severely on its oil imports to Eastern European countries, since under present trade arrangements, these countries cannot generate the hard currencies required to shift their oil imports to Western (including OPEC) sources. Moreover, the U.S.S.R's need for

industrial technology and equipment is very great. It quite simply has to export a large volume of some desirable commodities to finance these imports, and Soviet Bloc credits in the West are already hugh and probably near their limit. Until large exports of Siberian gas can be started, there may be little choice but to squeeze Soviet consumers to permit continued exports of oil to the West.

Under these circumstances, it is likely that the Soviet Union's oil export to the West will continue but that most of the incremental oil requirements of the East European countries would have to be met from outside the Soviet Bloc. In time, the two might offset each other. Accordingly, we do not agree with the CIA's forecast of large net Soviet Bloc oil imports in 1985. Our projection shows net Bloc oil exports declining to zero by 1985 and remaining there until 1990 (see Table 5-5).

Table 5-5

NET OIL TRADE POSITION OF SINO-SOVIET BLOC
(million barrels per day)

Net Exports

	1976	1980	1985	1990
Soviet Bloc[a]	1.2	0.7	0	0
China	0.2	0.5	0.5	0.5
Total	1.4	1.2	0.5	0.5

[a]Soviet exports to West minus Soviet and Eastern European imports from non-Soviet sources.

While our projection is more optimistic than the CIA's and that of Robert E. Ebel, a Soviet oil expert who projects net Soviet Bloc imports of 1.6 MM B/D by 1985 (9), it is not as optimistic as those of some forecasters, e.g., Professor Marshall Goldman of the Harvard University Russian Research Center. Our outlook is similar to that of the OECD, the recent report of the Congressional Research Service and a study published in December 1977 by a respected German research institute (10).

while there is considerable uncertainty in the West over Soviet oil reserves, those of the Peoples Republic of China are not known at all, apparently not even to the Chinese. Earlier notions of Middle East-size resources have been scaled down greatly, and there appears now to be a consensus that China will not be a major factor in the world oil market in the foreseeable future. However, Chinese production has expanded rapidly (nearly 20 percent/year in the past decade), and a small margin for exports has emerged.

The future trend of Chinese exports is subject to major ideological factors. The Chinese have set what seems to be a politically determined target of 1 MM B/D of exports to Japan in 1980. Western observers consider this unrealistic if only because the unusually high wax content of the crude imposes extra costs on refiners.* The question of whether an exhaustible resource like oil should be exported to finance imports of industrial equipment is heavily enmeshed with politics in the country. Certain political groups, including the present regime, support expanded foreign trade to foster economic development, while others do not. Forecasts of increased oil exports thus rest on the assumption that the group presently in control of the country will remain dominant.

Even so, it is doubtful that the Chinese will look toward much collaboration with Western firms to obtain the advanced technology needed for accelerated oil development. We projected therefore that Chinese exports will rise to 500,000 B/D in 1980 and remain at that level for the next ten years because rising internal demand will require all increases in production throughout that period. We believe this to be a distinctly conservative estimate of China's future export potential under politically favorable conditions.

DEMAND FOR OIL FROM THE NON-COMMUNIST WORLD OUTSIDE THE U.S.

The demand for NCW oil, including U.S. oil imports and supplies from the Sino-Soviet Bloc but excluding U.S. oil production, is shown in Table 5-6. By 1990, this could run as high as about 70 MM B/D under Case A assumptions (high growth, little conservation and high U.S. imports). With Case D assumptions (moderate economic growth, strong conservation and low U.S. imports) demand would be only about 54 MM B/D in 1990. The former figure implies that demand would be 88 percent

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*In fact, Japanese refiners have objected to their government's attempt to require the absorption of large volumes of Chinese crude oil.

Table 5-6

REQUIRED NON-COMMUNIST WORLD OIL PRODUCTION
OUTSIDE THE U.S., 1976 TO 1990

(million barrels per day)

	1976	1980	1985	1990	Growth 1976 TO 1990 (%/Yr.)
Case A					
NCW (Ex. U.S.) Oil Demand	31.1	35.1	43.7	55.7	4.3
U.S. Oil Import Demand	7.3	10.9	12.0	14.5	
Sub-Total	38.4	46.0	55.7	70.2	
Less: Sino-Soviet Net Exports	1.4	1.2	0.5	0.5	
Required NCW (Ex. U.S.) Oil Production	37.0	44.8	55.2	69.7	4.6
Case B/C					
NCW (Ex. U.S.) Oil Demand	31.1	34.3	40.8	49.9	3.4
U.S. Oil Import Demand	7.3	10.3	10.4	11.7	
Sub-Total	38.4	44.6	51.2	61.6	
Less: Sino-Soviet Net Exports	1.4	1.2	0.5	0.5	
Required NCW (Ex. U.S.) Oil Production	37.0	43.4	50.7	61.1	3.6
Case D					
NCW (Ex. U.S.) Oil Demand	31.1	33.4	38.0	44.3	2.6
U.S. Oil Import Demand	7.3	9.7	9.4	10.0	
Sub-Total	38.4	43.1	47.4	54.3	
Less: Sino-Soviet Net Exports	1.4	1.2	0.5	0.5	
Required NCW (Ex. U.S.) Oil Production	37.0	41.9	46.9	53.8	2.7

Sources: Data for 1976 are based on U.S. Bureau of Mines and BP Statistical Review of the World Oil Industry, 1976; projections are by PIRINC. See also Tables 5-1, 5-4 and 5-5.

Note: Required NCW (Ex. U.S.) oil production excludes additional production which may be required to build up strategic petroleum reserves in the U.S. and other OECD countries.

above the 1976 level; the latter, that it would rise by about 45 percent. The intermediate case (B/C) yields a demand of 61 MM B/D which would be 65 percent above the 1976 level. (For comparison purposes, Table 5-7 shows total NCW oil demand, including the United States, for the period 1976 to 1990.)

Could demand increases as high as those of Case A be met from foreign oil resources already proved and likely to be found before 1990? If not, what about Case B/C? What would be implied in terms of new discoveries and reductions in reserve/production ratios? How much of the increased demand is likely to be supplied from non-OPEC sources? What expansion of OPEC supplies would be required? Would the oil exporting countries be physically able to meet such demands? Would they be willing to do so and, if so, on what terms? These questions are discussed in the following section and the next chapters.

ADEQUACY OF TOTAL OIL RESOURCES

Proved reserves of NCW crude oil outside the United States, according to the Oil & Gas Journal, amounted to 466.4 billion barrels on January 1, 1977. Updating for subsequent revisions of the Saudi Arabian (11) and Mexican (12) figures, reserves totaled about 515 billion barrels (see Table 5-8). The OPEC members account for over 5/6 of this total. Most of the non-OPEC reserves are located in Western Europe (chiefly the North Sea) and the Western Hemisphere (Mexico, Canada and South America outside Venezuela and Ecuador which are OPEC members).

At the 1976 rate of production of 36.7 MM B/D, NCW proved reserves outside the U.S. were equivalent to 39 years' production. However, the R/P ratio varied greatly among producing countries. Among the non-OPEC nations, it ranged from 75 in Europe (primarily becuase North Sea production was just getting started) to 16 in the Western Hemisphere. For OPEC members, it varied all the way from 95 for Kuwait down to 20 or less for Indonesia, Algeria and Venezuela. Obviously, the resource positions (and policies) of the various producers are far from uniform; this fact carries important implications for the future.

In addition to these proved reserves the total amount of oil still to be recovered from existing and undiscovered fields in NCW countries (ex. U.S.) may have amounted to about 600 billion barrels at the end of 1976, based on the updated Moody estimates in Chapter 4. How much of this oil can we expect to find between now and the end of 1990? Historically, gross reserve additions in the NCW (excluding U.S.), including revisions and extensions of existing reserves, averaged about

Table 5-7

NON-COMMUNIST WORLD OIL DEMAND, 1976 TO 1990

(million barrels per day crude oil equivalent)

	1976	1980	1985	1990	Average Annual Growth 1976 To 1990 (% per year)
Oil Demand					
Case A					
NCW (Ex. U.S.)	31.1	35.1	43.7	55.7	4.3
United States	16.5	20.5	22.3	24.9	3.0
Total NCW	47.6	55.6	66.0	80.6	3.8
Case B/C					
NCW (Ex. U.S.)	31.1	34.3	40.8	49.9	3.4
United States	16.5	19.9	20.8	22.1	2.1
Total NCW	47.6	54.2	61.6	72.0	3.0
Case D					
NCW (Ex. U.S.)	31.1	33.4	38.0	44.3	2.6
United States	16.5	19.3	19.7	20.4	1.5
Total NCW	47.6	52.7	57.4	64.2	2.2

Sources: Data for U.S. in 1976 are from U.S. Bureau of Mines; other 1976 data taken from BP Statistical Review of the World Oil Industry, 1976; projections are by PIRINC.

Table 5-8

NON-COMMUNIST WORLD CRUDE OIL RESERVES AND PRODUCTION OUTSIDE THE U.S., 1976

	Reserves As Of 1/1/77 (billion barrels)	1976 Production (million barrels)	R/P Ratio (yrs)	Share of: NCW (Ex. U.S.) Reserves (%)	Share of: NCW (Ex. U.S.) Production (%)
Non-OPEC					
Asia-Pacific	8.9	427	21	1.7	3.2
Europe	24.5	328	75	4.7	2.4
Middle East	8.7	243	36	1.7	1.8
Africa	6.4	185	35	1.2	1.4
Western Hemisphere	25.8[a]	1,175	22	5.0	8.8
Sub-Total	74.3	2,358	32	14.4	17.6
OPEC					
Indonesia	10.5	548	19	2.0	4.1
UAE[b]	31.2	710	44	6.1	5.3
Iran	63.0	2,144	29	12.2	16.0
Iraq	34.0	756	45	6.6	5.6
Kuwait[c]	70.6	746	95	13.7	5.6
Qatar	5.7	177	32	1.1	1.3
Saudi Arabia[c]	154.6[d]	3,210	47	30.0	23.9
Algeria	6.8	347	20	1.3	2.6
Gabon	2.1	80	26	0.4	0.6
Libya	25.5	694	37	5.0	5.2
Nigeria	19.5	737	26	3.8	5.5
Ecuador	1.7	68	25	0.3	0.5
Venezuela	18.3[e]	836	22	3.0	6.2
Sub-Total	444.3	11,053	40	85.6	82.4
Total NCW (Ex. U.S.)	517.8	13,411	39	100.0	100.0

Source: Oil & Gas Journal, December 27, 1977, pp. 104-5 (except as indicated).

[a] Includes Mexico at 14.0 billion barrels, per The Wall Street Journal, June 22, 1977.

[b] Includes Abu Dhabi, Dubai and Sharjah.

[c] Includes 50% of Neutral Zone production.

[d] Revised figure per Oil & Gas Journal, February 14, 1977,p. 62. Originally published figure (110 billion barrels excluding Neutral Zone) which also appears in the 1976 Arabian American Oil Company Annual Report, represented only reserves which could be recovered without development drilling.

[e] Official figure reported by the Venezuelan government.

24 billion annually over the fourteen years 1963-76. One could argue that with the sharp increase in crude prices since 1973 and continued improvements in drilling technology in offshore areas where most of the remaining undiscovered oil is likely to be found, one can expect to find more oil in the next 14 years than in the previous ones. However, one may also say that probably all the relatively easily findable and accessible oil deposits have already been tapped so that the remainder will be more difficult to locate and will therefore be found at a slower rate than in the past.

There is no solid basis for judging which of these opposing tendencies will predominate in coming years. For present purposes, it is desirable to utilize a conservative assumption. We estimate therefore that gross reserve additions will amount to, say, two-thirds of the historical average, or some 16 billion barrels. This implies only modest drilling response for higher oil prices, which we expect to be at least maintained in real terms, and/or lower finding rates per unit of effort. Our number is actually somewhat lower than the projections in some industry forecasts of 15-16 billion barrels outside the U.S, since these refer only to new discoveries and our estimate includes revisions and extensions as well. It is also below the upper end of the WAES report's annual finding rate for the NCW (10-20 billion barrels) for the period 1975-2000 (13). Under our assumptions, gross discoveries by the end of 1990 would total 224 billion barrels or 37 percent of remaining unproved recoverable reserves in NCW countries excluding U.S. (Table 5-9).

Since cumulative (1976-90) oil demand in each of our three cases will exceed the volume of these gross discoveries, both proved reserves and R/P ratios will decline, in the absence of much larger finds than we have postulated. The question is, how much of a decline is tolerable? The current 39 year ratio is clearly substantially higher than is necessary to maintain "maximum efficient rates" of production. In the U.S. the current ratio is ten and has not been more than twelve for 14 years. Among major OPEC members, two countries -- Indonesia and Algeria -- have ratios of twenty or less, while Venezula is just slightly above 20.

Nevertheless, reductions in the reserves/production ratios are a matter of serious concern to producers, whether they are private companies or state entities. Proved reserves are their only certain source of supply; "probable" or "indicated" reserves represent a fairly reliable additional source but they are relatively

Table 5-9

NON-COMMUNIST WORLD RESERVE LIFE OUTSIDE THE U.S. UNDER ALTERNATIVE CASES, 1990

(billion barrels)

	Case A	Case B/C	Case D
Average Annual Growth Rate in Required NCW (Ex. U.S.) Oil Production (1977 to 1990)	4.6%	3.6%	2.7%
Proved Oil Reserves as of 1/1/77	515	515	515
Assumed Gross Reserve Additions (1977 to 1990)[a]	224	224	224
Cumulative Production 1977 to 1990[b]	270	250	231
Proved Reserves at Year-End 1990	469	489	508
Production in 1990	25.4	22.3	19.5
Reserve/Production Ratio: 12/31/90 (Yrs)	18	22	26

[a]Based on average finding rate of 16 billion barrels per year, equivalent to two-thirds of historical rate (1963 to 1976).

[b]See Table 5-6.

small, perhaps some 20 percent of proved reserves. All other oil has yet to be discovered and no one knows who will do so, where and when. Thus, countries with relatively low R/P ratios are either likely to resist further net reserve reductions by imposing production ceilings or will be technically unable to reduce their reserve/production ratio any further. Venezuela is a case in point of the first type, the U.S. (with a R/P ratio of under 10) of the second. The required reductions must therefore come largely from countries with relatively high R/P ratios.

How far each of these countries, inside and outside OPEC, will allow its R/P ratio to drop is a question heavily influenced by policy considerations, some of which are discussed in Chapter 6. Table 5-9 shows how sharp the decreases in reserves and reserve/production ratios would be, for the non-U.S. NCW countries collectively, if production between 1977 and 1990 were to increase at the average growth rates implied in our demand projections. The calculations indicate that proved reserves at the end of 1990 would be only fractionally down from current levels under Case D assumptions (low demand growth). At the intermediate growth rate reserves would fall by 5 percent or 26 billion barrels, while under Case A (high growth) assumptions, they would decline by 46 billion barrels or about 9 percent. The R/P ratio would decline to 26 in Case D, 22 in Cases B and C, and to 18 in Case A. While these represent sharp drops from the 1976 ratio of 39, even the lowest ratio shown for 1990 is as high or higher than the current ones for a number of large oil producing nations. However, for some countries it could mean ratios below their acceptable minimum level.

These comparisons warrant the same conclusions as in the previous chapter, namely that in terms of purely physical resource constraints, none of these growth rates would be unsupportable, taking the NCW countries as a whole. However, as we shall discuss in subsequent chapters, when considerations of a technical, economic or political nature are taken into account, different conclusions may be reached, particularly in Case A, our high growth case.

REFERENCES

1. John H. Lichtblau. "Can the Goal of the Administration's National Energy Plan Be Met?" Petroleum Industry Research Foundation, Inc. August 1977.

2. Report to the Congress by the Comptroller General of the United States. An Evaluation of the National Energy Plan. Washington, D.C., July 1977.

3. Congressional Budget Office. President Carter's Energy Proposals: A Perspective. Washington, D.C., June 1977.

4. Congressional Research Service, Library of Congress. Project Interdependence: U.S. and World Energy Outlook through 1990. Summary Report. Publication No. 95-31. Washington, D.C., June 1977.

5. U.S. Central Intelligence Agency. "The International Energy Situation: Outlook to 1985." Washington, D.C., April 1977.

6. U.S. Central Intelligence Agency. "Prospects for Soviet Oil Production," April 1977. "Prospects for Soviet Oil Production: A Supplemental Analysis," July 1977. "China: Energy Projections," November 1975. "China: Oil Production Prospects," June 1977.

7. National Petroleum Council, Committee on Future Energy Prospects. Topic No. 18: International Oil and Gas Supply. (Draft). Washington, D.C., February 1977.

8. "Soviet Union -- Export Drive Gathers Pace." The Petroleum Economist, February 1977.

9. Oil & Gas Journal, Special Issue, Petroleum 2000. August 1977.

10. Deutsche Institut for Wirtshaftsforschung, Berlin. As reported in Platt's Oilgram News Service, December 16, 1977.

11. Oil & Gas Journal. February 14, 1977.

12. The Wall Street Journal. June 22, 1977.

13. C.L. Wilson, et al. Energy: Global Prospects, 1985-2000. Report of the Workshop on Alternative Energy Strategies. New York: McGraw Hill Book Co., 1977, p. 126.

Chapter 6

OIL SUPPLIES AND PRICES FROM OPEC AND NON-OPEC SOURCES

In this chapter we address ourselves to the question of where the oil required under our three cases will come from, how much will be available from the various sources and under what likely price conditions.

We have assumed that oil supplies from non-OPEC sources will be the same in all cases, since they will come either from countries wanting to reduce oil import costs and dependency, such as the U.S., Canada, or Argentina, or from new entrants into world oil exports with substantial foreign exchange requirements such as Mexico or Egypt, or from new producers with readily available local and regional markets, such as the U.K. and Norway. We realize that our decision to hold non-OPEC oil production constant is open to some question. In Case A where pressure for incremental oil supplies from any source would be extremely strong and, as we shall see, real prices rise sharply, it is likely that some additional non-OPEC oil might be forthcoming. Case A is therefore a test of the availability of OPEC oil under the assumption that these factors will have no impact on incremental non-OPEC production.

Our oil demand growth rates all assume, as a starting point, constant real prices throughout the period. We then test whether under this assumption our projected OPEC oil requirements for 1990 can be met. We find that in Case D there is very little need for an increase in real oil prices and in Case B/C there will be a moderate real price increase leading to a slight reduction in our projected end year demand for OPEC oil, while in Case A required price increases will be substantial to reduce demand to available supplies. Thus, our Case A growth rate will probably not be met.

This brings us to the question of the reasonableness of our growth rates. On a total NCW basis <u>including</u> U.S. demand (see Table 5-7), even our highest growth rate is only about half the pre-1974 historic rate and even our lowest rate is nearly twice that of the latest four years (1973-77). It is of course true that the historic rate is no longer applicable because of the quantum oil price jumps

in 1973, and that the latest period includes two unusually severe recession years. But the fact remains that for nearly a quarter of a century right up to 1974, world oil demand consistently increased at a substantially higher rate than foreseen in our highest case. At the other end of the scale, the fact remains that four years of very little growth in world oil demand have now been tolerated, if unwillingly, by the world economies without political destabilization and that 1978 is unlikely to reverse this trend. In the future, recession periods may very well alternate with periods of rapid growth so that at times oil demand growth will be below our Case D projection and at times it may be above our Case A projection.

Taking a longer view, none of our three growth rates can be considered extreme in either direction (although, as pointed out, our highest growth case may not be met and thus represents potential rather than satisfied demand, at initially assumed prices). On the basis of current evidence, however, energy demand growth is likely to fall well below the maximum of the three case range. In our judgment, Case B/C offers a more realistic scenario than Case A, and Case D could be a more likely growth path than either.

NON-OPEC OIL SUPPLIES

By far the most exciting new oil finds of recent years are those of southeast Mexico, where production by 1990 may rival that of the other new major non-U.S. oil province, the North Sea. Less certain, but quite promising in the view of some well qualified geologists, is the potential elsewhere in Latin America, especially the Austral Basin offshore eastern Argentina. Smaller but still significant gains are expected in such Eastern Hemisphere countries as Egypt, Malaysia and India. These developments will more than offset possible production decreases in Canada and Australia and may raise total non-OPEC output outside the U.S. by 1990 to three times the 1975 level, or some 18 MM B/D (Table 6-1). A summary of developments in the most important areas follows.

Canada

Crude oil reserve and production trends have closely paralleled those of the U.S. in recent years; proved reserves peaked in 1969 and production has declined since 1973 (1). Exports to the U.S. have been sharply reduced and in 1975 the country once again became a net oil importer (2). Discoveries in the frontier regions (the Arctic Islands or the Mackenzie Delta) have been predominantly gas; the few oil strikes which have occurred have not developed sufficient reserves to support the high-cost transportation facilities needed to move them to southern markets.

Table 6-1

NON-COMMUNIST WORLD CRUDE OIL PRODUCTION
OUTSIDE THE U.S. AND OPEC, 1976 TO 1990

(million barrels per day)

	1976 (preliminary)	1980	1985	1990
Western Hemisphere				
Canada	1.6	1.5	1.1	1.3
Mexico	0.8	1.8	2.8	3.6
Argentina	0.4	0.5	0.7	1.0
Others	0.7	0.9	1.2	1.7
	3.5	4.7	5.8	7.6
Eastern Hemisphere				
Western Europe				
U.K.	0.2	2.0	2.7	3.7
Norway	0.3	1.0	1.3	1.6
Others	0.4	0.4	0.5	0.6
	0.9	3.4	4.5	5.9
Africa				
Egypt	0.3	0.7	1.0	1.2
Others	0.3	0.4	0.5	0.6
	0.6	1.1	1.5	1.8
Middle East	0.7	0.7	0.8	0.9
Asia-Pacific				
Australia	0.4	0.3	0.2	0.2
Malaysia	0.4	0.4	0.5	0.6
India	0.2	0.3	0.4	0.5
Others	0.2	0.3	0.4	0.5
	1.2	1.3	1.5	1.8
Total Eastern Hemisphere	3.4	6.5	8.3	10.4
NCW (Ex. U.S. and OPEC)	6.9	11.2	14.1	18.0

Source: Data for 1976 were taken from Oil & Gas Journal and Oilweek; forecast data by PIRINC.

Offsetting the lower volumes of crude will be increases in production of synthetic crude (syncrude) from tar sands and an expansion of production of heavy crudes such as Lloydminster. Reserves of both, especially tar sands, are large and production technologies are well advanced. However, costs are high and have been rising steadily. Also, environmental problems have been a factor in delaying new plant construction. Apart from the Syncrude project, scheduled for completion next year, the Canadian National Energy Board envisages only one additional unit (of 125,000 B/D) by 1987 and another by 1991. Total output from all sources under the National Energy Board's "Expected Case" thus would decline to just over 1 MM B/D by 1985 (3). After that we expect a very modest increase* (Table 6-1).

Mexico

Mexico's oil and gas potential has recently taken a dramatic upturn, with a series of discoveries in the southeast (Tabasco-Chiapas). As usual in such cases, all sorts of numbers were being quoted at first, but since early 1977 Petroleos Mexicanos (Pemex) reports of proved reserves are based on evaluations by U.S. geological consultants and thus, are comparable to other industry estimates. Proved reserves currently are given as 16.8 billion barrels (4) but this figure apparently includes the crude oil equivalent of natural gas found, which constitutes a high proportion of the total hydrocarbons recently discovered.** Largely on the basis of finds to date, Pemex has established plans to raise production from the current level of about 1 MM B/D to 2.2 MM B/D by 1982. About half of this total would be available for export (as would substantial volumes of natural gas as soon as a pipeline to Texas can be constructed) (5).

What makes Mexico's petroleum future so bright is that only a small number of the large structures identified by Pemex have been drilled to date -- only 10 percent, according to one recent report (6). Estimates of potential reserves thus are much

*Not considered in our forecast is the recent oil strike at West Pembina, in the province of Alberta, which seems to be a major find but whose magnitude cannot yet be evaluated.

**The gas-oil ratio for recent finds is reported to be around 6,000 cubic feet/barrel, which means that roughly half the total discovery consists of gas. See The Wall Street Journal, June 3, 1977.

larger than those of proved reserves. The figure often mentioned by Mexican officials is 60 billion barrels,* which puts Mexico in a league with Iran and Kuwait (which are second only to Saudi Arabia). Until additional structures are subjected to the drill, such numbers are necessarily speculative, of course. But what matters is that the constraint on Pemex's ability to increase production in the next decade or so is not lack of fossil resources but ability to finance and operate a vastly expanded program of exploration, production, transportation and manufacturing. (In addition to the southeast, Pemex is also optimistic of new finds elsewhere, e.g., Baja California.) The company has access to the requisite technical expertise. Given financial support from outside for some of its capital intensive projects, which apparently is forthcoming, Mexico should become a major factor in world oil markets during the 1980's. Thus, our assumption of a production level of 3.6 MM B/D by 1990, a 2.5 MM B/D increase over the mid-1977 level, seems reasonable.

Other Latin America

A number of respected geologists feel that the potential for significant oil and gas discoveries elsewhere in Latin America is most promising. Grossling, in particular, views published resource numbers for the Continent as worthless because exploration to date has been too sparse to develop data from which to derive tenable estimates (7). On the basis of his drilling density approach, his estimates run from two to five times those of other geologists (such as Moody). The Argentine shelf alone may hold some 200 billion barrels, in his view. This area, after long delay, will be tested in the next few years, since the government has recently modified applicable legislation to permit participation by foreign private companies.

Whatever the potential of Argentina, and possibly other regions of South America, the normal lead times make any major contribution to world oil supplies by 1990 doubtful. More probable than spectacular developments from entirely new areas is the slow, gradual expansion of production from existing producing regions, stimulated by high and rising energy prices and the strains which imports impose on the balance of payments of the oil-importing developing countries. We envisage that Latin American non-OPEC countries, outside Mexico, will be able to raise production by about 1.5 MM B/D to 2.7 MM B/D in 1990.

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*Pemex is reported to view this as a "low figure." See The Oil Daily, April 22, 1977.

North Sea

For a variety of technical and policy reasons, development of the North Sea has been slower than originally anticipated, in spite of the increase in world oil prices which made production more attractive directly as well as raising the cost of the major alternatives (imported oil). Expansion is well underway, however, and output is expected to exceed 3 MM B/D by 1980. Of this total, the U.K. sector will account for over two-thirds and Norwegian fields for under one-third (8).

For the U.K., there is greater uncertainty after that date. The most recent government "Brown Book" still gives a range of 100-150 million metric tons (2-3 MM B/D) "during the early 1980's" and private estimates also fall within this range (9). Published reserves estimates of 20-22 billion barrels for the currently licensed areas include some numbers for expected finds, but discovered resources appear sufficient to support output at the upper limit, assuming a reasonable reserve/production ratio (17 to 1).

Further expansion depends heavily on government policy, in particular whether the country wishes to become a sizable net exporter. This will be a major determinant in future leasing schedules, and thus the rate at which potential reserves will be converted to actual reserves. Additional resources remain to be tested, not only in new areas (e.g., north of the 62nd parallel and in disputed waters) but also at greater depths in some regions already producing. A recent Energy Plan Review Document published by the U.K. Department of Energy projects an output range from U.K. oil of 3.3-5.0 MM B/D for 1985, holding at that level to 1990 and then declining to 1-3 MM B/D by the year 2000 (10). Two other well known experts' forecasts both project output levels of 2.7 MM B/D by 1985 (11). On this basis and other indications we have conservatively assumed a production of 2.7 MM B/D for 1985 and 3.7 MM B/D for 1990.

Policy considerations are a greater constraint on production increases in the Norwegian sector. That country has not had to struggle with serious economic problems, as has the U.K.; moreover, there has been great concern over upsetting social structures and lifestyles and damaging the ecology. Current plans, which call for production targets of 1.2 MM B/D in 1981 and 1.4 MM B/D in 1987 represent a 20 percent reduction from the previous schedule (plus a one year delay) (12) ; we have used these as a basis of our estimates.

Other Areas

Production increases are likely or possible in a number of other areas, but not of the scope to match those of Mexico or the North Sea. Egypt has quite ambitious expansion plans covering the Gulf of Suez as well as established producing sectors. A large number of major U.S. and other companies have entered into joint venture arrangements with the government company (13). The fruition of these plans of course depends heavily on appropriate conditions in the region, including further Israeli withdrawals from the Sinai. Elsewhere, there are good prospects for moderate expansion of production in the Far East (including Malaysia and India), but Australian production appears to have passed its peak and will be sustained only if increased production of gas yields larger volumes of natural gas liquids.

REQUIREMENTS FOR OPEC CRUDE OIL

If one assumes that forces already set in motion will largely determine the growth of oil supplies from non-OPEC sources to 1990, OPEC crude requirements can be determined as a residual quantity (i.e., by subtracting non-OPEC supplies from total oil demand as previously defined). The results indicate (Table 6-2) that intermediate to long-term demand for OPEC crude will be strongly influenced by the energy demand scenario postulated. It could range from about 33 to 41 MM B/D in 1985 and from 36 to nearly 52 MM B/D in 1990, depending on the assumed economic growth rates and energy conservation efforts in our three cases.

Table 6-2 also shows that non-OPEC oil production will grow more rapidly than OPEC production during the period under study so that OPEC's market share will decline in all three cases. Yet, despite our assumption that non-OPEC oil output will be maximized (either because the producing countries want to back out imports or because they are newcomers to the oil export trade and have a need for high export earnings), in all but the lowest growth case the volume of the NCW's dependence on OPEC supplies will grow significantly, and even in the lowest case it will still be 66 percent of total NCW (ex. U.S.) oil demand.

We must now turn to the key question whether OPEC will meet the production levels set forth in Table 6-2 (which include both exports and OPEC internal demand). The question really consists of two parts: 1) will OPEC be able to produce these quantities; and 2) will it want to produce them. Let us start with the first.

Table 6-2

NON-COMMUNIST WORLD DEMAND FOR OPEC CRUDE OIL,
1976 TO 1990

(million barrels per day)

	1976 (preliminary)	1980	1985	1990	Average Annual Rate of Growth 1976 to 1990 (% per year)
Case A					
Required NCW Production (Ex. U.S.)	37.0	44.8	55.2	69.7	4.6
Non-OPEC Production (Ex. U.S.)	6.9	11.2	14.1	18.0	7.1
Required OPEC Production	30.1	33.6	41.1	51.7	3.9
Case B/C					
Required NCW Production (Ex. U.S.)	37.0	43.4	50.7	61.1	3.6
Non-OPEC Production (Ex. U.S.)	6.9	11.2	14.1	18.0	7.1
Required OPEC Production	30.1	32.2	36.6	43.1	2.6
Case D					
Required NCW Production (Ex. U.S.)	37.0	41.9	46.9	53.8	2.7
Non-OPEC Production (Ex. U.S.)	6.9	11.2	14.1	18.0	7.1
Required OPEC Production	30.1	30.7	32.8	35.8	1.2

Sources: Data for 1976 were taken from BP Statistical Review of the World Oil Industry, 1976. Future data are PIRINC projections. See Tables 5-6 and 6-1.

Note: Includes import requirements for the U.S.

Current sustainable OPEC crude oil productive capacity is estimated at 39.3 MM B/D by Petroleum Intelligence Weekly (14).* Thus, our 1990 Case D projection could be met from existing capacity. In Case B/C productive capacity would probably have to be increased by approximately 8.5-9.0 MM B/D or about 22 percent, to maintain a minimum flexibility -- say, 10 percent spare capacity -- in the system. Technically, this is an achievable target for OPEC as a whole over a 14-year period. Several OPEC members are able to increase their current productive capacity at least moderately (much more in some cases) without discovering any new reserves. Additional finds by some members during this period will add to the potential for capacity expansion. Thus, while the required expansion would probably be unevenly distributed among members, collectively OPEC could achieve it by 1990 if its members decided to do so early enough.

In Case A productive capacity would probably have to be increased by at least 18 MM B/D or by 46 percent. (If the CIA's estimate of current capacity is correct, the increase would have to be nearly 60 percent.) The ability to increase capacity by this magnitude is not so obvious. If resources among OPEC members were distributed in such a way that all could join proportionately in the expansion, the required annual growth rate of 3.0 percent might not be excessive. However some OPEC members may not be able to increase by that rate, or perhaps by any rate, without damaging ultimate resource recovery and others may actually register declines in productive capacity. The increase required from the remaining members would thus be substantially higher, raising the question of whether it is technically achievable.

To answer this question let us look first at the ratio of current OPEC proved and probable reserves to productive capacity, as shown in Table 6-3. As expected, the ratio of 34 is significantly lower than the 40-year ratio of reserves to production shown in Table 5-8. The table shows seven countries with ratios below 25. None of these can be expected to increase their productive capacity by the 46 percent required of all OPEC in our Case A. The largest of these seven producers is Iran, the oldest oil exporter in the Middle East. There is evidence that Iran's productive capacity is peaking and may actually start to decline sometime in the 1980's even with increasing reinjection of gas for pressure maintenance, unless

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*Estimates of productive capacity differ. CIA (15), for example, shows "operational" (i.e., sustainable) productive capacity of 36.1 MM B/D as of February 1978. The largest disagreements in the two estimates are for Saudi Arabia (11.8 vs. 10.5 MM B/D) and Iran (6.9 vs. 6.0 MM B/D), with Petroleum Intelligence Weekly the higher figure in each case. These discrepancies serve to underscore the importance to such estimates of differences in judgment.

Table 6-3

ESTIMATED OPEC PRODUCTIVE CAPACITY
AND RESERVES, 1977

	Estimated Productive Capacity (1) (million barrels per day)	(billion barrels per year)	Proved And Probable Reserves (2) (billion barrels)	Ratio (2):(1) (years)
Saudi Arabia[a]	11.8	4.31	181	42.0
Kuwait[a]	3.3	1.20	79	65.8
Libya	2.5	0.91	25	27.5
Iraq	3.1	1.13	36	31.9
U.A.E.	2.4	0.88	34	38.6
Algeria	1.2	0.44	7	15.9
Qatar	0.7	0.26	7	26.9
Iran	6.9	2.52	60	23.8
Venezuela	2.7	0.99	18	18.2
Nigeria	2.4	0.88	19	21.6
Indonesia	1.8	0.66	14	21.2
Others (Ecuador, Gabon)	0.5	0.18	3	16.7
	39.3	14.34	483	33.7

Sources: Estimated Productive Capacity: Petroleum Intelligence Weekly, February 20, 1978. Proved and Probable Reserves for Saudi Arabia (excluding Neutral Zone): Arabian American Oil Co. Annual Report, 1976. Reserves for Venezuela: Petroleos de Venezuela Annual Report. Other reserve data: U.S. Central Intelligence Agency, International Energy Biweekly Statistical Review, February 8, 1978.

[a]Including half of Neutral Zone.

substantial finds are made in unexplored new areas. The likelihood of this course of events has been reflected in frequent statements by the Shah and other Iranian officials that within 20-25 years the country will cease to be a significant oil exporter. Iran's plan to build nuclear power generation as an alternative future energy source also reflects this outlook. Thus, Iran is the only member of OPEC for which we have projected a decline in productive capacity to 1990.

The second largest among the seven producers with reserve/capacity ratios below 25, Venezuela, has one of the lowest ratios of any member. Its reserves, which showed a declining trend from the mid-1960's to the early 1970's, were increased sharply (by 5 billion barrels) in 1974 following the world oil price increase. The Venezuelan state oil company, Petroleos de Venezuela (Petroven), expects to maintain its current production level of 2.3 MM B/D, much of which is sustained by extensive use of secondary and tertiary recovery methods, to the early 1980's. But substantial new finds in new areas will have to be made in the next few years if existing productive capacity is to be maintained to 1990. Petroven is about to start a large scale exploration program, including the geologically promising continental shelf area which has never been opened up to private companies despite their interest in it (16). The Orinoco Heavy Oil Belt whose potential recoverable reserves are truly gigantic (several hundred billion barrels) but whose production costs are very high and whose oil is of low quality is also beginning to be developed but at a very slow rate. Altogether, we assume that these various new developments will about offset the decline in production from older reserves.

Indonesia, also one of the oldest oil producing nations, has an unusually rapid field depletion so that it requires continuous discovery of new reserves just to maintain its production level, particularly since its biggest field, Minas, is on the decline. Thus, Indonesia's productive capacity is unlikely to be significantly increased.

Algeria's output has remained unchanged at 1.0-1.1 MM B/D since 1972, despite an increase in the demand for the quality of crude oil it produces and the country's clear need for additional export revenues (it will have a substantial current account deficit this year). This together with the country's low R/P ratio would seem to indicate that Algeria will do well to maintain its existing productive capacity. Ecuador's and Gabon's production may increase somewhat but the volumes of both countries are insignificant relative to OPEC's total.

Among producers with a higher reserve/capacity ratio, Qatar seems unlikely to be able to maintain, let alone increase, its capacity. Its output in 1977 was only 76 percent of the 1973 volume, and is now below the 1972 level, whereas most other Middle East producers are well above it.

Our view of the productive potential of these countries is approximately in line with a recent Library of Congress report (17), which estimates that the collective productive capacity of these countries in 1990 could range from a decline of 2.5 MM B/D to an increase of 1.2 MM B/D, compared to 1977. For the purposes of our analysis we have assumed a drop in productive capacity of less than 1 MM B/D for these seven countries and that these and the other OPEC nations require a 10 percent capacity margin (i.e., that each member will produce at its sustainable maximum production rate, which is 90 percent of capacity).

The resulting 19 MM B/D additions to capacity required in Case A would therefore have to come from the six remaining OPEC members, about a 74 percent increase for them. However, among these, Libya, whose productive potential has dropped from a peak of 3.5 MM B/D in 1970 to about 2.5 MM B/D, is considered unlikely to be able to produce much more than about 3.0 MM B/D on a sustained basis. This would require a capacity increase of about one-third. Nigeria, unlike the other member countries with reserve/capacity ratios below 25, will be able to increase its capacity. However, for a variety of reasons, primarily its low undeveloped resource potential, it is not expected to be able to increase its productive potential by more than about 20 percent. Thus, the four remaining countries -- Saudi Arabia, Kuwait, Iraq and U.A.E.-- would have to raise their collective productive capacities by about 85 percent (to 38 MM B/D) and their collective 1977 production rate by about 125 percent (to 34 MM B/D).

As we concluded earlier, from a resource viewpoint such an increase might be feasible, given the very high reserve/productive capacity ratios of the four countries (from 32 to 66) and the fact that Iraq, which has the lowest ratio, is considered to have a very high potential of undiscovered reserves. From a technical point of view, however, the feasibility is doubtful, since it would require almost a doubling of Saudi Arabia's productive capacity. This would be an enormous undertaking and would have to be assigned a very high priority among the profusion of Saudi construction projects scheduled to be completed within our time frame. As of now this appears unlikely. A potentially more important barrier to an expansion of Saudi Arabia's sustained production rate to more than 20 MM B/D (requiring in excess of 22 MM B/D capacity) by 1990 are recent indications

of technical limitations to the producibility from its currently flowing fields. These involve such factors as pressure decline and water encroachment and will require considerable investment to keep the production rate in some of these fields from declining during the 1980's. Thus much of the increase in Saudi production, particularly above the 12-13 MM B/D level, would have to come from the 15-20 untapped known new fields. This is a slower, costlier and less certain process than increasing production from existing fields. It is therefore unlikely that Saudi Arabia would be technically able to produce oil at the rate required in Case A. Similarly, Kuwait will also face technical obstacles in increasing its production to the levels required by 1990. Thus, altogether, it appears that OPEC would be technically unable to meet its Case A oil requirements.

OPEC PRICING AND PRODUCTION POLICY

The next question is what level of requirements would the OPEC members want to meet? The answer is extremely complex, since it requires assumptions about future oil prices, the ability of various OPEC members to absorb the additional income from the higher production levels, the long-term economic development plans of these countries and their perception of how long their oil will last or how long there will be a market for it. Above all, the complexities are multiplied by the interaction of OPEC production policies and world oil prices.

In attempting to analyze these complexities it may be useful to start out with a number of assumptions:

1) All OPEC members will attempt, individually and collectively, as a minimum to maintain crude oil prices at present levels in real terms, i.e. in constant dollars. This is their announced minimum pricing policy which they have been able to implement in the past four years under adverse conditions (declining demand). Under our assumptions they should be able to do at least that well in the future in our lowest case and better in the others, as will be discussed later. Parenthetically, it should be noted that the adjustment of oil prices to maintain a constant value is by no means just a mechanical calculation. The derived figure depends on the base period selected, the currency in which it is expressed and, above all, the composition of the "market basket" whose price changes form the basis for the adjustments. Different selections can lead to very different results. OPEC has, in fact, never attempted to formally tie its marker crude price to any international index. Its spokesmen have, however, repeatedly stated that the price must be periodically adjusted for changes in the cost of imports into OPEC. Over the last four years marker crude price increases have roughly

approximated increases in the dollar value of export prices of the industrial countries. This has been accomplished through compromises between members arguing for higher increases and those, primarily Saudi Arabia, advocating lower or no increases. We expect this informal approximation rather than formal indexation will continue to prevail.

2) Our second assumption is that most oil importing nations have at least tacitly accepted current OPEC price levels and will not seriously attempt to reduce them or prevent their maintenance in real terms. However, these countries would oppose, although not necessarily successfully, any significant increase in the real price of oil imposed by OPEC.

3) Our third assumption is that all OPEC countries that are technically able to, will want to expand their production at least moderately; those countries that cannot do so will maintain their production as high as possible without violating proper reservoir maintenance procedures. The reasons for these production policies are that all OPEC members, even the largest, would like to raise their real oil export revenues at least somewhat over time, since all have rapidly growing populations, ambitious development plans and their leaders enjoy the power derived from access to large disposable funds. Those countries that cannot increase their revenues through higher export volumes will, in addition to maximizing production, also press for higher real unit prices, about which more will be said later.

4) Internal demand for oil will rise fairly rapidly in all OPEC members. Hence in those countries which can only maintain output at or near existing levels, exports are likely to decline. In countries with declining output, exports would decline more rapidly than production.

With these assumptions in mind we can now try to answer the question whether OPEC will want to supply the volumes required from it in each of our three cases and under what conditions, particularly price conditions.

Case D

In the lowest case, the answer is fairly obvious. An OPEC production growth rate of 1.2 percent leading to a production level not quite 5 MM B/D, or 15 percent, higher than last year's will actually be below OPEC's growth expectations. It could easily be met from Saudi Arabia alone which is currently undertaking a

productive capacity expansion to 14 MM B/D by the early 1980's and will probably be at a higher level by 1990. Iraq, Abu Dhabi, and Nigeria also have expansion plans while some of the other OPEC members have the potential to expand at least modestly, though they may not all do so. Kuwait, while probably reluctant to expand its capacity, may want to raise its output somewhat closer to current capacity, since for both domestic and export purposes it will need more associated natural gas than it can obtain at its current production ceiling of 2 MM B/D.

Altogether, then, in Case D OPEC would continue to have an excess producing capacity through 1990. Nevertheless, a few countries, such as Indonesia, Iran, Algeria and Venezuela, are likely to show some decline in exports, since their production can probably not be raised as much as their increases in domestic demand. These countries will therefore push strongly for an increase in real prices, particularly since Iran is expected to have a current account deficit from 1980 on. Venezuela and Indonesia now have deficits and they will be joined by Nigeria which is expected to continue to have current account deficits throughout the 1980's. The same is likely to apply to Libya from 1980 on if its exports do not increase from current levels.

These countries' demand for higher real prices may be opposed principally by Saudi Arabia for the same reasons it has done so since 1975, assuming that the political and economic orientation of the Saudi leadership will not change radically during the next 13 years. These reasons are:

1) Confidence that it will continue to generate current account surpluses for the foreseeable future and hence, does not require higher oil prices to meet its present and planned internal and external commitments.

2) Its perceived responsibility as a new economic super power not to contribute to global stagnation and inflation through substantial increases in the real price of oil.

3) Its political rivalry with Iran and its awareness that any further price increases would be much more beneficial to that country's economy than to that of Saudi Arabia or any other Persian Gulf producer.

4) Possibly, its concern about the impact of a continuing increase in real oil prices on the irreversible development of new energy sources, reflecting Saudi Arabia's unique long-term resource position.

5) The country's continued need and desire for friendly relations with the U.S. and its awareness of strong U.S. opposition to significant OPEC-imposed increases in real oil prices.

These views are, to the best of our knowledge, those of the present Saudi leadership, responding to present conditions and future prospects. As pointed out, a different Saudi leadership, or the existing leadership under political pressure, may of course respond differently at some future time.

Besides Saudi Arabia, the U.A.E., Kuwait, Qatar and Iraq can also be expected to have current account surpluses throughout the 1980's. Some, but not all, of these countries might support Saudi Arabia's price position. However, since Saudi strength by virtue of its actual and potential excess producing capacity is such that it can singlehandedly create a major world oil surplus in Case D if it so chooses, its minority position in OPEC does not detract from its ability to impose its policy, as has been demonstrated in the past three years. Hence, in the absence of Saudi Arabian acquiescence, the other OPEC members cannot sustain a higher separate price level without losing market volume.

We believe therefore that under Case D the most likely price scenario will be approximate maintenance of the current price in real terms until 1990. There is some chance for a slight real price decline in the period between now and the mid-1980's when all OPEC members will have some excess capacity. This could be followed by a very modest real price increase in the period to 1990 when some members will see their exports decline and, hence will start pressing harder for higher prices. But by large, under Case D we expect oil export prices by 1990 to be within about 10 percent either way of the current price, adjusted for inflation in world export trade.

Under the relatively low economic growth rate in this case the world inflation rate for export goods may amount to 5 percent annually over the entire period. Thus, the F.O.B. price of Saudi Arabian light crude, OPEC's marker crude, would rise in current (monetary) dollars from its present (1977) level of $12.70 to roughly $24/barrel plus or minus $2.40.

Case D then points up to two principal facts: 1) even under its very modest growth rate which will keep OPEC's productive capacity above requirements, prices will not decline, and 2) real price increases in the second half of the 1980's will be prevented or kept low only if Saudi Arabia actively opposes them. Without the implicit or explicit threat of the use of Saudi Arabia's excess producing capacity to enforce its pricing policy a two-tier price system could again develop

during that period. However, since the experience with the two-tier system in the first half of 1977 has shown that the principal beneficiaries are the companies which are able to buy the lower-tier oil, rather than ultimate consumers, Saudi Arabia may not wish to see such a system reintroduced. In fact, Oil Minister Sheikh Yamani said that much at a press conference in July 1977 (18).

Case B/C

In Case B/C OPEC production would have to be raised by 12 MM B/D from its 1977 level to 43 MM B/D in 1990 and productive capacity by 8.5-9.0 MM B/D. This could still be accomplished largely by Saudi Arabia alone unless its production problems turn out to be more serious than they currently appear. Oil Minister Yamani has recently been quoted as saying his country's production could be doubled from its present level of 8.5 MM B/D, but not "until peace is established in the Middle East" (19). However, in July 1977 Mr. Yamani was quoted as saying that "studies such as the recently published [April 1977] CIA report which anticipates that the [Saudi Arabian] Kingdom will produce 20 million barrels daily are figments of the imagination which we must not take seriously" (18).

Actually, under Case B/C Saudi Arabia would not have to raise its output to anywhere near 20 MM B/D. Through a combination of raising production ceilings closer to existing capacity and raising capacity where possible, the twelve other OPEC members may be able to increase their combined output from the 1977 level of 22 MM B/D to 26 MM B/D by 1990. This would still be below maximum feasible production. To achieve our projected volume of 43 MM B/D would then require 17 MM B/D of production from Saudi Arabia. If Kuwait, Iraq or the U.A.E. (all of which are able to do so) should raise its output by more than we have assumed in this calculation, required production from Saudi Arabia will drop accordingly.

Under conditions of stable real prices this would give the country an average annual real increase in oil revenue of approximately 4.5 percent from 1977 to 1990. While the Saudi Arabian economy clearly does not require any oil revenue increases for a number of years, the rate is relatively modest and can probably be partly absorbed internally through expansion of development plans and partly by increasing aid to selected developing countries. The present Saudi leadership may therefore not object to revenue increases on this order. On the contrary, as it becomes increasingly adept, sophisticated and involved an international and domestic monetary management, it will expect and count on some real revenue increases, just as would anyone who has adjusted to expectations of a rising level of income.

In Saudi Arabia, there appears to be some division between those likely to permit slow, steady output expansion and those reported to be opposed to it for economic and conservation reasons. The present policy planners belong to the first group. A change could, however, put the second group into policy-making positions. For our purposes, we assume, perhaps somewhat optimistically, that a slow steady output expansion, leading to a sustained producibility of about 16 MM B/D by 1990, will not be prohibited by the Saudi leadership in the face of a projected need for it. On this basis we believe that our projected Case B/C OPEC requirements of 43 MM B/D in 1990 can be met without straining the facilities of any OPEC members.

The price in the Case will not vary significantly from that in Case D until about 1983/1984, that is, it will remain approximately constant in real terms. After that, a number of OPEC members will produce either at capacity or at their desired maximum level while Saudi Arabia's excess capacity will be much less than under Case D so that its ability to exert a moderating influence on prices will be less but still significant.

Under these circumstances we foresee a modest increase in real prices, on the order of 3-5 percent annually, from 1983/1984 on, although not necessarily at uniform rates. Throughout most of this period this will have little effect on our projected oil demand growth, given the observed low short-term demand elasticity of crude oil. However, by 1990 the price increases should have a moderating impact on demand so that the actual amount of OPEC oil, and thus primarily of Saudi oil, required in that year is likely to be slightly less than we have projected under constant real prices.

The estimated increases would result in a real export price of approximately $15-17 per barrel for OPEC's marker crude by 1990. Assuming an accelerated inflation rate of 5.5 percent from 1977 to 1990 in part because of a faster economic growth rate than in Case D, the monetary price in the end year would be roughly $30-34.

We assume in this Case that pressure for moderation in real oil price increases will come not only from Saudi Arabia but also from the industrial importing nations as well as from the non-oil developing countries. For different reasons, we believe, the views of neither of these groups will be ignored by OPEC policy makers.

To sum up Case B/C, we believe the amount of oil required by 1990 could be supplied from existing sources at nearly constant real prices without straining the productive capacity of the OPEC countries or requiring them to produce more oil than they might be willing to. However, because of a combination of market forces and OPEC's continued price setting power, real prices are likely to rise somewhat faster in the later part of the period. This will reduce the growth rate in the end years so that the actual amount of OPEC oil required in 1990 will be less than under our constant real price assumption.

Case A

Our highest growth case calls for an OPEC output of nearly 52 MM B/D by 1990. We concluded earlier that it is highly uncertain that such a level can be technically attained by 1990. Therefore, the question of whether OPEC will want to produce at this level becomes somewhat moot. It is, however, of interest to determine how high OPEC's production might go in Case A, since that will determine how big the gap between supply and demand will be and by how much the price will have to rise to close it.

In Kuwait a production ceiling of 2 MM B/D has been imposed and enforced for some years. There is no indication that Kuwait has any intention to increase this ceiling. Its former Oil Minister, Abdul Mattaleb al-Kazemi, recently declared, "We have the capacity to produce 5 million barrels daily but are producing at a maximum rate of only 2 million barrels daily and are endeavoring to spread our oil resources evenly over 80 years" (20).

The Minister did say if Kuwait's revenue needs should rise "We will increase our production." However, with a population of about 1 million, a total land area of only 6,400 square miles, a per capita income of nearly $13,000 and a 1977 current account surplus of $5 billion, Kuwait's real revenue needs are unlikely to rise fast enough to justify this 5 MM B/D level. During the next three years we estimate that Kuwait's current account surplus will average $5 billion, yielding a cumulative current account surplus during the period 1974-1980 of nearly $42 billion. And since there is no present indication that the country is likely to find significant additional reserves, its relatively restrictive conservation policy would seem to serve its own best long-term interest, particularly if real oil prices rise.

On the other hand, Kuwait's industrialization and export diversification plans are largely tied to the availability of associated natural gas. Apparently, the country will need more natural gas by 1980 than it will have available from its current allowable maximum production. It is therefore not unreasonable to assume that Kuwait will slowly but gradually permit its production ceiling to rise. A ceiling of 3.5 MM B/D by 1990 in the face of a strong market for its oil, as foreseen in Case A, would probably be a maximum assumption.

The U.A.E. is even less in need of additional oil revenues than Kuwait. With a population of only 500,000 it had a per capita income of $17,000 and a current account surplus of nearly $4 billion in 1977. However, in the absence of any production increase and assuming constant real prices, the U.A.E.'s annual surplus would of course gradually decline. Hence, it may seek some increase in output. Additionally the country will be strongly prompted by the major importing countries to maximize its output. But with the reserves equal to less than 40 years of current productive capacity, the U.A.E. may resist a very sharp increase in production, say, more than 60 percent above its current level of 2 MM B/D. That would require a productive capacity of about 3.5 MM B/D.

Iraq's productive capacity,on the other hand, can be expected to move up all the way to our assumed 5.2 MM B/D target, since with a population of 12 million and a current account surplus of only $3 billion in 1977 it would by 1980 revert to a deficit position in the absence of production increases. Since the reserve potential for our projected increase is believed to be there, we assume that a productive capacity of 5.2 MM B/D and a sustainable production level of 4.7-4.8 MM B/D will be attained by 1990.

To balance NCW supply and demand, Saudi Arabia would have to produce 23 MM B/D by 1990 which would require a productive capacity of over 25 MM B/D. This is neither technically attainable nor would any Saudi government be likely to permit it, if it were attainable. To repeat Oil Minister Yamani's words, "Twenty million barrels daily are figments of the imagination which we must not take seriously." We assume therefore a maximum allowable Saudi production in 1990 of about 17 MM B/D, or slightly more than in Case B/C.

Perhaps, Saudi Arabia and some of the other Persian Gulf states can be induced to provide higher volumes. After all, if the economy of the Western world depends on a certain incremental volume of oil, those that have it available or can make

it available may find it difficult to keep it shut in. Needless to say, such a scenario is fraught with all sorts of political risks. Furthermore, by the time the world realizes the urgency of its need for these incremental quantities it may no longer be possible to complete the necessary facilities in time to avoid the crunch. If this were to happen prices could take a quantum jump of unforeseeable magnitude to bring supply and demand into balance, such as the one experienced in 1973.

An alternate and perhaps more likely scenario in Case A would be this: at a sustained annual increase in NCW (ex. U.S.) oil demand of 4.6 percent, OPEC prices would start rising significantly in real terms from the beginning of the 1980's on so that demand would be sufficiently reduced to match supply throughout the period.

It is extremely difficult to estimate a price under this scenario, since it will be determined on the one hand by the suppliers' perception of little or no available spare capacity and the value of oil to the economies of consuming countries, and on the other by the strong pressure of consuming countries to moderate the price increase so as not to destabilize the world economy. Valid arguments can be made for Saudi Arabia's joining either side of the dispute. However, regardless of Saudi Arabia's stance, the principal force pushing world oil prices up in Case A will be the market mechanism and not OPEC. In fact, OPEC's role could be reversed, i.e., for political reasons it may try to dampen some of the sharper increases caused by economic forces. In this it would be unlikely to prevail, since a cartel producing at capacity to meet effective demand is not in a position to enforce a price ceiling below market value. Thus, OPEC's function as a price setter would end, at least temporarily, in Case A.

If we assume that the maximum amount of oil available from OPEC in 1990 will be at least 6 MM B/D below the volume required under our Case A under constant real prices, the question is what market price increases, and from when on, are necessary to keep demand in line with available supply. The multiplicity of factors going into the answer would require a computer model. Even then it would be quite speculative, given the speculative character of most of the input. The best we can offer is our considered judgment of a price approximation to achieve the required result. We would assume that under a 4.6 percent annual growth rate in NCW (ex. U.S.) oil demand, real prices would start to rise from about 1981 on and could easily reach $16-18 per barrel by 1985 and $21-23 by 1990. In monetary terms this would be equivalent to $26-29 in 1985 and $45-49 in 1990, assuming,

say, a 6.0 percent world inflation rate in this Case. We would like to caution that these, as well as other price forecasts, are very inexact estimates, more indicative of trends than precise values, the actual dollar amounts having been estimated at EPRI's request.

(The real delivered cost of oil to most major markets can be expected to rise by more than the real F.O.B. price of OPEC's marker crude between 1977 and 1990. The principal reason is that the current very depressed conditions in the world tanker market will correct themselves sometime during the 1980's under all three of our cases, though the speed at which this correction takes place will be a direct function of the actual growth in NCW oil demand. Another factor likely to contribute to higher real oil transporation costs would be any of a variety of costly new safety equipment, both for new and old tankers, including some which will reduce the volume of cargo that can be carried. In the U.S., for instance, we expect the average real transportation cost by 1990 to be substantially above last year's figure of about 90¢/barrel as a result of these developments, notwithstanding the completion of one or two superports by then.)

Obviously, our price and demand projections reflect some elasticity coefficient, relating the two. What this coefficient is in the real world on a global basis is extremely difficult to determine, since crude oil cost is only one component of the price of oil products sold to ultimate consumers. The weight of this component varies from product to product and from country to country, ranging from as high as 85 percent for some large industrial users of residual fuel oil to less than 20 percent for automobile gasoline consumers in countries with high gasoline excise taxes.

In addition, the price elasticity of demand for crude oil will, in general, increase over time as its relative price increases, since the ability of consumers to substitute alternative energy sources through equipment modifications increases.

In our Case A, price increases starting in 1981/82 and resulting in a 65-80 percent increase over the constant price by 1990 is assumed to reduce world demand for OPEC oil by about 12 percent in the latter year from what it would have been under constant price conditions. Since the price increase would not be limited to OPEC oil but would probably apply to most NCW oil, at least at the consumer level, a more meaningful indication of the impact of our postulated price increase

on demand would be the reduction of total NCW (including U.S.) demand by 6 MM B/D, or 7.5 percent from the 81 MM B/D projected for 1990 in Case A under constant prices. The demand reduction would be effected over a relatively short period, probably no more than 8 years, and the responsiveness of demand to the price rise would be much more pronounced towards the end of the period.

In evaluating Case A, the only one of our three cases leading to a supply constraint by or before 1990, it should be reiterated that while we consider it the least likely case, it falls still within our parameter of reality.

REFERENCES

1. American Petroleum Institute et al. Proved Reserves of Crude Oil, Natural Gas Liquids and Natural Gas in the United States and Canada as of December 31, 1976. Washington, D.C., 1977, p. 230.

2. National Energy Board. Annual Report. Ottawa, 1976, p. 15.

3. National Energy Board. Canadian Oil Supply and Requirements. Ottawa, February 1977, p. 75.

4. The New York Times. September 9, 1977.

5. The Wall Street Journal. February 22, 1977.

6. Oil & Gas Journal. March 7, 1977, p. 78 and May 2, 1977, p. 120.

7. Bernardo F. Grossling. "Latin America's Petroleum Prospects in the Energy Crisis." Geological Survey Bulletin 1411. U.S. Department of the Interior, Geological Survey. Washington, D.C., 1975.

8. Organization for Economic Cooperation and Development. World Energy Outlook. A Report by the Secretary General. Paris, 1977, pp. 45-48.

9. The Petroleum Economist. June 1977, p. 217.

10. The Petroleum Economist. July 1977, p. 274.

11. Colin Robinson, Jon Morgan. "North Sea Oil and the British Economy 1977-85." London. Staniland Hall Associates, Ltd. (2) "North Sea Report." Mackenzie & Co. Edinburgh.

12. The Wall Street Journal. June 19, 1977.

13. The Wall Street Journal. February 2, 1977.

14. Petroleum Intelligence Weekly. February 20, 1978.

15. U.S. Central Intelligence Agency. International Energy Biweekly Statistical Review. February 8, 1978.

16. The Petroleum Economist. September 1977, pp. 349-350.

17. Congressional Research Service, Library of Congress, Project Interdependence: U.S. and World Energy Outlook through 1990. Summary Report, for the Committees on Energy and Natural Resources and on Commerce, Science and Transportation, U.S. Senate, and the Committee on Interstate and Foreign Commerce, U.S. House of Representatives. Publication No. 95-31, June 1977, pp. 53-56.

18. Middle East Economic Survey. Vol. XX, No. 40. July 18, 1977.

19. Platt's Oilgram News Service. September 13, 1977, p. 3.

20. Middle East Economic Survey. Vol. XX, No. 42. August 8, 1977, p.2.

Chapter 7

SUPPLY AND DEMAND BEYOND 1990: CRISIS OR ADJUSTMENT?

In the previous chapter we have shown that a growth rate in NCW oil demand (incl. U.S. import requirements) of up to 4 percent annually can be met through 1990 from known oil deposits plus likely new discoveries. A significantly higher growth rate, such as the 4.6 percent shown in Case A, would create the set of conditions referred to in the media and elsewhere under the popular definition of "energy crisis". This could be defined as a rapid increase in real oil prices over a relatively short period, with the impact falling almost entirely on the demand side, since supplies would be temporarily constrained by capacity limitations. The consequent forced reduction in oil demand could create economic dislocations of significant proportions. Simultaneously, the likely attempt of consuming nations to vie for access to the limited supplies could lead to destabilization of international relations.

The "energy crisis" would of course be of limited duration, since the assumed supply constraints must be considered temporary, given the sharp price increases which would precede and accompany it. The crisis would result from a combination of short term physical and other non-economic limitations of oil and oil competitive energy supplies and a relatively price-inelastic demand for these supplies. The higher prices brought about by the crisis or, more likely, in anticipation of it, would naturally stimulate increases in energy supplies and improvements in the efficiency of their utilization. Eventually these would eliminate the constraints and end the crisis.

Thus, the potential problem period, economically and politically, of any future energy shortage might be relatively brief, perhaps no more than 5-6 years. But that could be long enough to cause significant economic and political destabilization.

It might be worth recalling in this connection that the historically unique 350 percent world oil price increase during 1973 has, so far, not brought forth significant amounts of non-conventional oil or other new energy supplies, nor a

dramatic improvement in the efficiency of energy utilization. On the other hand, neither has it caused any significant economic or political destabilization, considering its magnitude and suddenness. One may therefore be tempted to conclude that future price increases of a less extreme nature could be absorbed by the world economic system with equal facility.

This may be so. But there could also be differences. Since 1974 oil has been readily available at prevailing prices in incremental quantities, with considerable volumes to spare, so that the high price of the post-1973 period has coincided with a substantial surplus in available production--a consequence of the fact that the price has been set by a cartel (OPEC) and not by market factors. By contrast, in our Case A "crisis" scenario, market factors would force the price up through demand increases in excess of supply additions, so that all productive surplus eventually disappears. Under these conditions a crunch, i.e. a situation in which incremental supplies of oil or substitute energy are temporarily unavailable in the face of unmet demand, is theoretically entirely possible. One only has to consider the time span required to bring on new energy supplies and the various non-price factors which influence their commercial availability to appreciate this possibility. The likelihood of the possibility becoming a reality is of course another matter.

Through 1990 the probability of an energy crisis is relatively low, since NCW oil demand is much more likely to grow at a rate of less than 4 percent than at a higher one. But 1990 is only thirteen years away. It is therefore pertinent to ask whether an energy crisis or a reasonably smooth adjustment of world energy supply and demand will come after 1990. The present chapter attempts to answer this question for the 15-year period ending in 2005. Because of the higher degree of uncertainty in this period we will not try to quantify the answers, as we have done for the earlier period, but will limit ourselves to determining likely trends in the requirements and availability of oil between 1990 and 2005.

Two unequivocal statements can be made about the post-1990 period: 1) the ultimate amount of recoverable conventional oil still in the ground will be substantially less (by approximately 250 billion barrels or 15 percent) at the beginning of the new period (1990) than it was at the beginning of the period we have just examined (1977) (see Table 5-9) and the world reserve/production ratio will have dropped significantly; and 2) the economic, political and technological forces which have been set into motion on a global scale since 1974 to conserve scarce forms

of energy and develop alternate sources for them, both with special emphasis on oil, are almost certain to reduce the growth in NCW oil demand in the 1990's below the rate prevailing in the 1980's. In other words, we will have less oil left but our incremental demand will also be lower, certainly in percentage terms and very likely also volumetrically.

It is reasonable to postulate that both these trends will continue until oil consumption levels off and then starts declining. The question is which will determine which: will oil demand eventually stop growing because more efficient oil utilization and the availability of alternate sources will reduce the need for more oil? Or will the declining remaining resources dictate a temporary reduction in demand through the imposition of prices high enough to eliminate unmet demand? The first kind of development can be described as a gradual adjustment process, the second,as we have said, would lead to a demand-induced energy crisis.

A logical starting point for our inquiry into the availability of oil beyond 1990 is an examination of how long NCW demand (ex. U.S. demand but including U.S. import requirements) can continue to grow at the rate assumed in each of our 3 cases before it reaches the level of likely maximum NCW (ex. U.S.) production. We have seen in Chapter 6 that the required production in Case A of nearly 70 MM B/D will not be reached, because of production ceilings in Kuwait, U.A.E. and Saudi Arabia and also because of possible technical difficulties in doubling Saudi Arabia'a productive capacity between now and 1990. Thus, we have estimated the maximum volume of oil available in 1990 to be about 64 MM B/D including 46 MM B/D from OPEC.

Let us assume that non-OPEC oil production, which we have projected to grow at 7.1 percent annually between 1976 and 1990 to 18 MM B/D, will continue to grow for only a few more years and at a much reduced rate, say about 3 percent annually to 1995, even under the stimulus of continued real price rises. This would raise it to 21 MM B/D by then. Discoveries outside OPEC will of course still be made thereafter and recovery rates from existing fields will also be increased, as the oil industry gains experience in the technology of enhanced recovery methods and continuing real oil price increases improves the economics of recovery processes (a recent study predicts an improvement in the world recovery rate from the current 25 percent of the discovered resource to 40 percent by the end of the century [1]). However, we assume that after about 1995 these additions will only be enough to offset declining production in older fields for a number of years.

This may seem like a pessimistic assumption, given the fact that about 60 percent of the undiscovered recoverable conventional NCW reserves outside the U.S. are not located in OPEC countries, according to Moody (see Chapter 4). Furthermore, no systematic exploration of the deep sea and the Arctic areas (with the exception of Northern Alaska) has yet been undertaken, due partly to technical and partly to economic reasons. Both these obstacles can be expected to lessen progressively over the next 15 years, as prices rise, sharply from the early 1980's on in Case A and more moderately and somewhat later in Case B/C. It is interesting to note in this connection that the consensus of 28 experts, published at the 10th World Energy Conference in Istanbul in Septemeber 1977, estimated total recoverable oil reserves from the Arctic and the deep water areas at about 280 billion barrels.*

On the other hand, some forecasters have projected that production from the North Sea and the Alaskan North Slope, which only began on a significant scale this year, will start to decline from about 1990 on, if both are produced near their maximum efficient recovery rates. Thus, a great deal of oil will have to be found just to maintain prevailing production levels during the last decade of this century.

Now let us look at the maximum available production from OPEC. We have estimated that in 1990 (under Case A) the actually attainable upper limit will be about 46 MM B/D. But purely on the basis of resource availability it could have been significantly more, particularly from the Persian Gulf countries.

In these countries, further production increases should be technically achievable through the expenditure of sufficient funds over extended periods to maintain existing production at optimum levels, and to find and to develop new reserves to offset the decline in the older fields.

By 1995/96 these efforts should enable Saudi Arabia to raise its sustainable production rate by 2-3 MM B/D over the assumed maximum 1990 level, to 19-20 MM B/D. Kuwait, the U.A.E. and Iraq should be able to raise their collective output by about 3 MM B/D during the same period. We can assume that the other OPEC members will be able to more or less maintain their collective production at the 1990 rate through similar forms of massive investments in exploration and secondary recovery projects. In Iran this might include the injection of non-associated gas for oil

*These reserves are in addition to the 1,900 billion barrels estimated by this group to be recoverable with today's economics and technology.

reservoir pressure maintenance, according to government reports. In Venezuela it would include the commercial development of the Orinoco Oil Belt which is known to contain vast amounts of heavy oil and which could supply 700-800,000 B/D of oil by the mid-1990's on the basis of the current government's plans.

The additional income ensuing from these relatively modest production increases between 1990 and 1995 would probably not be considered excessive by the three Persian Gulf countries with expected continuing current account surpluses (Saudi Arabia, Kuwait, and the U.A.E.). In the case of Saudi Arabia for instance, disposition of the revenue obtained from an annual 2.2-2.5 percent increase in production from 1990 to 1995 would probably create no problem, assuming real price increases are kept within reasonable limits during this period. (It should be noted in this connection that during the first nine months of 1977, the country's production increased by nearly 12 percent largely as a result of the government's pricing policy.)

Altogether, then, OPEC's sustainable maximum production rate might be about 51 MM B/D by 1995. This is approximately in line with a number of long-term forecasts by oil companies of OPEC's maximum productive capacity. However, in some of these forecasts the maximum is reached before 1995.

Adding our projected 21 MM B/D of non-OPEC NCW production (outside the U.S.) to our OPEC figure, we arrive at a total maximum NCW (ex. U.S.) production of 72 MM B/D. This level could be attained by 1995 at the earliest but may be required sooner or later in each of our three cases. In Case A, we have assumed in Chapter 6 that rising prices due to supply limitations will reduce the growth in demand from our original projection of 4.6 percent annually to an average of about 4.0 percent for the period 1976-90. Let us use this rate to calculate the date when demand will reach the maximum available level of production. Even this slower increase in Case A leads to a supply constraint in the early 1990's, when 72 MM B/D will be required before that quantity is projected to be actually available. In Cases B/C and D we will use the same growth rates as shown for the period 1976-90 in Table 6-2. Neither of these cases will require our assumed maximum production level before 1995.

The Calculations are shown below:

REQUIREMENTS FOR NCW OIL[a] BEYOND 1990 UNDER CONTINUATION OF PRE-1990 GROWTH RATES

	1990 (MM B/D)	Annual Growth Rate	1992 (MM B/D)	1995 (MM B/D)	2002 (MM B/D)
Case A	63.7	4.0%	73.0[b]		
Case B/C	61.1	3.6%		73.0[b]	
Case D	53.8	2.7%			73.0[b]

[a]Includes only import requirements for the U.S.

[b]Maximum NCW (ex.U.S.) sustainable production rate, which cannot be attained before 1995.

In each of the maximum production years, the NCW (ex. U.S.) reserve/production ratio would be about 14-15 years, assuming some further reduction in the average annual finding rate from the 16 billion barrel volume projected for the period 1976-90 (see Table 5-9). This ratio could probably decline by no more than another two or three years, at the most, since no oil exporting country is likely to permit a ratio of less than 10 years, while some, such as Saudi Arabia, Kuwait, Abu Dhabi and perhaps, Mexico, can be expected to insist on maintaining higher levels.

In essence, the above figures show that while foreign NCW oil demand (incl. U.S. import requirements) could grow at a rate of up to 3.5 percent from 1976 to the mid 1990's, from then on no further growth would be possible because of physical supply limitations. Demand could probably be maintained for a few more years at the maximum level by a drawdown of the reserve/production ratio but would have to start dropping by the end of the century. On the other hand, if the growth rate from 1976 on were to average only 2.5 percent, it could continue at that pace into the first few years of the next century and would then level off. Thus, very broadly speaking, at our assumed fixed long-term growth rates we have 15-25 years within which to rearrange our energy requirements so that no part of the NCW's incremental energy requirements are met from oil sources. A few years beyond these dates we may also have to cope with declining conventional oil supplies.

Before trying to determine whether these end dates of the growth in world oil demand will be reached through an adjustment process or will trigger an energy crisis, it is important to remember that they assume a straight continuation of

the 1976-90 growth rates into the 1990's. This is a possibility but certainly not a probability. As mentioned earlier, the global effort to improve energy utilization, encourage petroleum conservation and develop substitutes for petroleum must be expected to have some visible impact well before 1990 and even more so thereafter.

For instance, the technology required for large-scale energy conservation is much more effective with new capital equipment than with retrofitted existing equipment. But the turnover of capital stock takes decades, not years. Hence energy efficiency per unit of GNP will rise gradually throughout the 1980's and 1990's, and the energy/GNP growth ratio will decline correspondingly. For example a worldwide NCW energy/GNP ratio of slightly below 0.8 in the 1990's, which could hardly be termed a radical drop from that of the previous period, would reduce energy demand growth to 3.2 percent annually, slightly below that of our Case D projection, while allowing world GNP to continue to grow at the relatively high rate of 4 percent annually.

The same factor of improvement over time applies also to the development of oil-competitive alternate resources and non-conventional oil resources. Thus, while conversion of existing industrial plants and electric power stations from gas or oil to coal may proceed much more slowly in the U.S. than the Administration has projected in its National Energy Plan, economic and policy considerations will assure coal a relatively high share in new facilities. Hence, the Administration's coal consumption target for 1985 may be reached 5-6 years later. Certainly by the late 1990's coal, together with nuclear power, can be expected to reduce oil used for U.S. power generation below last year's volume of 1.65 MM B/D, bringing about a corresponding reduction in oil import requirements.

In the case of synthetics, or other unconventional new oil sources, both in the U.S. and abroad, commercial production prior to 1985 will be insignificant. But by then the first generation of commercial synthetic oil and gas plants should be operative. Meanwhile real crude oil and natural gas prices will have started to rise, combining additional economic incentives with improved technical feasibility. Thus, by the mid-1990's the U.S. might produce 1.5-2.0 MM B/D of synthetic oil and gas equivalent and by the year 2000 perhaps 2.5-3.0 MM B/D. The governmental incentives and encouragements which are required in addition to market incentives to achieve targets of this magnitude within our time frame may finally be forthcoming under a new program recently announced by the Secretary of Energy as

"Phase Two" of the Administration's National Energy Plan. The plan is expected to emphasize "supply strategies" for shale oil and synthetic fuels and to lean heavily on various forms of governmental incentives and assistance. The Secretary has stated that the new program would result in about 2.5 MM B/D of synthetic fuels production by the late 1990's. It should be cautioned that without an effective governmental program of this nature, the Secretary of Energy's target can not be reached or approached.

Outside the U.S., synthetic oil production will increase in Canada from the Athabasca Tar Sands where production is scheduled to reach 350,000 B/D by the late 1980's and could approach 1 MM B/D by the end of the century. Similarly, production from Venezuela's Orinoco Heavy Oil Belt, as mentioned before, will start and could reach at least 1 MM B/D by the end of the century.

With respect to atomic energy, we believe if the industry's good safety record continues for another 5-6 years, public resistance to nuclear power plants, which has been a major factor in construction postponements and delays, will greatly diminish, just as has been the case with other major innovations which were initially opposed for a variety of fears. It is also likely that by the mid 1990's the present generation of nuclear reactors will be supplemented, at least abroad, by a number of commercial breeder reactors and nuclear waste reprocessing plants, thus reducing the problem of nuclear waste disposal.

(However, it should be cautioned that if the recent substantial reduction in new orders for atomic power reactors from previously announced targets outside the U.S. continues into the 1980's, our NCW forecast of non-oil energy supplies by 1990 may have to be reduced and our oil demand forecast increased.)

Solar and other forms of renewable energy, as well as geothermal energy, will all be too insignificant to matter commercially on a global basis in the 1980's but can be expected to start making measurable contributions to world energy supplies from the early 1990's on. The WAES report estimates that by the year 2000 solar energy in the industrial countries may contribute up to 2 MM B/D of oil equivalent (1). This would be equal to approximately 2.5 percent of the likely total NCW oil requirement in that year.

Finally, outside the U.S., natural gas supplies can be expected to rise substantially throughout the remainder of this century and probably, into the early years of the next. Foreign gas supplies may, in fact, be today where U.S. gas supplies were in

1951 when most of their uses were local, much of the gas was flared in the field and no company was interested in searching for gas per se. Between then and 1972 U.S. gas supplies rose from 19 percent to 32 percent of total U.S. energy consumption. A somewhat similar situation has prevailed until quite recently with respect to gas supplies outside the major consuming areas, particularly in OPEC members and the Soviet Union.* A report prepared for the World Energy Conference in Istanbul on the world outlook for gas to the year 2020 (3) estimated that by the year 2000 global availability of natural gas from conventional sources will be nearly twice as high as in 1985, 143 exajoules vs. 77 exajoules. In oil equivalent this would be an increase from about 35 MM B/D to about 65 MM B/D, or an annual growth rate of 4.2 percent over the 15 year period to the year 2000. The report foresees a decline in world supplies between 2000 and 2020. But OPEC's productive gas capacity, which by 2000 will account for 28 percent of global capacity (compared to 15 percent in 1985), will continue to grow to 2020. The report points out that substantial additional gas supplies could be available by 2000 from unconventional sources such as coal, biomass and geopressured resources.

In another optimistic forecast of OPEC's gas potential, Nordine Ait Laoussine, Executive Vice President of the Algerian state company, SONATRACH, recently estimated that based on a 20-year reserve/production ratio, OPEC could eventually produce at least 1.1 trillion cubic meters of gas per year, equal to 20 MM B/D of oil (4). Much of it would be exported. (Current plans and projects under construction will raise OPEC gas exports to the oil equivalent of 3 MM B/D by about 1985, compared to 0.4 MM B/D in 1976). Realization of such targets would require hugh amounts of capital --$300-350 billion for maximization of OPEC exports alone, according to Laoussine's estimates. A logical and likely source for part of this money could be those OPEC members which would continue to accumulate current account surpluses from growing volumes of oil production and/or increases in real unit prices.

Without trying to quantify the impact of all the developments described above, it is quite reasonable to assume that they will 1) lead to more energy conservation and greater efficiency of energy utilization in the 1990's than in the 1980's, and 2) permit total non-oil energy supplies to grow at least as fast in the 1990's and the first years of the next century as we have projected for the 1980's, about 5 percent annually. The combined impact of these two developments on post-1990 oil demand would of course be to reduce its growth below the long term pre-1990 rate, assuming no change in the GNP growth rate projected in each of our cases.

*In the OPEC countries some 4 TCF of gas per year are currently flared. This is equal to nearly 2 MM B/D of oil.

Thus, the production ceiling in NCW oil is likely to be reached somewhat later in all three cases than we have estimated in the table earlier in this chapter. How much later depends, however, more on the growth rate in demand up to 1990 than on its subsequent reduction. In our Case D, for instance, which assumes a growth rate of 2.7 percent to 1990, a moderately lower rate thereafter could keep demand growing for at least another 15 years. Real price increases required to balance supply and demand would therefore be relatively modest until sometime after the year 2000. Case D, then, would fit our description of a gradual adjustment process. It would permit a gradual transition over a period of 25 years of more from oil to non-oil sources to meet NCW's incremental energy demand.

In Case A, on the other hand, the level of demand reached by 1990 would be so close to the attainable maximum production level that even a substantial drop in the growth rate, after 1990, due to the aforementioned improvements in energy conservation and the development of alternate energy sources, could not prevent demand from becoming supply-limited early in the last decade of the century. Hence, in Case A market forces would cause the sharp increase in the real price of oil that we have postulated from the early 1980's on to continue into the 1990's to balance supply and demand. OPEC administered pricing policies might change the timing of such increases somewhat, but are unlikely to change their magnitude.

This case would therefore lead to an "energy crisis", as defined earlier in this chapter, in the first half of the 1990's. However, as we have said before, the duration of the crisis would be limited, since over a period of time the price increases would bring forth additional oil or oil-competitive energy supplies. To judge from historic experience, the eventual impact of the crisis-induced price rises on the supply side could well result in an overstimulation, creating new surpluses and driving energy prices down from their peaks. But this reversal in the price trend would probably occur only towards the end of the century, following several years during which constraints in the availability of incremental energy supplies would keep general economic growth rates below "normal" levels.

In Case B/C some growth beyond 1990 would still be possible but only at a sharply reduced rate. If the assumed pre-1990 rate of 3.6 percent in oil demand were cut in half after 1990, the NCW production maximum would probably not be reached until the end of the century. However, such a radical drop in the growth rate may not be attainable without some further real price increases. Accordingly, the moderate

price increases we have projected in this Case for the second half of the 1980's would accelerate somewhat in the 1990's. Thus, while Case B/C would fall short of the definition of a crisis scenario, it would entail many of the same characteristics, e.g., significant price increases. But the price required to bring the growth in oil demand to a halt by the year 2000 would certainly be less than that required in Case A to arrest growth by 1995, and thus the time to develop alternate resources to meet incremental energy demand would be longer. These differences should permit the adjustment process to be much less severe than that required under crisis conditions.

The above estimates show that if foreign NCW oil demand (incl. U.S. import requirements) grows at an annual rate of 3.5-4.0 percent between now and 1990, it will become supply-limited between 1995 and 2000, notwithstanding significant long-term improvements in oil and other energy conservation and the development of alternate energy sources.

A longer, more gradual and less costly transition to the period when oil demand will level off would require an oil demand growth rate in the 1980's approximately in line with that assumed in our Case D. In assessing the prospect for such a growth rate it should be remembered that all our cases are based on relatively high global economic growth rates for the period up to 1990. Thus, our "moderate" NCW (ex. U.S.) GNP growth rate, implicit in Case D, for the period 1980-90 (see Chapter 2) is 4.5 percent annually, or only about half a percentage point below the 1960-76 historic rate for the same region. For the U.S. our "moderate" 1980-90 growth rate of 3 percent is also about half a percentage point below the historic rate for the period 1960-76.

Is it likely that the growth rate will be significantly lower than we have assumed, partly because of the recent rise in energy costs? If so, this would have a significant corollary effect on reducing energy demand and, hence, oil demand. Let us examine this proposition.

By definition, no system based directly or indirectly on finite resources can keep growing indefinitely at a fixed growth rate, since eventually the magnitudes of the increases would become literally unmanageable. Thus, some gradual reduction in the world's future economic growth rate must be assumed. Since the period 1960-76, for various reasons, was characterized by an exceptionally rapid average growth rate, the expected deceleration in the period ahead could be quite substantial by

comparison with this latest period but still compare favorably with a much longer historic period, such as the last 40-50 years.

This would apply particularly to the industrial (OECD) nations which would have to carry the bulk of any deceleration of the world GNP and energy growth, since they currently account for over 80 percent of NCW aggregate GNP and energy consumption. By definition, the economies of these countries are relatively mature and their standards of living relatively high. It is therefore reasonable to assume some saturation factor in their future economic developments which would be reflected in declining growth rates. Even more important is their very slow population growth rate -- 0.9 percent annually in recent years and 0.8 percent projected for the remainder of the century. Thus, if the average real GNP growth of the NCW industrial countries were to move to a long term rate near 3 percent annually from about 1980 on, per capita income and standard of living would continue to rise substantially in real terms. While such a rate may be below present political expectations, it may prove to be quite tolerable given appropriate socio-economic adjustments.

In fact, the reduced growth rate would probably have a beneficial long term effect on one of the twin economic evils of modern industrial societies, persistent inflation. It could of course aggravate the other evil, excessive unemployment, However, this could be compensated, at least partly, by allocative measures and other direct action designed to offset high unemployment. Furthermore, the most persistent and undesirable form of unemployment in industrial countries, namely youth unemployment, is likely to be steadily reduced by natural causes in the next two decades as the share of youth in the labor force declines as a consequence of low birth rates in the 1960's and 1970's.

This is not to deny that a sustained slowdown in the industrial countries' economic growth rates would exacerbate certain social and political problems. But to the extent to which these problems can be alleviated by limited action or will be contained by extrinsic factors, adjustment to such a trend becomes more likely, regardless of current rhetoric to the contrary.

Actually, most industrial countries have lived with a sharply reduced growth rate for the past four years. The first two were of course recession years but neither in Europe nor in Japan have the GNP growth rates returned to the averages of the

1960's and early 1970's in the subsequent two years, nor are they likely to do so in 1978. Quite possibly, these countries' recent and current economic behavior may not reflect the short term down phase of a cyclical trend but a long term structural change towards a significantly slower growth rate. Any economic forecast must consider this possibility, in view of the growing evidence of its existence.

The rest of NCW consists of less developed countries most of which have a rapid population growth, averaging about 2.5 percent annually. The economies of these countries will therefore have to grow at substantially faster rates than those of the industrial countries if their per capita living standard is to improve.

The OPEC countries, which form part of this developing world, may have both the financial means and the energy resources to grow at their maximum sustainable rate. Long term, this could be 6 percent annually, or well over twice their expected population growth rate.

Most of the other developing countries would have to grow at substantially lower rates because of rising structural economic and resource limitations and also because of the impact of the slower growth of the industrial nations which are the principal market outlets for the developing countries. If these factors were to reduce the economic growth rate in the non-OPEC developing world to 4.3-4.4 percent annually in the 1980's, this would put it significantly below the long term historic growth rate (1960-76) of nearly 5.5 percent. But it would still be nearly 75 percent faster than their current population growth rate, and thus still permit an improvement in their standards of living. Furthermore, a modest decline in these countries' composite population growth rate is expected from about 1985 on. In a world of high energy costs and declining real economic growth rates in the major import markets, a growth rate of nearly 4.5 percent per annum may well be their maximum achievable rate during the transition period from oil to other sources for the world's incremental energy demand. What effect such a rate would have on political developments in the developing countries is beyond the scope of our inquiry. Parenthetically, it may be worth noting that historically, most changes towards greater or lesser political stability in these countries were due to factors other than the growth rate of their economies.

The result of these various developments would be a composite NCW (including U.S.) economic growth rate of about 3.4 percent. Given our assumption that energy demand will grow at a somewhat slower rate than GNP and that oil demand will grow more slowly than total energy demand, such a GNP growth rate would generate a significantly slower growth in energy and oil demand than we have projected in our Middle Case or High Case. It would require a growth rate in energy demand of under 3 percent and a growth rate in oil demand of about 2.2 percent. This would be in line with our Low Case (Case D) projection. (See Table 5-7). If that rate could be attained at the beginning of the 1980's it could continue into the first few years of the next century. However, since the growth rate in the 1990's will, under all assumptions, be somewhat lower than in the 1980's, supply limitations on oil demand would be unlikely to occur until sometime after our end year of 2005. By then, the need for additional oil supplies will probably have ceased. Thus, the transition from oil to other sources for NCW's incremental energy requirements would be relatively slow and gradual under this scenario, as would be the increase in real oil prices.

Under our Case D, with its somewhat optimistic assumptions regarding future energy conservation and improvements in the efficiency of energy utilization, such a growth rate would be achievable. Under less optimistic assumptions in energy savings it could still be achieved if government policies, or their failures, were to keep the NCW's annual GNP growth rate in the 1980's at about 3.4 percent, which is below our low economic growth assumption. Thus, to a considerable extent, the probability and extent of a world energy crisis in the 1990's may be predetermined by the world economic growth rate in the 1980's.

In summary, then, oil demand in the 1990's and beyond will grow at a substantially lower rate than in the 1980's under almost any reasonable assumption. The demand growth rates assumed in our Cases A and B/C for the 1980's would probably cause severe to moderate supply constraints in the middle to late 1990's. The constraints could last several years and would be preceded and accompanied by substantial real increases in oil and competitive energy prices which would eventually correct the imbalance. On the other hand, the growth rate for the 1980's assumed in our Case D would permit oil demand to continue to rise at the required subsequent rate to our selected end year (2005) without the need for sharp increases in real prices to balance supply and demand. The probability of the Case D scenario would be greatly enhanced if the NCW's economic growth rate in the next 15-20 years should be substantially below that of the past 15-20 years, a development, which in our view, is not at all unlikely.

REFERENCES

1. C. L. Wilson, et. al. Energy: Global Energy Prospects, 1985-2000. Report of the Workshop on Alternative Energy Strategies. New York: McGraw Hill Book Co., 1977.

2. Report on Oil Resources, 1985-2000. Conservation Commission, Tenth World Energy Conference. Istanbul, August 1977.

3. W. T. McCormick, Jr., et. al., American Gas Association. "The Future for World Natural Gas Supply." A report prepared for the Tenth World Energy Conferece. Istanbul, August 1977.

4. Nordine Ait Laoussine. "LNG Exports -- A Contribution to World Energy Supplies in the Decades to Come." OPEC Review. Vol. I, No. 7. October 1977.

APPENDIX A

POLITICAL FACTORS AFFECTING THE PRICE AND AVAILABILITY OF OIL IN THE 1980's

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INTRODUCTION

The global price of oil and its availability to customers in the international market have been determined, since the early 1970's, primarily by OPEC. OPEC was formed in 1960 to maximize for its members the monetary gain from the exploitation and export of their hydrocarbon resources.* With its membership rising from five to thirteen in the past 18 years, OPEC has consistently controlled from 80 to 90 percent of the world's oil exports. In the same period, energy consumption in the industrial economies of Europe, Japan, and North America has risen dramatically. Within the energy budget of the industrial world, oil has displaced coal as the leading fuel. The indigenous petroleum reserves of the world's largest consumer, the United States, have been declining since 1970, making that country increasingly dependent on imports from OPEC. The cohesion of the cartel has been strengthened by the predominant position of Saudi Arabia, whose share in OPEC's total production rose from 17 percent in 1970 to about 30 percent in 1977 and which controls about 30 percent of OPEC's aggregate spare capacity.

Political factors have significantly added to OPEC's strength. The withdrawal of British forces from the Persian Gulf after 1970 and the evacuation of Wheelus Air Base in Libya by the United States left a power vacuum where oil producing states felt free to assert their economic interest without fear of military intervention. The Arab-Israeli war of 1973 gave OPEC's Arab members (which account for 60 percent of the cartel's production) the sense of moral justification in reducing their output in the fall and winter of 1973-74, and the resulting panic prices on the spot market created the backdrop for the quadrupling of oil prices enforced by OPEC's Arab and non-Arab members alike.

*For a full discussion of the origins of OPEC, see Rustow and Mugno, OPEC: Success and Prospects, New York: New York University Press, 1976.

The immediate background of the Tehran and Tripoli agreements of February and April 1971, which in effect shifted from multinational companies to OPEC governments control over rates of production and prices of exports, reveal the crucial contribution that specific and temporary political factors can make. The pressure for the intensive round of negotiations was initiated in the summer of 1970 by Libya, where a radical military junta had taken over the year before from a conservative monarch; and they were begun at a time when another radical regime, in Syria, had refused to allow repairs to the damaged TAPLINE that transported much of Saudi oil to the Mediterranean, thereby setting off an unprecedented shortage in the tanker market.

Six of OPEC's members are located in the Middle East, four in Africa, two in Latin America, and one in Southeast Asia. All of these are areas of longstanding and deepseated domestic and regional political instability, characterized by coups, attempted revolutions, civil wars, and interstate conflict. And these factors may be expected to have an influence on oil developments in the future as they have in the past.

Aside from the political factors that relate to OPEC countries or their neighbors, there is the broader political scene involving relations between consumer and producer governments. Coordination of consumer country policies through such institutions as the International Energy Agency (IEA), founded in 1974, and negotiations between producers and consumers in such settings as the Conference on International Economic Cooperation (1975-77) are intended, among other things, to affect by political means the international economics of petroleum and may indeed do so in the future.

Finally, a variety of political factors influence the availability of oil exports from countries that are not, or not currently, members of OPEC, such as Britain, Norway, and Canada among the northern industrial countries; Oman, Mexico, Angola, Malaysia, and others among the developing countries; and the Soviet Union and China among Communist nations.

This appendix will therefore consider the following topics: Cohesion and Conflict Within OPEC; Internal Stability and Instability of OPEC Countries; Regional Conflicts; Possibility of a New Embargo; The Saudi Regime and Its Future Options; Policies of Non-OPEC Exporters and of Consumer Countries; and The Role of the Sino-Soviet Bloc.

COHESION AND CONFLICT WITHIN OPEC

All thirteen members of OPEC are considered developing countries. Their economies, aside from the petroleum sector, are by and large pre-industrial and underdeveloped. All thirteen members have a colonial or quasi-colonial past, Venezuela and Ecuador having attained independence in the early 19th century, and nine other members having proceeded from colonial, mandate, or protectorate status in the period between 1945 and 1961. Saudi Arabia and Iran, though technically always independent, were, in effect, under American and British hegemony, respectively, until the 1950's. This common heritage, which also includes resentment of having local oil resources developed by foreign Western companies for their own benefit and that of their customers, has been an important political factor in OPEC's cohesion as a cartel. It is no coincidence that no serious thought has been given, on either side, to extending OPEC membership to capitalist-developed or Communist oil exporting countries. But let us add at once that, given this solid "Third World" (and hence latently anti-Western or South vs. North) ideological base of OPEC, its precise membership has been of little economic consequence. Its control of the world export market has guaranteed OPEC the position of price leader. All significant non-OPEC exporters -- Canada, Norway, the U.K., Oman, Mexico, Malaysia and others -- have pegged their export prices at OPEC levels. The Soviet Union has raised the price of its exports to other Communist countries toward that level, and even domestic American producers have moved toward that same level as far as government regulations allow.

There is a lingering anti-Western animus continuing to find expression in the political rhetoric that emanates from such capitals as Tehran, Algiers, Tripoli and Riyadh; in support by OPEC countries of resolutions in favor of a "New International Economic Order" in the UN General Assembly or at UN Conference on Trade and Development (UNCTAD)meetings; and in efforts (not always successful) to shape a common front of oil-producing and non-oil producing developing countries within the Conference on International Economic Cooperation.

Beneath this common ideological surface, there is little political cohesion within OPEC. Rather, OPEC's cohesion has been mainly economic, based on the prospect of common gain (currently exceeding $100 billion a year) from maintaining the cartel and fear of a corresponding loss in case of its dissolution. All significant contacts between and among OPEC members in different geographical regions are only oil-related. Even among OPEC members in the same world region, political

tensions are rife. Iran and Saudi Arabia are vying for regional predominance in the Persian (or as the Saudis would insist, the "Arab") Gulf and have been engaged in a lively arms race. Iran and Iraq have been at odds in a protracted territorial dispute at the Shatt al-Arab, and Iran for years supported the Kurdish insurgent movement in Iraq. (Note however, that both of these conflicts were settled following the OPEC heads-of-state meeting at Algiers in 1975.) Iran also has continued to supply oil to Israel throughout all of the recent Arab-Israeli wars. Among the Arab OPEC members there is intense animosity between the radical regimes in Libya, Iraq, and Algeria, on the one hand, and the conservative monarchies in Saudi Arabia and the United Arab Emirates on the other. Even on the common Arab-Israeli issue there is a sharp cleavage between the first three (as members of the so-called "rejection front") and Saudi Arabia (as acknowledged leader, along with Egypt, of the more moderate forces).

However, in raising petroleum prices first slowly and then rapidly in 1971-74, conservative monarchs in Iran and Saudi Arabia cooperated with radical military rulers in Algeria, Iraq, and Libya, and democratic governments in Venezuela -- and the resulting price structure has been emulated by democratic and Communist exporters outside OPEC. Economic opportunities, and not politics, thus have determined the price strategy for OPEC and other producers.

Those alignments and divisions among OPEC producers that have been of relevance to the price and availability of petroleum (aside from the Arab embargo of 1973-74) have also been primarily economic. The major division, as has often been noted, is between the "high absorbers" -- those countries which have relatively low per capita incomes from petroleum, dispose of a number of additional assets for economic development, and hence are eager for additional income from petroleum--and the "low absorbers"--those countries with small populations, few if any assets other than petroleum, and large foreign exchange reserves, which are more interested in preserving the value of their existing foreign assets than adding to their accumulations. Since "high absorbers", such as Iran, Indonesia, Algeria, Venezuela and Nigeria, are already producing near their respective capacities, they have naturally been eager to raise prices. Conversely the "low absorbers" have had considerable spare capacity and have favored more modest price increases. The Saudis, in particular, holding the world's highest accumulation of foreign reserves and adding annually to their foreign exchange surpluses, have no interest in endangering the health of the world economy on which the value of their accumulated assets depends. Hence the policy they have favored since 1974 has been one of keeping prices steady

in real terms, or letting them decline slightly (also in real terms) at times of global recession.

These policy differences between high and low absorbers have been reflected in the periodic price discussions at OPEC's semi-annual meetings. The only political variations on this basic economic theme have been the attitudes of Libya and Kuwait, which, although among the low absorbers, have generally sided with those in favor of more rapid price increases -- Libya out of a generalized "radical", anti-Western attitude, and Kuwait because its large Palestinian population makes compromises in this direction seem opportune. In December 1976, the differences between price hawks favoring a 10 percent increase and price doves unwilling to go beyond 5 percent remained unreconciled. The resulting dual price structure for the first half of 1977 meant a considerable shift in sales from the first to the second group, especially in the Persian Gulf. If production and revenue figures for the first half of 1977 are compared with those for the second half of 1976, it turns out that Saudi Arabia increased production by 4 percent for a revenue increase of 6 percent, whereas Iran and Kuwait lost 11 percent and 27 percent in production for revenue losses of 5 percent and 22 percent respectively. The major lesson of the dual-price interlude once again was economic: the inability of non-Saudi producers, in view of the large Saudi spare productive capacity, to make a profit on prices above those favored by the Saudis. In short, the dual price episode proved not the political fragility but the economic durability of the cartel. From the point of view of the self-interest of each of its members, if the OPEC cartel did not exist it would have to be invented, or reinvented.

If in the last two decades of this century economic factors should threaten the cohesion of the price cartel, political tensions may serve as an excuse for, or as a precipitant of, intra-OPEC economic warfare. But as long as very sizable economic gains stand to be made from preserving the cartel, the cartel is likely to survive or at least to be rebuilt quickly after any brief interlude of price warfare.

INTERNAL STABILITY AND INSTABILITY OF OPEC COUNTRIES

There have been many instances of internal political instability and upheaval in various OPEC countries, including the overthrow of the Shah of Iran and his restoration by the Zahedi coup (1953), the Nigerian civil war of the mid-1960's, the extremely bloody revolution in Indonesia which replaced the left-wing Sukarno

regime with a right-wing military regime under General Suharto (1965), a series of military coups in Iraq since 1958, an intermittent insurgency of Kurdish tribesmen in northern Iraq, the military coup in Libya (1969) which replaced King Idris with Colonel Qaddafi, the assassination of King Faisal of Saudi Arabia (1975), recurrent coups d'etat in Ecuador, and instances of Castro-ite urban terrorism in Venezuela. It is not unlikely that the 1980's and 1990's will continue to bring such instances of political turmoil, including conceivably the overthrow of some of the present conservative monarchies, or the replacement of one of the current military juntas by another. In making such an assessment, however, it should be recalled that such instances of violent overthrow of regimes have been less frequent in the 1970's than they were in the 1950's and 1960's, one reason presumably being the monies that oil-rich governments are able to spend on enlarging, equipping, and training internal security forces, and on providing employment opportunities for potentially dissident members of their elite -- in short, on satisfying many of the immediate aspirations of alternative elites.

It is remarkable that relatively few of the upheavals just listed have had any direct impact on the production of oil or on the oil policies adopted by successive governments. The Mossadegh-Zahedi crisis in Iran in 1953, though directly related to oil, is too remote in history -- the political economy of oil having changed thoroughly in the meantime -- to hold any useful analogies for the future. Among the other events mentioned, the civil war in Nigeria significantly delayed and curtailed oil production in 1967 and 1968; and the Qaddafi coup of 1969 brought as its sequel a much more aggressive policy by Libya toward the international oil companies, which indeed became a crucial factor in launching OPEC on its meteoric rise.

But the events in Libya are of somewhat limited value as a portent for the future, because they acted mainly as a political catalyst to make Libya and other OPEC countries fully aware of the bargaining advantages implicit in their economic situation. It can be argued persuasively that since 1974 the OPEC countries have already taken the fullest advantage of their bargaining position, that they will continue to do so in the future under "conservative" as well as "radical" regimes and that therefore the potential gains from future shifts to "radicalism" are strictly limited.

A closer examination of the Libyan situation in 1970, moreover, reveals the intense interplay between economic and political factors even at that time. Libya's proximity to the prime European market and the low sulfur content of its oil at a

time of tightening environmental regulations in consumer countries, put its oil at a premium against that of other exporters. The closing of Suez in 1967 added greatly to the transport premium. The result was that Quaddafi inherited from the preceding monarchy foreign exchange reserves equivalent to three years' worth of Libyan imports that enabled him to threaten credibly a shutdown of his country's oil industry in case the companies failed to meet his demands. Also from the monarchy Qaddafi inherited a situation where a single government dealt with as many as a score of foreign companies, some of them with no other crude oil sources except Libya. Whereas the monarchy had used this bargaining advantage to increase production, Qaddafi used it as a tactic to raise prices. The shutdown of the TAPLINE in the summer of 1970 and the resulting all-time record in tanker rates was a bargaining windfall that would have strengthened the hand of any Libyan government. In short, we see that many of the elements that made possible Qaddafi's victory were outside his immediate control, and several were inherited from the conservative regime. What Qaddafi brought to the negotiations was a novel, aggressive style and a political determination to exploit his opportunities to the hilt.

In sum, it seems likely that for the remainder of this century political factors will provide only a minor variation on basic economic factors determining intra-OPEC relations and OPEC's price and production policies. Perhaps the overthrow of one or another of the current OPEC regimes might make its successor take a somewhat more aggressive tone in dealing with other OPEC countries, or with the consuming countries. Yet it is very much an open question whether such greater assertiveness would take the form of price increases above the prevailing OPEC level (as recurrently in Libya) or of hidden discounts below that level (as recently in Iraq).

REGIONAL CONFLICTS

All the developing countries from which oil is exported are in areas marked by recurrent and protracted regional conflict. One such conflict, that between Arabs and Israelis, has had a crucial effect on the price and availability of oil via the embargo and price rises of 1973-74. The next section will deal specifically with the possibility of recurrence of an embargo scenario. At this point we should keep in mind that the embargo was not so much part of a purely Middle Eastern intraregional conflict as it was of an Arab-American interregional conflict. The question that primarily concerns us in the present section is how likely intraregional conflicts in the Middle East and other oil exporting regions

(such as South Asia and the Caribbean) will be in the next two decades, and how likely such conflicts are to have repercussions on the availability and price of oil to the outside consumers.

There have been four rounds of open warfare between Arabs and Israelis (1948, 1956, 1967, and 1973); from each round of fighting to the next, Arab countries have acted with increasing solidarity. Each led to some disruption of oil trade: the 1948 war led to the permanent closing of the Iraq Petroleum Company's pipeline to Haifa, the 1956 conflict interrupted passage through the Suez Canal, the major oil route from the Middle East westward at the time, and from the 1967 war until 1975 the Suez route again remained closed. The 1973 war, of course, resulted in the largest interruption of all, the Arab oil embargo. Another notable feature of the Arab-Israeli conflict has been the growing involvement of major outside powers, notably the Soviet Union and the United States, as arms suppliers, as diplomatic participants during each round of war, and as would-be peacemakers or mediators afterward.

There is much additional potential for regional conflict within the Middle East and North Africa. The recurrent dispute between Iran and Iraq and the regional arms race between Iran and Saudi Arabia have already been referred to. Iran also has provided military support for the Sultan of Oman against Communist-supported insurgents in the Southern Omani province of Dhofar -- an operation which, initially at least, was viewed with some apprehension from Riyadh. There have also been tensions between Saudi Arabia and South Yemen, recurrent bitter disputes between Iraq and Syria; Libyan-inspired attempts at subversion in Egypt, Sudan, and Tunisia, and reciprocal Egyptian-supported plans for subversion in Libya; intermittent border warfare between Algeria and Morocco in the former Spanish Sahara; and territorial claims (now dormant for some years) of Iran against Iraq and Bahrain, of Iraq against Kuwait, and among other neighboring states.

Such tensions and disputes having been endemic in the Middle East and North Africa since their transition to independence, it can be predicted with some confidence that these or similar conflicts will recur between now and the end of the century. It is more difficult to predict what their impact on oil supplies from the region will be. On the past record transportation routes have clearly been the most vulnerable. But there are always alternative transportation routes: after 1948, the Iraqi pipeline to Lebanon and a new one to Syria were beginning to handle the full flow from northern Iraq. Upon the recent suspension of the flow from Iraq through Syria, Iraq developed two alternative pipeline routes, one to its

own Persian Gulf coast, and the other via Turkey to the Mediterranean. Similarly, the massive flow of oil that used to go by conventional tanker through the Suez Canal before 1967 was soon handled by supertankers plying the route around the Cape of Good Hope from the Persian Gulf. The world tanker fleet today would be able to handle substantially larger volumes than the present demand for oil, and any foreseeable increase in that demand is not likely to catch up with the aggregate capacity of tankers now afloat, in storage,or on order before the mid or late 1980's.

Regional military conflicts in the Middle East have had even less effect in the past on oil supplies than have interruptions of transport. Military operations on the Sinai and along the Suez Canal temporarily suspended production of Egyptian fields on either side of the Suez Canal. But for most of the period from 1967 to 1975, a tacit understanding between Israelis and Egyptians allowed continued operations of fields or refineries on both sides-- even though (or precisely because) both sets of fields were within easy artillery range of the hostile military forces. Whatever the cause of conflict and the relative strength of forces, the revenues from oil production would be one of the very major prizes which neither side, in struggling for its possession, would want to negate.

To refer to a variant scenario sometimes considered in the international relations literature: mining of the Strait of Hormuz would be militarily feasible, and would suspend the flow of more than half of the oil in the international market; but it would interrupt equally the flow from each one of the seven Persian Gulf producers so that none would be interested in a blockage. On the other hand, the nature of such a mining operation is too complex to be carried out by saboteurs against the wishes of regular naval forces.

The scenario changes if one imagines one or the other superpower becoming directly drawn into a military conflict in the Persian Gulf region. In such a situation, destruction of oil fields or terminal facilities, or mining of the Strait of Hormuz might readily occur as a result of the military action itself or of sabotage by defending forces. But it is hard to conceive involvement by one superpower that would not provoke similar involvement by the other, and in a full-fledged U.S.-Soviet conflict, the oil fields of the Persian Gulf and oil transport routes on all of the world's high seas would in any event be among the most vulnerable targets.

Regional conflicts of a similar nature to those in the Middle East are readily conceivable in other regions where oil is produced and past which oil is transported. Most Southeast Asian countries have been embroiled in periodic conflicts with their neighbors--Thailand-Malaysia, Thailand-Cambodia, Cambodia-Vietnam, etc. The Horn of Africa (Ethiopia-Somalia) and Southern Africa (Angola, Rhodesia, South Africa) will continue to be centers of regional or internal-racial conflict as well as targets for Soviet penetration. Of course, most of the oil in global trade is transported in tankers not far from the coasts of Somalia, Mozambique, South Africa, and Angola. The Caribbean has long been a region of instability, and various scenarios of internal coups or regional conflict could plausibly be developed. Yet as noted before, oil production might continue in a civil war (as in Iraq or Angola) or across the cease-fire lines (as at Suez). Even a total shutdown in one of the smaller OPEC members could probably be compensated for by increased output elsewhere. (Algeria produces only 3 percent, and Qatar, Ecuador, and Gabon each less than 1 percent, of OPEC's total.) Local overland transport routes, if blocked, can be readily bypassed. And a disruption of global tanker routes on the seas would be likely only as a prelude or accompaniment to a global war between the Soviet Union and the United States, and thus falls outside the scenarios considered within this study.

POSSIBILITY OF A NEW EMBARGO

As pointed out, all previous Arab-Israeli military conflicts have affected the flow of Arab oil, although the effect and type of interruption varied from case to case.

It is generally assumed that oil could not escape direct involvement in any future round of war between these two antagonists. Certainly, this is the official and unofficial view of the U.S. government, and the governments of most other oil importing countries.

For policy purposes this is probably a good assumption. But the connection between a future Arab-Israeli conflict and another Arab oil embargo is not as automatic as is often assumed. This is not to deny the potentially formidable impact of the Arab oil weapon. But whether it will actually be mobilized in full force may depend largely on the specific circumstances surrounding the outbreak of a renewed conflict and on the attitude of the major importing countries, particularly the U.S., towards the conflict.

For instance, if the war resulted from a preemptive strike by Israel into Arab territory, the U.S. and other major importers might well adopt a critical attitude towards Israel and would send it no war materiel, nor would Israel be likely to request it. In such a situation, invocation of the Arab oil weapon could be counter-productive, since it would be likely to change sympathetic, or at least "evenhanded", attitudes towards the Arab position in the U.S. and elsewhere to hostile ones. Particularly, Saudi Arabia, with its growing economic and political ties to the U.S. might be reluctant to join, let alone take the lead, in an embargo under these conditions.

On the other hand, if, as in 1973, the conflict began with an Arab invasion of Israeli controlled territory, and if the U.S. once again extended tangible and intangible support to Israel this could also be expected to trigger the Arab oil weapon again in the form of a selective or general oil export embargo. In a conflict whose immediate cause would lie in a grey area between the two cases described, the use of the Arab oil weapon might depend on Arab perceptions of U.S. "even-handedness" during the conflict.

The effectiveness of the Arab oil weapon, if and when used, depends of course on the size and duration of the export reduction. Potentially, it could be far more serious than last time for two reasons: 1) world dependence on Arab oil has increased substantially in the last several years--in the U.S. for instance, Arab oil imports have more than tripled between 1973 and 1977 to 3.2 MM B/D -- and will continue to rise in the 1980's; and 2) the major Arab oil producing countries-- Saudi Arabia, Kuwait, U.A.E. and Libya--are far richer today, i.e., have more foreign exchange reserves, than in 1973 and could therefore sustain the economic impact of an export reduction much longer than last time.

In recognition of this threat most major importing countries have joined together in an emergency oil sharing program under the auspices of the IEA and are also increasing their non-commercial oil stocks. If a future embargo does not extend significantly beyond the duration of the actual armed conflict, its impact could probably be absorbed by the importing countries,judging from the duration of the previous conflicts. On the other hand, if the full force of the Arab oil weapon is brought to bear for an extended period of time, its impact on the industrial countries of the world could be very serious during the next 15 to 20 years. However, in such an eventuality other considerations would also come into play

such as retaliatory actions on the part of the importing countries, as broadly hinted by former Secretary of State Henry Kissinger in his veiled threat of the use of force in case of "actual strangulation" of the West.

In summary, the threat of an effective extended Arab oil embargo is real but limited. It is quite unlikely in the absence of an actual armed Arab-Israeli conflict; it is likely but by no means certain in case of such a conflict; and it would probably have to be maintained well beyond the duration of the conflict to cause major damage.

THE SAUDI REGIME AND ITS FUTURE OPTIONS

Because of Saudi Arabia's crucial position as the residual producer -- and therefore, price setter -- within OPEC, the internal situation in that country deserves somewhat closer examination. The assassination of King Faisal and the smooth succession to King Khalid as nominal and Prince Fahd as de facto ruler would seem to be an indication of the basic stability of the present monarchy. As a result of the massive inflow of oil monies since the early 1970's, Saudi Arabia has been undergoing its most rapid phase of economic and social development. Social services are being expanded, education is being brought to new groups of the population (including, for the first time, women), and the once traditional autocracy is beginning to be transformed into a technocratic bureaucracy. The continuation of Sheikh Ahmad Zaki al-Yamani in his post as Petroleum Minister symbolizes the stability of Saudi oil policies throughout this period of transformation. These policies may be described as 1) keeping the price of oil relatively stable at the levels they reached by mid-1974, keeping up with inflation in times of world prosperity and lagging slightly in times of world recession; 2) being willing to act as OPEC's residual supplier; 3) keeping the enormous Saudi foreign exchange reserves invested on a widely diversified pattern in the United States, the Eurodollar market, and elsewhere; 4) using some of the Saudi oil income for subsidies to Egypt, Syria, Sudan, Jordan and some other Arab countries so as to reinforce their relatively moderate position in regional politics and to prevent spread of Soviet influence to the Arabian peninsula and reverse it in Northeast Africa; 5) attempting to use Saudi Arabia's oil influence (as in the embargo of 1973-74) to persuade the United States to follow an "evenhanded" course as between Arabs and Israelis and to speed a peace settlement acceptable to moderate Arabs.

Saudi Arabia's ability to impose its price preference on other OPEC members depends on its surplus productive capacity, which in turn depends on its financial surplus.

As the largest holder of foreign exchange accumulations in the world, and with a consistent current account surplus, Saudi Arabia can allow its production to remain considerably below the capacity of its fields. Saudi reserve production capacity, in turn, is a double-edged weapon in potential price fights within OPEC. When others increase prices beyond the level approved by the Saudis, as in early 1977, the Saudis can step up production, draw away the customers from others, and thus convert price increases into a net financial loss. If others should cut prices in hopes of increasing their market share (that is, start the kind of internal price war that has broken many past cartels in commodities other than oil), the Saudis can cut prices while increasing both production and revenues longer than any one else.

The same Saudi influence extends, of course, far beyond OPEC itself. Saudi Arabia accounts for about 30 percent of OPEC's output; OPEC supplies about one-half of all oil consumed globally, which in turn amounts to just under one-half of the world's primary energy consumption. Yet the 7 percent Saudi share in global energy production placed the country in the position of price setter for all petroleum -- and to some extent for all energy -- much as a 7 percent shareholding might secure working control of a diffusely owned industrial corporation.

This key role within OPEC and within the global energy market along with their enormous financial holdings, has been the Saudis' major political asset. In recent years, it has enabled them to rely on far subtler diplomatic techniques than the "oil weapon" of embargo and cutback that propelled them into this power position. When Saudi minister Yamani in December 1976 opted for a 5 percent price increase against the 10 percent advocated by others, he expressed the hope that the United States would show its "appreciation" for such price moderation -- presumably by bringing Israel to the conference table, Similarly, early in 1978 there were hints that U.S. failure to supply Saudi Arabia with the advanced military aircraft it was seeking might result in Saudi Arabia going along with the price hawks at future OPEC meetings.

Saudi Arabia's ability to put pressure on the United States (and incidentally other Western countries) by its decision on oil price and production and on the disposal of its oil investments will increase sharply whenever the world's demand for oil imports will have caught up with available supplies from other exporters, so that future increases in supply depend solely on Saudi production decisions.*

* For a scenario that foresees that contingency by the mid-1980's see D.A. Rustow, "U.S. Saudi Relations and the Oil Crises of the 1980's", Foreign Affairs, April 1977.

The question then will be no longer whether the Saudis will take special measures to inflict damage on the United States, such as an embargo and cutback, but whether they will take special measures to prevent damage that otherwise will inevitably come to the U.S. -- and indirectly the world -- economy.

It should be emphasized that this question arises basically as an economic contingency -- that of world demand for oil imports at current real prices sharply exceeding available exports -- and that, according to other parts of this report, such a contingency is the least likely of several distinct scenarios for the 1980's and 1990's. If, however, such an acute economic shortage did set in, the same political options of raising either production or price would be available to both a conservative regime of the present type and to a possible "radical" regime that might succed it. Once again, as emphasized in similar contexts before, a more "radical" regime would not create a new economic situation; rather it might be inclined to exploit more aggressively (that is, with less consideration to the consumers in Western countries) the economic opportunities inherent in the situation. However, under certain circumstances, a "conservative" regime in Saudi Arabia that found itself dissatisfied with progress toward an Arab-Israeli settlement acceptable to it, or with American policy toward the continuing conflict, might do the same.

POLICIES OF NON-OPEC EXPORTERS AND OF CONSUMER COUNTRIES

Compared to Saudi Arabia and other OPEC producers, the countries to be considered in this final section are likely to play a far lesser political role in influencing the availability and price of petroleum for the remainder of this century.

There already are some sizable non-OPEC exporters of oil, including Mexico, Malaysia, Oman, Norway, Trinidad, Egypt and Angola. Others are sure to be added to this list as petroleum prices remain high and exploration proceeds with a view to multiplying and diversifying sources of supply. Yet the existence and future likely appearance of such non-OPEC exporters adds little to the foregoing economic-political analysis. All of the exporters just mentioned have sold, and will continue to sell, their product at the "world price" as set by OPEC with due allowance for differences in gravity, sulfur content, and proximity to major markets. While this price remains high, all of them have a powerful incentive to encourage exploration and expand production. Political factors will be quite irrelevant to these basic price and production decisions -- that is to say, democracies, communist regimes, military

distatorships, and others have equally potent incentives for producing and exporting as much oil as they can and for selling it at whatever price the international traffic will bear.

The incentive for adding to the amount of global production and to the number of producers is economic; the possibilities of doing so are determined above all by technical, geological factors. The largest of the non-OPEC oil exporters currently account for no more than 1 percent of global oil trade each, and there is little chance that they will approach the size of exports of the 3 or 4 largest OPEC producers. And the fact that more producers are likely to put more oil on the world market is itself an added guarantee against political problems in any one of the newer producing countries having any decisive impact on the global oil market.

The policies of major oil-importing countries obviously have a considerable effect on price and availability of oil on the world market. To mention just three examples, the protectionist oil import quota program in the United States between 1959 and 1973 increased the pressure on international oil companies to sell Middle Eastern oil in Western Europe and Japan; traditionally high gasoline taxes in Europe have had a profound effect on the volume and type of refined products consumption in Europe; and according to recent OECD estimates, "accelerated policies" for conserving energy consumption and stimulating production of energy alternatives in its member countries might reduce their oil import needs by as much as 30 percent below levels that would otherwise obtain in 1985.

Other policies have been proposed for both the United States and other industrial countries in the OECD that would be aimed not at preventing a future shortage that would enhance the power of the OPEC cartel, but at breaking the cartel's existing power. Among these are proposals to secretly auction import tickets for the United States, and the proposal to break up the vertical integration of the international oil companies through enforced divestiture. Such measures, it would seem, would be at best ineffectual and at worst counterproductive. It is difficult to conceive of OPEC countries, which have maintained their economic cohesion despite bitter political differences, turning over their marketing to anonymous agents just so as to enable their largest customer to break up their cartel.

The vertical divestiture proposal overlooks the fact that OPEC's control of the market rests on control not of downstream operations but of prices at the upstream end. And such control would, of course, be unaffected by any rearrangements at the downstream end.

It should be emphasized that "accelerated policies" such as envisaged by OECD, are designed to prevent a supply and price crisis in the mid or late 1980's, not to break uo the present structure of OPEC. Even with its exports reduced to about 10 percent below current levels, OPEC as a whole would still run a foreign payments surplus, and those members that ran a payments deficit could readily balance their budgets by using up accumulated reserves, or by borrowing from other OPEC members or elsewhere in the financial markets, or by scaling down some of their development projects--or indeed by raising the price of oil.

For the United States the possibilities for conservation and alternative energy development are greater than for any other major industrial country. The legislative fate of President Carter's energy program of 1977 however, does not make it seem likely that very dramatic measures will be taken. And note that the import level in the United States in 1985 projected by Carter was 6 MM B/D, and as envisaged in the OECD's accelerated policy case 4.3 MM B/D -- enough to alleviate our payments burden and to restore greater independence to our foreign policy, but not enough to make us self-sufficient in energy, to uncouple our domestic price from the international price of oil, or to threaten the viability of the OPEC cartel.

THE ROLE OF THE SINO-SOVIET BLOC

Among Communist countries, Russia has for some time been an oil exporter, and China is becoming one. But oil consumption in the Soviet Union is increasing steadily, and some estimates are that the Soviet surplus will barely be enough to supply the needs of other Bloc (COMECON) countries by the early 1980's, and that the COMECON area as a whole will be in balance by the mid-1980's. (See the discussion in Chapter 5 of this report). China's domestic needs for oil also are rising with growing industrialization, but need for foreign exchange provides a potent motive for oil export. Again, according to informed estimates, China is likely to remain a modest net exporter. Here, too, the quantities are not likely to be large enough substantially to affect the global picture of price or availability.

The Soviet Union's quiet but very active policy in various Third World regions may, however, become a political factor to be reckoned with. The Soviet Union's drive for an active or even dominant role in the Middle East since the mid-1950's has gone through many advances and setbacks. Its most notable net contribution

probably has been to speed the drive of the region toward full independence in the late 1950's and 1960's, and the aggressive price policy of OPEC may thus be seen as a partial consequence. Relations remain closest with Iraq. Egypt and Syria, although their relations with the Soviets have notably cooled since the early 1970's, remain equipped with Soviet weapons. There is strong Soviet influence in South Yemen and the Horn of Africa, and recently closer relations have been initiated with Libya. The most active recent drives have been in Southern and Eastern Africa, and Cuba has played a major role in this effort. The close political cooperation between Havana and Moscow again raises at least the possibility of a new Soviet bid for influence, at some opportune point in the future, in the Caribbean and parts of Latin America.

The question relevant in the present context is how such growing Soviet influence would affect the international oil picture -- and the most plausible answer, for the time being, would seem to be: very little. Iraq's experience since the 1960's shows that the Soviets do not possess the advanced technology to help substantially in the development of oil resources in the developing world; nor have Iraq's close political ties with the Soviets in any way reduced the volume of its exports to the West. Pro-Soviet takeovers, that is to say, are unlikely to change the direction of petroleum trade that would otherwise prevail. Pro-Communist governments must manage the same oil reserves as the preceding conservative regimes and sell the product on the same global market. This of course in no way denies the strategic and financial gain that the Soviets would derive from such a takeover (especially of a country like Iran) but to reap the financial gain the country in question would have to continue exporting to capitalist hard-currency countries.

As far as price is concerned, on the other hand, strongly conservative or even fiercely anti-Soviet regimes such as Iran or Venezuela have been just as militant in driving up the price of petroleum as have more radical or pro-Soviet regimes in Iraq or Libya.

The most serious danger, presumably, would be a possible Communist take-over in Iran. Once again, the danger would not be a diversion to the Soviet Union of oil supplies that would otherwise have gone to the West. Rather, the danger would be that of permanent entrenchment of Soviet power near the world's major sources of petroleum on the Persian Gulf. In such a situation, disruption of Middle Eastern oil exports through closure of the Strait of Hormuz would become a readily

available alternative. Here again, the same comments apply that were previously made with regard to possible Soviet disruption of the oil tanker routes around Africa: such interference with the West's energy supply is imaginable only as a prelude or sideplay of a full-scale great power conflict in which far more would be at stake than the price and availability of oil.

SUMMARY

Economic factors are likely to remain the crucial determinants of the price and availability of oil for the remainder of this century. The political factors that played such a prominent role in the petroleum crisis of 1973-74 are likely to have less of an effect in the future--not because of any absence of political instabilities, struggles, or complications, but rather because the political will to exploit economic opportunities already is there and because any new infusions of political will cannot of themselves transform the economic realities.

More specifically, this appendix has suggested that the Middle East and other developing regions that supply over 90 percent of global oil exports will be politically as unstable -- or nearly so -- in the next quarter century as in the last. Yet coups, civil or regional wars, and the advent of radical juntas have had little effect on utilization of productive capacity and prices. The crucial determinants are technical and economic: in the future as in the past, and under juntas as under monarchs, countries will export to Western markets to earn hard currencies, and seek to increase their earnings by raising prices or output if they have large populations and hence a high "absorptive capacity" for funds.

Actions by the superpowers that would halt the flow of Middle East oil are conceivable (e.g., a Russian blockade of the Persian Gulf or a U.S. invasion of some of its shore), but only as prelude to, or part of, a global armed conflict, a scenario beyond the scope of this report.

In sum, with the possible exception of another embargo, technical and economic factors (oil discoveries and conservation, development of other fuels, economic growth, the financial needs of producing and the financial abilities of exporting countries, etc.) rather than political factors are likely to remain the major determinants of the availability and price of oil on global markets.