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DEPARTMENT OF ECONOMICS
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ENERGY ENVIRONMENT STUDY

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Raymond Strangways, Principal Investigator

and

Usman Qureshi

Final Report
For the period May 16, 1980 - March 15, 1981

Prepared for the
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

Under
Research Grant NAG1-66
B.G. Batten, Technical Monitor
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FOREWORD

The energy environment today and a view of what is likely to be the environment in the mid eighties and nineties is most important to timely policy development and wise R&D activities. Just as the United States was not prepared for the sharp reduction in energy supply and increase in cost occurring in 1973, it may find that it is ill prepared for the 1990's. In order to understand what may be the long-range energy environment, it is necessary to assess how the 1980's may differ from the 1970's as to energy supply pressures and yet how the 1990's might once again bring an increase in energy problems, but with reduced energy substitution and conservation options. The energy trend for the future is a very comprehensive question and many studies have been conducted to provide guidance. Thus, it was the purpose of this study team to expose for consideration possibly important differences in parameters to be faced in the 1990's vs. the 1980's vs. the 1970's. Such differences and their associated energy environments may provide road signs for a wise energy policy and supportive technology development. Therefore, the reader should review this document with an understanding that it was the study team's purpose to provide thoughtful speculation with supportive logic to expose important considerations for long-range planning rather than limiting speculations to minor extrapolation of historical data. We encourage readers to analyze the overall assumptions and rationale and relate the reported findings to long-range R&D concerns.

Bobby G. Batten
NASA Study Manager

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We also acknowledge a debt of gratitude to Mr. Donald Maiden, EET Program Manager, NASA Headquarters, who conceived the need for this study and encouraged us to undertake it.

The responsibility for errors and omissions solely rests with the authors.

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ENERGY ENVIRONMENT STUDY

By

Raymond Strangways[1] and Usman Qureshi[2]

EXECUTIVE SUMMARY

Introduction

This report provides a comprehensive assessment of the international demand for and supply of oil between the years 1980 and 2000. It also includes estimates of future world oil prices and their implications the price of jet fuel. Specifically, three critical ques-tions are investigated: (1) How long will the world supply of oil continue to keep pace with its demand under likely trends in its use and discovery? (2) At what price will demand and supply clear the world oil market? (3) What does the analysis imply about the price of jet fuel? Previous energy studies have projected supply and demand based upon an arbitrarily assumed price of oil. The present study follows the reverse procedure, which is more consistent with microeconomic analysis, provides a more logical and fruitful approach to answer the questions raised above. First, we project the demand for and supply of oil. Second, we put the two together to draw price implications for crude oil. Finally, we examine implications for the price of jet fuel.

On the demand side, two principal factors affecting the world demand for oil over the next two decades are identified: these are (1) GNP growth rates and (2) petroleum conservation and conversion measures. On the supply side, six principal factors are isolated as being crucial for projecting the world supply of oil: (1) the magnitude of proven reserves, (2) net additions to proven reserves, (3) the minimum ratio of reserves to production, (4) rate of oil production that

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exporting countries permit, (5) net imports from the communist countries, and (6) synthetic fuel production. For each of these eight factors affecting world supply and demand, three projections consisting of low, medium, and high values are presented. The three demand projections could be combined with the three supply projections to construct a total of nine supply-demand scenarios for projecting petroleum prices. Of these, only three scenarios are examined for price implications. The first scenario is the combination of the medium demand and medium supply to obtain a midlevel scenario. This is the scenario which the authors judge most likely to occur. The second scenario combines low demand and low supply to provide a low-level scenario, and the third joins high demand and high supply to obtain a high-level scenario. The second and third scenarios are judged possible, but considerably less likely. The three scenarios are then analyzed and the price of petroleum is projected for 1990 and 2000 for each scenario. Finally, the relationship between the price of petroleum and the price of jet fuel in the United States is examined, and jet fuel prices are projected for 1990 and 2000 for each scenario.

Petroleum Demand

One of the major determinants of the world demand for oil is GNP growth rate. The reason is that petroleum is an input into the production of goods and services along with labor, capital, and other resources. An increase in output produced requires an increase in all inputs including petroleum. Thus growth in the demand for petroleum depends on the growth of GNP. To estimate growth in the demand for oil, economic growth rates are projected for medium, high, and low demand scenarios for the decades of the eighties and the nineties.

For WOCA (World Outside Communist Areas) an average annual GNP growth rate of four percent is projected for the medium-demand scenario which we judge most likely to occur. Average annual GNP growth rates of five and three percent are projected for the high and low scenarios, respectively. For areas included in WOCA, average annual GNP growth rates vary from 2 percent for the low scenario for the United States to 6.5 percent for the high scenario for Japan, and 4.8 percent for the medium scenario for Canada. These rates are then used as an input to project the demand for petroleum in WOCA for 1990 and 2000 for each scenario.

The other major factor impacting the world demand for petroleum is the level of conservation in the use of oil and the rate of conversion to other sources of energy. OPEC prices quadrupled between 1973 and 1974 and have more than doubled since 1976. These price increases, as well as regulations by national governments aimed at reducing oil consumption, account for most of the conservation and conversion efforts in WOCA.

In the residential/commercial sector, substantial savings in the use of fuel oil are being realized by increased insulation, improved building designs, and efficiency in the use of oil for space heat. It is estimated that these conservation measures will enhance fuel efficiency by as much as 40 percent by the year 2000 in WOCA. Since 1979 there has been an increasing trend toward conversion from oil heat to natural gas and electricity in the residential/commercial sector in the United States. This trend is apparent in both the steady decline in new homes installing oil heat and the rate at which oil heating systems in existing structures are being converted to natural gas and electricity. We project such a conversion to take place over the next 30 years. The low-conversion scenario (high demand for oil) assumes a straight line depreciation of existing fuel oil furnaces. Other scenarios assume more rapid conversion to other energy sources.

The electric utility sector in the United States and the rest of WOCA is subject to mandatory governmental regulations aimed at converting oil- and gas-fired burners to coal-fired power plants and nuclear generating facilities. In the United States the Power Plant and Industrial Fuel Use Act of 1978 prohibits the use of oil or natural gas in new electric utility generation plants or in new industrial boilers with a fuel heat input rate of 100 million Btu's per hour or greater.

Similar regulations prohibiting the use of oil-fired burners in generating electricity were in effect in WOCA long before their introduction in the United States. The conversion of oil-fired burners to coal-fired plants is projected to take place over the next 20 years under low, medium, and high conversion scenarios. The analysis applies to both the United States and WOCA.

We define the manufacturing sector as consisting of all those industrial activities in which interfuel substitution is readily feasible. In these activities conversion to other fuels is projected to take place over the next 20 years at varying rates, thereby affecting the demand for oil.

The other industrial sector includes those productive activities in which potential for interfuel substitution is limited. Due to the peculiar character of the production processes in agriculture, construction, mining, and chemical feedstocks, which uniquely favor the use of oil, the prospect for interfuel substitution is highly limited. Oil consumption in this sector is directly related to the level of output which, in turn, depends on economic growth rates. Therefore, we have estimated the demand for petroleum in this industrial sector by taking into account the various assumed economic growth rates for WOCA.

The transportation sector in the United States is a major consumer of petroleum and promises great potential for conservation and fuel efficiency improvements. A primary reason for this lies in the mandated fuel economy improvements for domestic automobiles and in the growing emphasis on other modes of transportation, including mass transit. High gasoline prices have induced changes in driving habits and increased demand for new fuel-efficient cars. Conservation in the use of fuel by automobiles is further reinforced by a switch to diesel-powered vehicles which are more efficient than the gasoline-powered automobiles. There is also a growing emphasis on electric and hybrid vehicles in the United States. However, the extent of their market penetration in the near term depends heavily on the rate of battery development and government incentives for commercialization. These developments have been incorporated in demand projections made by several private and government organizations in recent years. One of these, that of the Presidential Study Commission, forms the basis for projecting the transportation demand for petroleum in the U.S. for this study.

In the rest of WOCA, the outlook for petroleum demand in transportation is quite different from that in the United States. Many countries already use mass transit systems and drive smaller fuel efficient automobiles. These countries will not be able to achieve improvements in efficiency comparable to that projected for the United States. Therefore, for the rest of WOCA we project an increase in the demand for petroleum in the transportation sector for 1990 and 2000 in proportion to the economic growth rates for each area and scenario.

Petroleum Supply

Analysis of the factors determining the supply of petroleum begins with proven reserves, which are oil estimated to be economically attractive to produce under current conditions from fields where oil content has been confirmed by drilling and testing. Gross additions to proven reserves result each year from genuine new discoveries, revised estimates of previously discovered fields, and improved recovery techniques. It is not possible to say what proportion of gross additions over the next two decades will come from each of the three sources stated above. Early in the period most will no doubt be from new discoveries and reassessments. As we get closer to the year 2000, relatively more will come from enhanced recovery as the technological problems are gradually overcome. In constructing our supply scenarios, we evolve a rationale assuming gross additions to proven reserves in WOCA of 15 billion barrels per year. The low-supply scenario assumes gross additions of 12 billion, and the high-supply scenario assumes 18 billion barrels annually. In all three scenarios two-thirds of gross additions are assumed to be in the non-OPEC areas and one-third within OPEC.

Over the next 20 years, the limited availability of proven reserves will limit annual production in much of WOCA. The technology of oil extraction is such that it takes an average of 15 years to exploit a newly discovered field, including the time necessary to develop the required infrastructure. Thus, for countries with relatively limited reserves, their annual volume of output may be increased only with an expansion of proven reserves. For countries with vast reserves, as in the Middle East, annual output will probably be determined by economic and political aspects rather than by technical limiations. For all three supply scenarios, we assume that the R/P ratio for the non-OPEC areas of WOCA remains at 15/1.

In seven OPEC countries, Saudi Arabia, Iran, Kuwait, Qatar, the United Arab Emirates, Iraq, and Libya, proven oil reserves are so vast and R/P ratios so high that the availability of reserves does not present a relevant technical limit to oil production at the present time. Although we do not consider the R/P ratio to be the relevant factor constraining total OPEC oil production for the period under consideration, we do believe that OPEC nations will establish production limits below the level that is technically feasible. Several arguments are presented to support this conclusion. First, six OPEC countries, Saudi Arabia, Kuwait, Qater, the United Arab Emirates, Iraq, and Libya, have extensive balance-of-trade surpluses. Despite a substantial increase in imports, their balance-of-trade surplus increased rapidly, and, in the final quarter of 1979, was running at an annual rate of 104.5 billion. This is an excessive amount to be absorbed or to be invested abroad. Political opposition to sizable direct foreign investment and low yields on financial assets make oil in the ground a competitive alternative to expanded production. For our most likely scenario, we project that OPEC nations will limit production to 36 MBOD (million barrels of oil per day).

Soviet oil production is projected to peak in 1985 and decline moderately before stabilizing. Oil consumption will likely follow the economic growth rate. The residual which is available for export will gradually decline and become zerc sometime between 1983 and 1992.

Communist China is not expected to increase oil exports at an extremely rapid rate. Exports will be increased only as needed to provide foreign exchange to support economic growth. Chinese exports will roughly offset the loss of Soviet oil to the free world.

Synfuels are liquids and gases readily substituted for conventional oil and natural gas in most applications. They can be derived from oil shale, coal, heavy oil, tar sands and agricultural products. However, many barriers relating to technology, excessive costs, large investments, and environmental problems must be overcome before synthetic fuels can make a significant contribution to energy supplies. Although there is virtually no synthetic fuel production in the world today, the technological base for such an industry already exists. The world price of crude oil has risen to a level that makes oil shale and tar sands economically attractive and liquification of coal marginal. Production of synthetic liquid fuels by 1990 will be minimal, but may reach a level of 8 MBOD by the year 2000.

Supply-Demand Interaction and Price Projections

The extent to which the OPEC countries are expected to increase the price of petroleum over the coming years depends on the market conditions of demand, non-OPEC supply, and willingness of the OPEC countries to restrict production. Consequently, we bring together the separate demand and supply projections to examine the price implications. We conclude that the price of petroleum will rise during the 1980's, though at a more moderate rate compared to the 1970's.

It is hypothesized that prices of kerosene products will closely follow the price of crude. An econometric model is developed to measure more precisely the relationship between the price of crude and the price of jet fuel. The regression results obtained are statistically significant, and are used to project the price of jet fuel. Price projections for crude oil and jet fuel are shown in tables A and B.

Perhaps the most significant conclusion to be derived from this entire study is that the petroleum market will tighten substantially in the 1990's. This will occur in all three scenarios and in spite of the marked increase in synfuel production that we have projected. The reason for the tighter market is that the process of conservation and conversion will have been substantially completed and into its final stages. At that point the demand for petroleum will be dependent primarily on the level of economic activity. Only a major technological breakthrough such as the complete replacement of the automobile fleet by electric cars could forestall this tightening of the market in the 1990's.

Table A. Crude petroleum real-price projections for 1990 and 2000 (in 1980 dollars per barrel).

	SCENARIO		
YEAR	LOW DEMAND-LOW SUPPLY	MIDLEVEL	HIGH DEMAND-HIGH SUPPLY
980	$ 35	$ 35	$ 35
1990	$ 43	$ 52	$ 63
2000	$ 77	$102	$150[a]

[a] projected price for 1999 immediately preceding a projected shortfall

Table B. Projected price of jet fuel in the United States in 1980 prices (dollars per gallon).

YEAR	SCENARIO: LOW DEMAND-LOW SUPPLY	SCENARIO: MIDLEVEL	SCENARIO: HIGH DEMAND-HIGH SUPPLY
1980	$ 0.92	$ 0.92	$ 0.92
1990	$ 1.11	$ 1.32	$ 1.57
2000	$ 1.89	$ 2.46	$ 3.56[a]

[a]Estimate for 1999 preceding a projected shortfall in 2000.

INTRODUCTION

The production of petroleum in the United States peaked in 1970 and has since declined substantially. The price of a barrel of crude quadrupled between 1973 and 1974, resulting in sharp increases in the Consumer Price Index and the deepest recession in the history of the United States since the 1930's. It is evident that by the 1990's the world's conventional oil resources will be seriously depleted.

The nature of the energy problem is twofold. First, the population of the world has been growing rapidly for the last several centuries, escalating sharply during the twentieth century. Second, the Gross National Products (GNPs) of many nations have been growing steadily. For example, the GNP of the United States has been growing at an average annual rate of slightly over four percent for a century (refs. 1, 2). Analogously, there have been high GNP growth rates for the economies of Western Europe, the Soviet Union, Canada, and Japan. Just as a growing population requires energy to support it, so does growing economic activity. The industrial countries have not abandoned their pursuit of sustained economic growth, nor have the developing countries relinquished their expectations for catching up with rich nations in higher standards of living. However, there are not enough petroleum reserves to sustain indefinitely the production levels of both industrial and developing countries.

Petroleum resources are concentrated in a few nations. Proven U.S. reserves of petroleum peaked at 47 billion barrels in 1970 and then declined to the present level of 28 billion barrels. This occurred in spite of the one-shot addition of 10 billion barrels from Prudhoe Bay, Alaska, in 1970. In the 1950's the U.S. found 1.25 barrels of oil for every barrel extracted from the ground, but by the late 1970's this dropped to about 0.5 barrel. Lately the reserves in the United States have been declining by 1.25 billion barrels a year. Just to maintain the current production would require a discovery rate 50 percent higher than that of the last 10 years.

Recent discoveries in the North Sea have added 25 billion barrels of reserves, but the United Kingdom is expected to be a net importer within a decade. Petroleum resources on the Arabian Peninsula are so plentiful that the cost of producing a barrel is less than two dollars, but even this resource is finite. Furthermore, OPEC countries are expected to maintain ceilings on production and may supply only a small proportion of the total world demand.

The era of cheap and plentiful petroleum is coming to an end and world demand for petroleum will soon be pressing the available supply. We will never again have as much oil or gas as we have today, nor will it be as cheap. The solutions are voluntary conservation and rapid development of alternative sources of energy, especially synthetic fuels.

In this study three critical questions are explored: (1) How long will the production of oil continue to keep pace with demand under likely trends in its use and discovery? (2) At what price will it be available? And (3) what does this analysis imply about the price of jet fuel?

STUDY PLAN

Most energy studies in recent years* have begun by assuming a future world price for petroleum, then proceeded to project supply and demand implied by the assumed price. This procedure is based on the obvious fact that both future demand and supply depend in great measure on the price in the market. However, at this juncture we believe that the reverse procedure is more fruitful. Increases in the price of petroleum in the 1970's, particularly following the near doubling in 1979 to 1980, have set off changes in both demand and supply that are not likely to be reversed under any forseeable price developments. Therefore, in this study we first project demand for petroleum, then the supply of petroleum. We then put the two together to draw price implications for crude oil and, finally, for jet fuel.

Two principal factors are isolated as being particularly crucial for projecting the Free World demand for oil over the next two decades: (1) GNP growth rates and (2) conservation and conversion measures.

Six principal factors are isolated as being particularly crucial for projecting the supply of oil: (1) the magnitude of proven reserves, (2) net additions to proven reserves, (3) the minimum ratio of reserves to production, (4) the rate of oil production that exporting countries permit, (5) net imports from the Communist countries, and (6) synfuel production.

Each of these eight factors is analyzed one at a time. For each one the typical procedure is, first, a theoretical analysis of why and how this factor can be expected to affect either the demand for or supply of petroleum and, second, examination of some historical or empirical data concerning this factor. Third, on the basis of steps (1) and (2) we make specific assumptions regarding quantitative values which this variable may take on over the coming two decades. This step clearly is conjectural and requires considerable exercise of judgment.

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*Most notably the path-breaking study performed by the Workshop on Alternative Energy Strategies (WAES) (see refs. 3-6)

Different observers may make different judgments and reach different conclusions. However, we believe that this procedure makes clear and explicit just where assumptions must be made and what our assumptions are.

To account for the fact that reasonable people may have different judgments, assumptions are made for each of three possibilities. The first possibility is the medium or mid value. This value is the authors' judgment regarding what is most likely to happen to this specific factor during the 1980's and 90's. The second possibility is a low-demand or low-supply value. This is the authors' judgment regarding a low value which might be possible but is unlikely to occur. The third possibility is a high-demand or high-supply value which might be possible but is unlikely to occur.

To summarize, for each of eight factors affecting supply and demand, three values are presented for low, medium, and high possibilities. The three demand projections could be combined with the three supply projections to construct a total of nine supply-demand scenarios for projecting petroleum prices. We have chosen to examine only three scenarios for price implications. First is the combination of the medium demand and medium supply to give a midlevel scenario. This is the scenario which the authors judge most likely to occur. The second scenario joins low demand and low supply, and the third joins high demand and high supply. These two scenarios are judged possible but considerably less likely. They jointly provide upper and lower bounds to projections for the two decades. These three scenarios are then analyzed and the price of petroleum is projected for 1990 and 2000 for each scenario. Finally, the relationship between the price of petroleum and the price of jet fuel in the United States is examined, and jet fuel prices are projected for 1990 and 2000 for each scenario.

DEMAND ANALYSIS

Introduction

Two principal factors affecting the Free World demand for oil are (1) GNP growth rates and (2) conservation and conversion. These factors are discussed in detail in the subsections which follow.

Economic Growth Rates

Theoretical Analysis

The world demand for petroleum depends on world real GNP, and the growth in petroleum demand depends on GNP growth. The reason for this is quite simple. Petroleum is an input into the production of material goods and services along with labor, capital, and other resources. An increase in production requires an increase in the usage of all inputs, including petroleum. Thus, growth in the demand for petroleum depends first on the growth of GNP.

However, GNP growth rates are subject to fluctuations due to the occurrence of business cycles. Business cycles interrupt the process of sustained economic growth, setting off changes in the growth of real output and, consequently, in the demand for oil. The economic history of the last 150 years organizes itself so easily into a series of 3- to 10-year cycles that the reality and existence of business cycles becomes unmistakably obvious.

Economic growth and business cycles are closely intertwined. During the expansion phase of the cycle they reinforce each other, and income, output, and economic activity in general increase at a noticeably faster rate. Then, during the ensuing contraction phase, they oppose one another and business activity slows, or perhaps even falls, for a period of time. The continued occurrence of business cycles over the next 20 years can be confidently predicted; however, the length of specific expansions or contractions cannot be predicted at all. For example, it is impossible today to forecast whether the year 1990 will be a year of expansion or a year of contraction. Therefore, no attempt is made in this study to predict business cycle fluctuations or their impact on the demand for petroleum.

In projecting economic growth rates in this study, it is assumed that steady rates of economic growth will not be interrupted by the occurrence of business cycles. Thus, the economic growth rates projected here are long-term trends representing the growth process and not a specific growth rate for each year. This approach is adopted so that the influence of business cycles on economic growth is minimized and long-run trends can be projected.

Historical Data

Table 1 shows the GNP growth rates for the World Outside the Communist Areas (WOCA), industrial nations such as the United States, Canada, and Japan, and a number of selected regions, i.e., Europe, the Middle East, Latin America, Africa, and Australia. The data are presented for 1960-70, 1968-77, and 1973-77. These three periods were chosen because of the wide range of economic conditions that existed in each period.

The decade of the sixties was a period of comparatively favorable economic conditions and rapid growth in output. Real GNP in WOCA increased at an average annual rate of 5.2 percent in the sixties. During most of this period, the United States experienced rapid economic expansion with very little or no inflation.

The Consumer Price Index began to rise in 1967 and peaked in 1969 with seven percent annual inflation. Only 1960 and 1970 were years of economic contractions, and these were relatively mild. Western Europe, Japan, and Canada also enjoyed steady economic growth during the sixties with virtually no inflation in West Germany, Switzerland, Denmark, and Japan. All in all, WOCA and other areas included in the sample experienced high rates of GNP growth ranging from 4.3 percent for the United States to 10.5 percent for Japan as illustrated in column 1 of table 1.

On the contrary, the 1973-77 period was marked with economic uncertainty and cyclical depression. The United States, Western Europe,

Table 1. Historical GNP growth rates (annual percentage change).

AREAS	PERIODS 1960 - 70 HIGH GROWTH (%)	1968 - 77 MEDIUM GROWTH (%)	1973 - 77 LOW GROWTH (%)
WOCA	5.2	4.0	2.7
USA	4.3	2.6	2.0
Canada	5.6	4.8	3.4
Europe (Exc. Turkey)	4.7	3.5	1.8
Japan	10.5	6.7	3.2
Middle East(Inc. Turkey)	7.9	8.5	5.9
Latin America	5.5	6.5	4.8
Africa	5.4	5.2	4.9
Asia (Exc. Japan)	4.8	4.9	5.3
Australasia	5.3	3.9	2.9
World	4.7	4.3	2.8
Developed Market Economies	4.1	3.5	2.2
Developing Market Economies	5.6	6.3	5.3
Communist Countries	6.7	6.2	5.3

Source: ref. 7

and Japan experienced the worst recession since the Great Depression of the thirties. Unemployment in the United States reached the level of nine percent simultaneously with double digit inflation. Oil prices quadrupled in 1973, resulting in serious cutbacks in production levels of the industrial nations and disruption of their economies. World peace was threatened by a war in the Middle East and the oil embargo of the United States. Under these disruptive conditions, economic growth rates fell substantially to 2 percent in the United States and 1.8 percent in Europe. In Japan, the growth rate was a mere 3.2 percent, and only 5.3 percent in the developing economies. Overall, WOCA achieved a 2.7 percent growth rate in spite of these unfavorable conditions.

GNP growth rates for 1968-77 (shown in table 1, column 2) reflect performance of the economies during a combined period of economic expansion and contraction. Data are based on two years of rapid economic growth offset by two years of severe recession with five years of moderate GNP increases. GNP growth rates varied from a low of 2.6 percent for the United Stats to a high of 8.5 percent for the Middle East with WOCA averaging 4.0 percent. Because the 1968-77 period includes both the peaks and troughs of the business cycle, combined with a five-year period of sustained economic growth, this period should serve as a more realistic norm for making future GNP growth projections.

Scenario Assumptions

Recently the earlier optimistic estimates of real GNP growth for the market economies have been revised by more pessimistic projections for the future. Both government and private studies predict moderate economic growth rates through the decades of the eighties and nineties. While it is believed that the market economies included in WOCA could grow somewhat slowly, exceptionally low GNP growth rates over two decades do not appear probable nor acceptable by governments in the industrial or developing nations. Low GNP growth rates contribute to high unemployment and have potentially disruptive economic and political effects, especially for the developing nations. Therefore, whereas it is difficult to project accurately the real GNP growth rate for the period 1980-2000, it is quite reasonable to assume that national governments would do all they could to achieve an economic growth rate consistent with high employment. This would require an average annual GNP growth rate of four percent. We believe that WOCA can and will achieve this rate, and therefore project an average annual GNP growth rate of four percent for the decades of the eighties and nineties for our medium demand scenario, which we believe is the most likely to occur. This four percent average for WOCA is consistent with a low of three percent for the United States and a high of six percent for the developing economies. GNP growth rates for other subdivisions of WOCA for the medium-demand scenario are shown in column 2 of table 2.

Alternatively, a relatively high annual GNP growth rate of five percent may be achieved in WOCA if the favorable conditions of the sixties are repeated. Therefore, we project a high rate of economic growth of five percent for WOCA for the decades of the eighties and the nineties. Because petroleum is an essential input to all production processes, a GNP growth rate of five percent would be associated with a high world demand for oil. Growth rates for individual areas within WOCA for the high-demand scenario are given in column 3 of table 2.

Conversely, WOCA may realize a relatively slower annual rate of GNP growth for the decades of the eighties and the nineties. A steady increase in the world price of petroleum may force the industrial nations to cut back production, slowing down economic growth rates. Assuming that the above conditions prevail, we project a slower rate of GNP growth of three percent per year for WOCA for the decades of the eighties and nineties, contributing to a smaller world demand for petroleum. Low-demand scenario growth rates for subdivisions of WOCA are given in column 1 of table 2.

Conservation and Conversion

The term "conservation" as applied to energy has a variety of meanings which are often confused. Some possible meanings include the following: (a) doing without, i.e., reduced consumption of goods and services which require energy input and a resulting reduction in real income; (b) changing the composition of consumption in favor of those

Table 2. Projected GNP growth rates: 1980 - 2000 (annual percentage change).

AREA	LOW-DEMAND SCENARIO	MEDIUM-DEMAND SCENARIO	HIGH-DEMAND SCENARIO
WOCA	3.0	4.0	5.0
USA	2.0	3.0	4.0
Canada	3.4	4.8	5.6
Europe (Exc. Turkey)	2.2	3.5	4.7
Japan	3.5	4.5	6.5
Developing Economies	5.3	6.0	6.4
Australasia and South Africa	2.9	3.9	5.3

goods requiring less energy input and whose relative prices have fallen; (c) changing the choice of production technique to use less of the energy input whose relative cost has risen, and (d) innovation, i.e., the setting up of a new low-cost production technique requiring less of the higher priced energy input.

Political discussions of the need to conserve energy generally assume definition (a), i.e., doing without. Conversely, in this study the definitions for conservation and conversion of petroleum are intended to exclude (a) and to include meanings (b), (c), and (d). The activities implied by this usage are primarily willful choices by consumers and producers in response to changing relative prices and motivated by self-interest.

In addition to these willful choices, consumers and producers throughout WOCA have been constrained by governmental decrees dictating changes in both consumption and production to reduce the use of petroleum. Conservation and conversion are used here to include these dictated actions to reduce petroleum consumption.

Conservation and conversion activities have already been initiated throughout WOCA which will have dramatic impacts on the demand for petroleum. These impacts will vary widely among the various sectors of the economy, depending primarily on the extent to which conversion to other fuel sources is feasible. To examine these forces in detail, the economy is divided into five sectors: residential/commercial, electric utilities, manufacturing, transportation, and the nonmanufacturing component of the industrial sector. Demand projections are made for each of these sectors for six subareas of WOCA and totaled to estimate the demand for oil in WOCA for the 1980's and the 1990's.

Residential/Commercial Sector

Theoretical and empirical analysis. - In recent years, conservation in the use of oil for heating residential and commercial structures has been accelerated throughout WOCA due to OPEC price increases and government regulations aimed at reducing demand. Conversion to other sources of energy, such as natural gas, electricity, and solar energy, has enhanced conservation efforts. Substantial savings in the consumption of oil are being realized by increased insulation, caulking, and weather stripping in new and existing dwellings, by introduction of heat pumps, and by conversion to other sources of space heat. In Europe and Japan greater emphasis on improved building designs and efficiency in use of fuel oil for heat have added potentials for reduced oil consumption in the residential and commercial sector. According to the WAES Study (ref. 3), conservation measures in WOCA are expected to improve fuel efficiency by as much as 40 percent by the year 2000.

Currently, there are about 15 million residential and commercial oil heat customers in the United States, comprising 20 percent of the total energy market for this sector. More than 55 percent use natural gas; approximately 15 percent heat with electricity; and the rest use bottled gas, wood, coal, kerosene, and solar heat. Oil heat is dominant in the northeast United States and New England where the cost of heating has escalated sharply since 1976.

Since 1979, there has been a significant trend toward conservation in the use of oil in the residential and commercial sector of the United States. The trend is increasingly apparent in the steady decline in the number of new homes installing oil heat. The percentage of newly constructed homes equipped with fuel oil furnaces dropped to 6 percent in the second quarter of 1979 from 11 percent in 1976 (ref. 8). Surveys indicate that most homes in the Washington, D.C., Maryland, and New Jersey areas are constructed near gas lines. Real estate agencies claim that homes equipped with natural gas heating systems sell quicker. With oil heat in the declining stage of its life cycle, there is significant empirical evidence to support the argument that by 1985 no newly constructed single and multiple family dwellings will be equipped with oil furnaces.

Other significant evidence of conservation in the usage of oil in the United States is the rate at which the oil heating systems in the existing residential commercial structures are being converted to natural gas and electricity. The American Gas Association estimates that approximately 765,000 homeowners have converted to natural gas since late 1978, and many more are in the process of doing so or are expected to do so in the near future. There is persuasive argument for conversion to natural gas which remains abundant in supply and is cheaper than oil. Price deregulation under the Natural Gas Policy Act of 1978 has encouraged production. Since the Act was passed, gas prices have risen only 38 percent with the average gas bill only $60 higher in the winter of 1980 over the 1979 season (ref. 9). On the other hand, the real price of oil is expected to continue to rise over the current decade. Prices of natural gas will increase also, but such price increases are not expected to catch up with oil prices. Therefore, gas heat is by far a cheaper choice for the 1980's and will continue to provide a strong incentive to consumers for conversion from oil heat.

Of course, the major impetus towards both conversion and conservation efforts in the residential and commercial sector has been provided by rapid price increases of No. 2 heating oil relative to price increases of natural gas and electricity. As figures in table 3 indicate, prices of No. 2 heating oil, natural gas, and electricity increased by roughly the same proportion through 1978. However, the doubling of oil prices in 1979-80 following the Iranian Revolution suddenly changed the relative price structure. From 1976 to March 1980, the price of No. 2 heating oil increased 139 percent while natural gas was up 94 percent, and electricity only 37 percent. This marked the beginning of the dramatic shift away from oil for heating in the residential/commercial sector--a trend which is not likely to be reversed.

Scenario assumptions. - We believe that in the residential/commercial sector conversion from oil heat to other sources of space heat will take place over the next 30-year period. Such conversion may occur under any one of the following three assumed scenarios.

Beginning with 1980, under the low-conversion scenario (high demand for oil), a straight line depreciation is assumed with the replacement of oil heat furnaces by other systems only as the existing equipment wears out. Under this assumption, in 1990, as illustrated in figure 1, 27 percent of all those residential and commercial customers who presently use oil for space heat will convert to other sources of

Table 3. Average energy prices to residential customers in the United States.

YEAR	NO. 2 HEATING OIL (cent/gal)	NATURAL GAS (cent/1000 ft^3)	ELECTRICITY (cent/kWh)
1976	40.6	184.6	3.09
1977	46.0	226.4	3.42
1978	49.4	262.6	3.69
1979	65.6	323.1	3.97
March 80	97.0	357.9	4.24
		INDICES	
1976	100	100	100
1977	113	123	111
1978	122	142	119
1979	162	175	128
March 80	239	194	137

Source: ref. 10

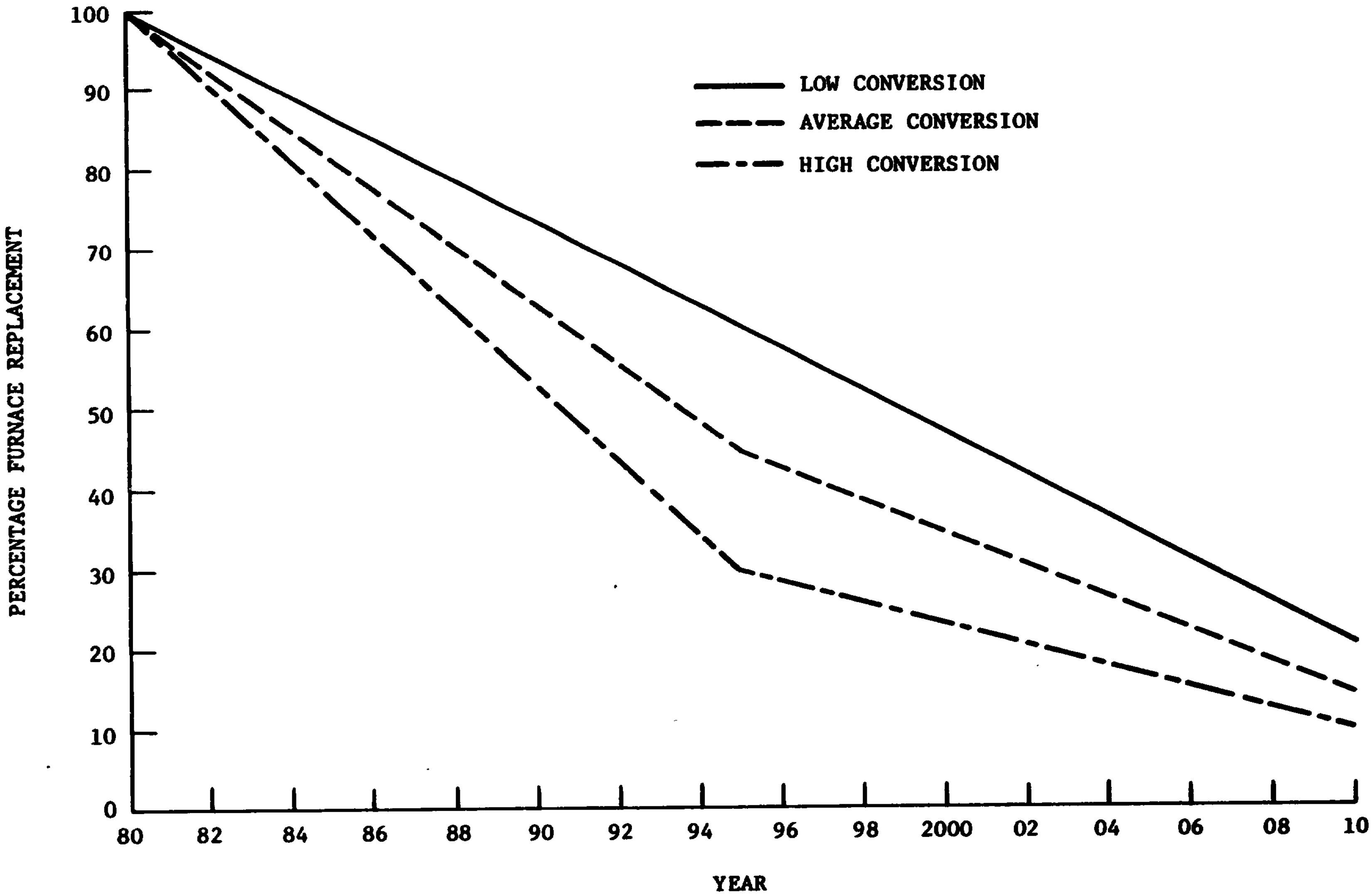

Figure 1. Projected replacement schedules for fuel oil furnaces in the residential/commercial sector.

heat while 73 percent will continue to utilize fuel oil systems. In the year 2000, the percentage of those converted to other sources of heat is assumed to increase to 53 percent with 47 percent of consumers still heating their dwellings with oil furnaces. By the year 2010, about 80 percent of the current oil heat customers are assumed to switch over to other sources of heat with 20 percent still utilizing oil as a means for space heat.

This straight line depreciation and replacement of equipment over 30 years seems to be the minimum rate of conversion that could be reasonably expected. It is considerably more likely that conversion to other fuel sources will take place more rapidly than assumed in the low-conversion scenario. In response to the relative price changes that have already occurred, it is expected that more than 50 percent of the present oil heat equipment would be replaced in the first half of the depreciation period, with the conversion rate tapering off in the second half of the period.

Thus, under the average conversion scenario (medium demand for oil), the assumed replacement rate is that which is considered most likely to occur. Again, beginning with 1980, as illustrated in figure 1, it is assumed that of those residential and commercial customers who presently heat with oil furnaces, 37 percent will convert to alternate systems by 1990, their percentage eventually increasing to 66 percent in the year 2000 and to 85 percent in 2010. Consequently, 63 percent of the oil heat customers in the residential and commercial sector will continue to utilize fuel oil as a primary source of space heat in 1990 with the percentage decreasing to 34 and 15 percent in 2000 and 2010, respectively.

While it is most likely that conversion will take place at a pace comparable to that assumed in the average conversion scenario, it is possible that conversion may take place more rapidly. This possibility is covered by the high-conversion scenario. Under the high-conversion scenario (low demand for oil), a high replacement rate of fuel oil furnaces is assumed. It is assumed that in 1990 approximately 47 percent of current oil heat customers will switch over to alternate systems with the number eventually rising to 77 percent in the year 2000 and to

90 percent in the year 2010. Customers who continue to use fuel oil as a source of space heat are assumed to be 53 percent, 23 percent and 10 percent of their 1980 level in the years 1990, 2000, and 2010, respectively, as illustrated in figure 1.

Demand Projections. - Implications of the scenario assumptions for the United States are detailed in table 4. Under the low conversion the number of oil heat customers will decline from 15 million in 1980 to 11 million in 1990. This represents a reduction in the demand for oil from 3.40 million barrels per day (MBOD) to 2.50 MBOD. By the year 2000, the number of customers is expected to decline to 7.1 million, resulting in a consequent reduction in the demand for oil to 1.61 MBOD. By the year 2010, the number of oil heat customers is expected to decrease to 3.0 million with the demand for oil eventually diminishing to 0.69 MBOD.

Under the average-conversion scenario, the number of oil heat customers is projected to decline from the 1980 level of 15 million to 9.5 million in 1990 with a decline in the demand for oil from 3.40 MBOD in 1980 to 2.10 MBOD in 1990. For the year 2000, the number of customers is estimated to decline to 5.1 million with the demand for oil shrinking to 1.10 MBOD. Analogously, the figures for the year 2010 are estimated at 2.3 million oil heat customers with the demand for oil at 0.52 MBOD.

Under the high-conversion scenario it is projected that the number of oil heat customers in the United States will decline from 15 million in 1980 to 8 million in 1990. This will reduce the total market demand for oil to 1.8 MBOD in 1990 from 3.40 MBOD in 1980. For the years 2000 and 2010, the number of oil heat customers is estimated at 3.5 and 1.5 million, respectively. This is expected to reduce the demand for oil from 3.40 MBOD in 1980 to 0.80 MBOD in 1990 and 0.35 MBOD in 2010.

Because the same international prices of crude petroleum are faced by all industrial nations and because rational economic consumers anywhere in the world respond to price increases by cutting back consumption, identical conversion rates for fuel oil furnaces and similar conservation efforts are applied to the residential/commercial sector

Table 4. Projected demand for oil in the residential/commercial sector of the United States.

SCENARIO	TIME PERIOD	NO. CUSTOMERS (in millions)	CUMULATIVE PERCENT DECLINE	AMOUNT OF OIL UTILIZED (MBOD)
Historical	1980	15.0	--	3.40
Low Conversion/ High Demand	1990	11.0	27	2.50
	2000	7.1	53	1.61
	2010	3.0	80	0.69
Average Conversion/ Medium Demand	1990	9.5	37	2.16
	2000	5.1	66	1.16
	2010	2.3	85	0.52
High Conversion/ Low Demand	1990	8.0	47	1.81
	2000	3.5	77	0.80
	2010	1.5	90	0.35

in WOCA as in the United States. Table 5 presents data reflecting the demand for oil in the residential/commercial sectors of a number of selected areas and WOCA. Demand projections are made for these areas for the years 1990 and 2000 by using low, average, and high conversion rates previously discussed and portrayed in figure 1. These data are then utilized in projecting the total demand for oil in WOCA for 1990 and 2000 for the residential/commercial sector.

In summary, fuel oil consumption in the residential/commercial sector of WOCA is quite sensitive to higher prices. High oil bills are expected to encourage conservation by discouraging installation of fuel oil furnaces in new single and multi-family dwellings, by encouraging conversion from oil heat to natural gas and electricity in existing structures, and by enhancing improved insulation and efficient building designs. The conversion of fuel oil facilities to other modes of space heat is projected to take place over the 30-year period as the existing equipment wears out or may proceed at the average or higher rate of conversion. Conservation in the use of fuel oil in the residential/commercial sector of WOCA is expected to lower the fuel input per unit of output produced and, consequently, reduce the demand for oil.

Electric Utility Sector

Theoretical and empricial analysis. - Beginning with World War II until 1973, the demand for electricity in the United States increased at an average annual rate of seven percent while the average price per kilowatt hour (kWh) paid by users decreased (ref. 11). The quadrupling of oil prices in 1974 and the subsequent rise in coal prices produced a sharp break in these trends. By 1977 the annual growth rate in the demand for electricity declined to 4.2 percent and subsequently to 3.7 percent in succeeding years. In 1973 the average price per kWh of electricity paid by residential and industrial customers was 3.4 and 1.7 cents, respectively. By 1977 prices were up to 4.1 and 2.5 cents per kWh. Further price increases in the ensuing years reflected higher fuel costs, increased construction costs, and environmental control costs.

In the United States, oil and natural gas account for the major

Table 5. Projected demand for oil in the residential/commercial sectors of WOCA (million barrels of oil per day).

AREAS	LOW DEMAND SCENARIO		MEDIUM DEMAND SCENARIO		HIGH DEMAND SCENARIO	
	1990	2000	1990	2000	1990	2000
WOCA	5.00	2.22	5.96	3.26	6.90	4.45
USA	1.81	0.80	2.16	1.16	2.50	1.61
Canada	0.29	0.13	0.34	0.19	0.40	0.26
Europe (Exc. Turkey)	1.77	0.79	2.11	1.17	2.44	1.57
Japan	0.33	0.15	0.40	0.22	0.46	0.30
Developing Economies	0.75	0.33	0.89	0.49	1.03	0.66
Australasia and South Africa	0.05	0.02	0.06	0.03	0.07	0.05

fuel usage in the generation of electricity. On November 9, 1978, in an all-out effort to reduce the demand for oil in the electric utility sector, President Carter signed five major bills into law that constitute the National Energy Act (NEA). Four of the Acts have significant implications for the electric utility sector. These focus especially on fuel conservation, adjustment of pricing policies, and reduction in the demand for oil due to interfuel substitution.

Most important for our purposes here is the Power Plant and Industrial Fuel Use Act of 1978 (ref. 12). This Act prohibits, with certain exceptions, the use of oil or natural gas in new electric utility generation facilities or in new industrial boilers with a fuel input rate of 100 million Btu's per hour or greater. It also prohibits, with minor exceptions, the use of natural gas by existing power plants after January 1, 1990. The Act further empowers the Department of Energy to issue orders requiring specific electric-generating facilities to convert from oil to coal. Exemptions may be granted if a facility cannot be converted or if doing so would increase costs. The overall effect of the Act is to increase the share of electricity generated by coal and to reduce the share generated by oil and natural gas.

In addition to this legislative imperative, there is some economic reason to convert from oil to coal. In November 1978, the cost per Btu from residual fuel oil was almost double that from coal. One year later, oil was almost triple the cost of coal (see table 6). Thus, operating costs are considerably lower for coal than for oil, particularly since the oil price increase following the Iranian Revolution. Although the price of coal will no doubt rise due to the increasing demand, it is almost certain that this disparity in cost between oil and coal will widen even further in coming years.

The principal impediment to immediate conversion of all existing oil-fired boilers is the high capital cost of coal-fired boilers. A typical oil or natural gas boiler costs between $300,000 and $500,000 and can be installed in 30 to 60 days. A comparable coal boiler costs about $9,000,000 and takes 3 to 4 years for installation.* With

*Data provided by Mr. Ed Peters of the Department of Energy.

Table 6. Cost of fossil fuels to electric utilities in the United States.

DATE	COST (per million Btu) COAL	RESIDUAL FUEL OIL	RATIO OF OIL TO COAL
November 1978	$1.16	$2.26	1.9
November 1979	$1.28	$3.67	2.9

Source: ref. 8

interest rates at historical levels, this cost difference is highly significant in delaying conversions.

A second impediment to the installation of coal-fired boilers is the environmental protection problem. The smallest electrostatic precipitator costs about $1.5 million, and a great deal of time is required to produce environmental impact studies and obtain all the necessary approvals.

Finally, there are some existing oil plants that simply cannot be converted to coal. A good deal of space is required for storage and handling of coal, and some oil facilities just do not have the rquired space to convert.

In conclusion, there are both legal and economic reasons to convert oil-fired electric-generating plants to coal or other energy sources. At the same time there are legal, economic, and physical impediments to conversion. Therefore, we cannot expect conversion in the electric utility sector to be either complete or rapid.

Scenario assumptions and demand projections. - With ever-increasing emphasis on conservation of oil in the electric utility sector, we believe that the process of conversion of oil-fired burners to alternative energy sources will take place over the next 20 years under one of the following 3 scenarios (see fig. 2 and table 7). Under the low-conversion scenario it is projected that the demand for oil in the electric utility sector will decline to 1.5 MBOD in 1990 from 1.7 MBOD in 1980. This represents a 15 percent reduction in consumption. By the year 2000, the demand for oil is projected to decline 40 percent to 1.0 MBOD. This demand for oil will be forthcoming from those utilities which will continue to utilize oil-fired burners in 1990 and 2000.

Under the average-conversion scenario it is estimated that the demand for oil will decline to 1.2 MBOD in 1990 from a total of 1.7 MBOD in 1980 due to higher conversion rates of oil-fired burners. This represents a 33 percent decrease in the amount of oil consumed. By the year 2000 the demand for oil is projected to decline to 0.8 MBOD, indicating a 55 percent reduction in the amount of oil consumed.

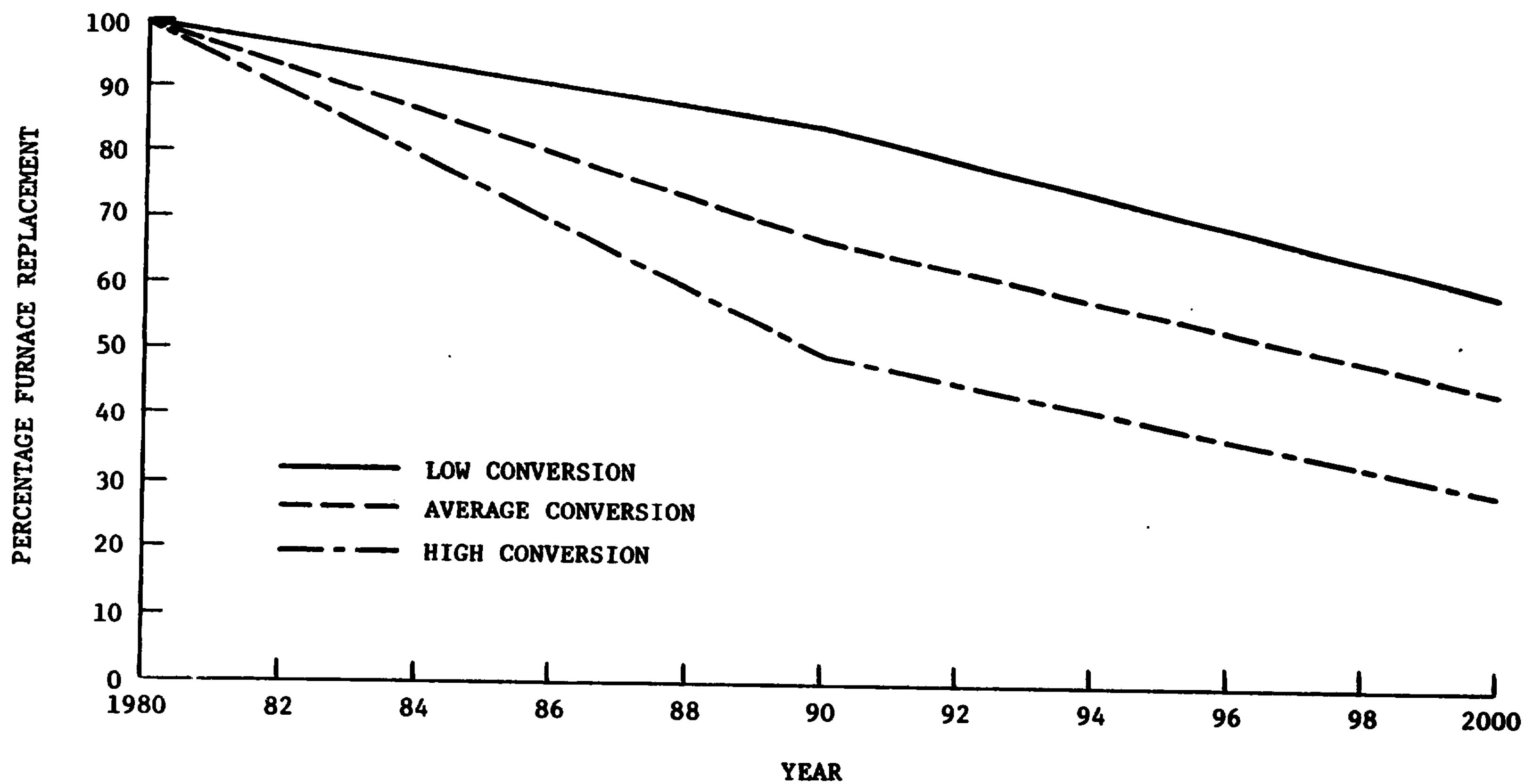

Figure 2. Projected replacement schedules for fuel oil furnaces in the electric utility sector.

Table 7. Projected demand for oil in the electric utility sector of the United States.

SCENARIO	TIME PERIOD	CUMULATIVE DECLINE (%)	OIL UTILIZED (MBOD)
Historical	1980		1.7
Low Conversion/ High Demand	1990	15	1.5
	2000	40	1.1
Average Conversion/ Medium Demand	1990	33	1.2
	2000	55	0.8
High Conversion/ Low Demand	1990	50	0.9
	2000	70	0.5

The high-conversion scenario projects a much faster rate of conversion of oil-fired burners to other power plants. It is projected that electric utilities will consume 50 percent less oil and cut back demand to 0.9 MBOD by 1990. Reduction in the demand for oil is estimated to be 70 percent in the year 2000 compared with the 1980 level. This means a decline from 1.7 MBOD in 1980 to 0.5 MBOD in the year 2000.

The rationale presented above can be extended to WOCA, where mandatory government regulations aimed at converting oil-fired burners to coal-fired power plants and to nuclear-generating capabalities were in existence long before these regulations were introduced in the United States. The reason is that the Western European industrial nations and Japan are more heavily dependent on imported oil than is the United States. Also, if approval and construction time aspects are controlled effectively, nuclear generation is a more economical means of producing electricity which not only keeps the cost at a minimum but also contributes substantially to the conservation of oil in the electric utility sector. For these reasons, identical conversion rates of oil-fired burners are applied to electric utility sectors in WOCA as in the United States. Table 8 presents data reflecting the demand for oil in the electric utility sectors for six selected areas as well as WOCA. Oil demand projections are estimated for these areas for the years 1990 and 2000 under the assumed low, medium, and high demand scenarios. These data are then aggregated to project the total demand for oil in WOCA for 1990 and 2000.

In summary, the demand for oil in the electric utility sectors is subject to mandatory conservation enforced by the national governments. Conversion of oil-fired burners to coal-fired burners is projected to take place over the next 20-year period under the low, average, and high conversion scenarios. Such conversion is expected to reduce the demand for oil in the electric utility sector over the coming two decades.

Table 8. Projected demand for oil in the electric utility sectors of WOCA (million barrels of oil per day).

AREAS	LOW-DEMAND SCENARIO		MEDIUM-DEMAND SCENARIO		HIGH-DEMAND SCENARIO	
	1990	2000	1990	2000	1990	2000
WOCA	2.91	1.75	3.93	2.63	4.95	3.50
USA	0.78	0.47	1.06	0.71	1.33	0.94
Canada	0.03	0.02	0.04	0.03	0.05	0.04
Europe (Exc. Turkey)	0.93	0.56	1.25	0.83	1.58	1.11
Japan	0.51	0.30	0.68	0.46	0.86	0.61
Developing Economies	0.65	0.39	0.88	0.59	1.11	0.79
Australasia and South Africa	0.01	0.01	0.02	0.01	0.02	0.01

Manufacturing Sector

Theoretical analysis. - In order to assess more accurately the demand for oil in the industrial sector, we have divided this sector into two subgroups on the basis of the nature of economic activity and the possibility of interfuel substitution. Accordingly, we have defined the manufacturing sector, subgroup one, as consisting of all those manufacturing activities where interfuel substitution is readily feasible. Subgroup two, the other industrial sector, is defined to include all those oil-consuming industrial activities where possibilities of interfuel substitution are limited. This sector includes agriculture, residential and nonresidential construction, mining of metallic and nonmetallic minerals, and chemical feedstocks. All other industrial activities are included in the manufacturing sector.

In the manufacturing sector, fuel oil is used primarily to generate heat. This may be for space heat or for part of the production process, e.g. drying in paper and textile production. Other types of fuels are also used for the same purpose, so it is relatively easy to substitute other fuels for oil in response to the rising price of oil. The same arguments and data presented in discussion of the residential/commercial and electric utility sectors are applicable to the manufacturing sector and need not be repeated.

Scenario assumptions and demand projections. - We project that interfuel substitution in the manufacturing sector of the United States will occur over the next 20-year period under one of the following three scenarios. Figure 3 illustrates interfuel substitution rates for each scenario.

Table 9 provides data on the demand for oil in the manufacturing sector of the United States under the three assumed scenarios. In 1980 the demand for oil in the manufacturing sector was 1.05 MBOD. Our low-conversion/high-demand scenario projects that the demand for oil will decline to 0.64 MBOD by 1990 and to 0.21 MBOD by 2000. This represents 40 and 80 percent reductions in the demand for oil in the manufacturing sector by the years 1990 and 2000, respectively, compared with their 1980 levels. The remaining 60 and 20 percent of the demand for oil

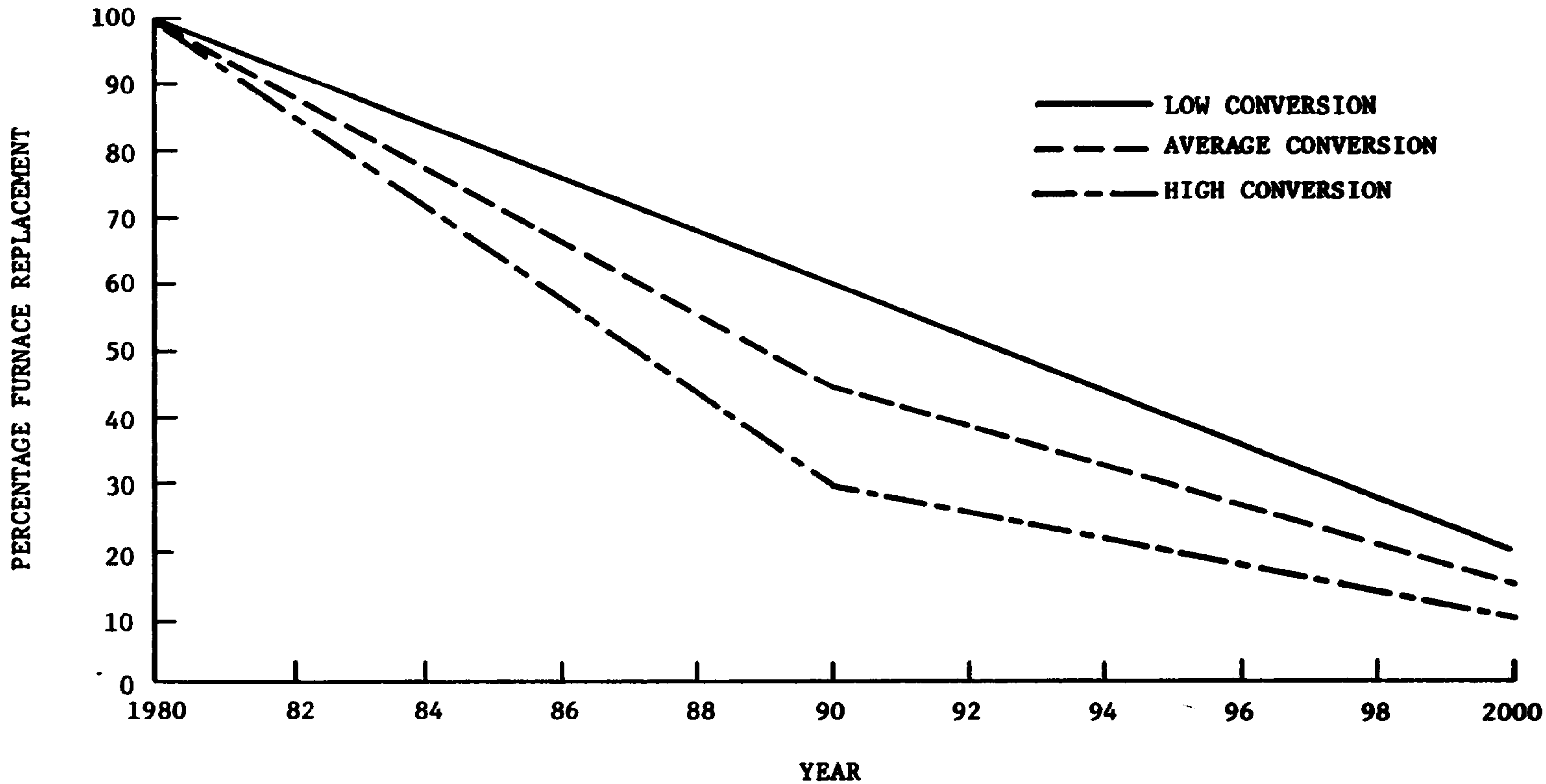

Figure 3. Projected replacement schedules for fuel oil usage in the manufacturing sector

Table 9. Projected demand for oil in the manufacturing sector of the United States.

SCENARIO	TIME PERIOD	CUMULATIVE DECLINE (%)	OIL UTILIZED (MBOD)
Historical	1980		1.05
Low Conversion/ High Demand	1990	40	0.64
	2000	80	0.21
Average Conversion/ Medium Demand	1990	55	0.48
	2000	85	0.16
High Conversion/ Low Demand	1990	70	0.32
	2000	90	0.11

will be consumed by those establishments which continue to use oil as a source of energy.

For the average-conversion/medium-demand scenario, different rates of oil demand are projected. It is etimated that demand for oil will decline from 1.05 MBOD in 1980 to 0.48 MBOD by 1990, and subsequently to 0.16 MBOD by 2000. This represents a 55 percent decrease in the demand for oil by the year 1990 and 85 percent by the year 2000 when compared with the 1980 levels. The remaining demand will be forthcoming in 1990 and 2000 from those manufacturing establishments which continue to utilize oil as a source of energy in producing their output.

Under the high-conversion/low-demand scenario, demand for oil is projected to decline from 1.05 MBOD in 1980 to 0.32 MBOD by 1990, resulting in a 70 percent decrease when compared with the 1980 level. This decline is projected at 90 percent in the year 2000, contributing to further reductions in the total demand for oil in the manufacturing sector to 0.11 MBOD.

The various levels of demand for oil just projected under three different scenarios depend on world oil prices. Higher prices hasten interfuel substitution and, consequently, reduce the consumption of oil in the manufacturing sector. Because firms in any country will respond to resource price increases by cutting back consumption and by undertaking resource input substitution, identical interfuel conversion rates are applied to all manufacturing sectors in WOCA as in the United States. Table 10 exhibits data indicating demand for oil in the manufacturing sectors of six selected areas for the years 1990 and 2000 under the three assumed scenarios. These data are in turn aggregated to project the total demand for oil in WOCA for the years 1990 and 2000.

In summary, oil consumption in the manufacturing sectors of WOCA is sensitive to higher oil prices. Such prices are expected to hasten interfuel substitution, which we project will take place over the next 20 years under the assumed low, medium, and high demand scenarios. Interfuel substitution is expected to lower oil consumption in the manufacturing sector, thereby impacting the demand for oil in WOCA.

Table 10. Projected demand for oil in the manufacturing sectors of WOCA (million barrels of oil per day).

AREAS	LOW DEMAND SCENARIO		MEDIUM DEMAND SCENARIO		HIGH DEMAND SCENARIO	
	1990	2000	1990	2000	1990	2000
WOCA	2.15	0.73	3.22	1.08	4.31	1.44
USA	0.32	0.11	0.48	0.16	0.64	0.21
Canada	0.05	0.02	0.08	0.03	0.10	0.04
Europe (Exc. Turkey)	0.96	0.32	1.43	0.48	1.91	0.64
Japan	0.44	0.15	0.66	0.22	0.89	0.30
Developing Economies	0.35	0.12	0.52	0.17	0.70	0.23
Australasia and South Africa	0.03	0.01	0.05	0.02	0.07	0.02

Other Industrial Sector

Theoretical analysis. - In this study we have defined the other industrial sector to include those productive activities in which potential for interfuel substitution is clearly limited. These activities comprise agricultural production, residential and nonresidential construction, mining of metallic and nonmetallic minerals, and chemical feedstocks. In agriculture, diesel oil is demanded for such uses as mechanical plowing, harvesting, and fruit picking. This demand is satisfied at diverse locations by making fuel available where productive activities are being carried out. Similarly, in residential and nonresidential construction, the demand for oil is generated by numerous earth-moving activities and movement of materials. As in the case of agriculture, the demand for oil is satisfied by supplying it at various construction sites to operate construction equipment. Analogous arguments can be made for mining of metallic and nonmetallic minerals and, with some modification, for chemical feedstock. The crucial point, however, is that, due to the peculiar character of production processes in agriculture, construction, mining, and chemical feedstock, the prospect for interfuel substitution is quite limited.

Oil consumption in the other industrial sector is directly related to the level of output which, in turn, depends on economic growth rates. High economic growth stimulates output, which requires increased usage of all factor inputs including the various types of industrial fuels, i.e., middle distillates, gasoline, kerosene, diesel fuel, residual fuel oil, etc. Therefore, higher rates of growth of output in the industrial sector mean higher demand for oil, and lower growth rates mean lower demand. It can therefore be concluded that, due to the limitation of interfuel substitution and because oil is a factor input in the production process, the demand for oil in the industrial sector may vary directly with the GNP growth rates for the decades of the 80's and the 90's. Accordingly, we have made the following demand projections by assuming low, medium, and high demand scenarios.

Scenario assumptions and demand projections. - An earlier section of this paper examined historical GNP growth rates for WOCA and selected geographic subareas. Growth rates were then projected for WOCA and six subareas under three demand scenarios. These GNP growth rate projections, shown in table 2, form the basis for projecting the demand for oil in the other industrial sectors of WOCA and its six subareas.

For the United States, GNP growth rates of two, three, and four percent are projected for the low, medium, and high demand scenarios. Under the low-demand scenario, we project that a 2 percent annual rate of GNP growth in the United States for the decades of the 80's and the 90's will generate demand for industrial fuel oils amounting to 3.30 MBOD by 1990 and 4.00 MBOD in 2000. The figures are summarized in table 11.

For the United States, economic growth rates averaging three percent per year for the decades of the 80's and the 90's are projected under the medium-demand scenario. Our etimates are that the demand for oil in the industrial sector is expected to be 3.68 MBOD and 4.94 MBOD in 1990 and 2000.

The high-demand scenario assumes economic growth rates in the United States averaging 4 percent annually throughout the decades of the 80's and the 90's. The demand for industrial fuel oils is, therefore, estimated to be 4.22 MBOD by 1990 and 6.43 MBOD by 2000.

The analysis applied to the United States has been extended to WOCA. The demand for oil in the industrial sector of WOCA is assumed to be a direct function of the GNP growth rates. Demand estimates have beem projected for the years 1990 and 2000 by assuming different economic growth rates under low, medium, and high demand scenarios for all areas comprising WOCA. These estimates are shown in table 11 and are included in the total demand for oil in WOCA for the years 1990 and 2000.

In summary, there is a limited potential for interfuel substitution in the other industrial sector. The demand for industrial fuel oils depends on the size of output, which in turn depends on the assumptions of economic growth rates. Oil demand projections are made for WOCA under low, medium, and high demand scenarios.

Table 11. Projected demand for oil in the other industrial sectors of WOCA (million barrels of oil per day).

AREAS	LOW DEMAND SCENARIO		MEDIUM DEMAND SCENARIO		HIGH DEMAND SCENARIO	
	1990	2000	1990	2000	1990	2000
WOCA	13.52	18.96	15.04	23.10	16.82	28.43
USA	3.30	4.00	3.68	4.94	4.22	6.43
Canada	0.42	0.59	0.49	0.79	0.53	0.91
Europe (Exc. Turkey)	3.56	4.43	4.09	5.77	4.65	7.35
Japan	1.45	2.05	1.61	2.50	1.98	3.72
Developing Economies	4.38	7.34	4.71	8.43	4.91	9.13
Australasia and South Africa	0.41	0.55	0.46	0.67	0.53	0.89

Transportation Sector

Theoretical analysis. - The transportation sector is a major consumer of petroleum. In 1978 it consumed 53 percent of all the petroleum used in the United States. Petroleum represents about 97 percent of this sector's energy requirements (ref. 13). Transportation affects every aspect of a nation's economy. It promotes economic growth and the delivery of social goods, enlarges the area consumers and industry may draw upon for resources and products, and facilitates the distribution of private goods and services. The resulting specialization and economies of scale provide wider choices for consumers at lower prices. Also, a viable transportation system shapes cities, unifies a nation, makes the world accessible, and plays a key role in national defense and international trade. Its lack could frustrate a nation's economic and social growth.

In the United States, the transportation sector uses petroleum to move people and commodities by five modes of travel: highway, air, rail, marine, and pipeline. It is in this sector that the potential for conservation and efficiency improvement in the use of petroleum is extremely significant. A primary reason for this lies in the mandated fuel economy improvements in the automobile industry and in the growing emphasis on other modes of transportation, including mass transit and the electric and hybrid vehicles. Furthermore, as the single largest consumer of petroleum, the United States transportation system is highly sensitive to oil price increases and petroleum supply uncertanties. Higher fuel prices not only motivate changes in the driving habits which enhance conservation, but also increase demand for more fuel-efficient new cars whose efficiency is rapidly approaching the mandated standards. For example, the average new car mileage expected by meeting the standards in 1985 is approximately 27.5 miles per gallon (mpg). The current General Motors fleet average for new car efficiency is about 22.4 mpg and is expected to exceed the mandated standards by averaging 31 mpg in 1985 (ref. 14). As more efficient new cars are purchased and older less efficient ones are scrapped, the average fleet efficiency is expected to improve further. Conservation in fuel use by automobiles is reinforced by a switch to diesel-powered vehicles, which are estimated to be 50 percent more efficient than gasoline-powered automobiles.

Recently there has been a growing emphasis on electric and hybrid vehicles in the United States. Some 2,000 electric vehicles have been built and offered for sale in this country (ref. 15). Hybrid vehicles which are powered by a combination of electric motors and internal-combustion engines are not yet commercially available. Emphasis on electric and hybrid vehicles is based on conservation of fuel and the following expectations:

(1) Electric or hybrid vehicles would successfully compete with conventional vehicles in the urban market;

(2) The net effect if using electric-powered vehicles would be a reduction in petroleum demand;

(3) If batteries are charged during periods of low electric demand, i.e. during the night, utility peak-power requirements would not be adversely affected and electric generation could become more efficient; and

(4) Environmental protection would be facilitated because it is easier to control emission from a few stationary electric power stations than from a large number of moving vehicles (ref. 15).

The extent to which these expectations are met depends primarily on battery development. The battery is the main constraint on the ability of electric or hybrid vehicles to compete with liquid-fuel vehicles. In the near future, three batteries, lead-acid, nickel-iron, and nickel-zinc have a reasonable chance of becoming commercially available. At the present time, none of these batteries possesses the power, endurance, or conversion efficiency which would enable the battery-powered vehicles to match the performance of conventional automobiles. General Motors Corporation plans to introduce a small electric-powered car in the 1984 model year with a top speed of 80.5 km/hr (50 mph) and a range of 161 km (100 mi) without recharging the battery (ref. 14).

Due to limited range and acceleration, near-future application of electric vehicles is likely to be confined to a few commercial vehicles for urban use. These are not expected to be common as second family cars until the 1990's at the earliest. The extent of their market penetration through the year 2000 is uncertain and depends heavily on the rate of battery development and government incentives for commercialization.

Scenario assumptions and demand projections. - In projecting demand for oil in the transportation sector of the United States, we have relied heavily on estimates made by many private and government studies, including one by the Presidential Study Commission. The most notable feature of these studies is the anticipated decline of the rate of growth in oil demand throughout the decades of the 1980's and the 1990's. Table 12 lists these studies as well as their projected demands for oil in the years 1990 and 2000. The estimates vary from 9.82 MBOD to 11.70 MBOD for the year 1990 and from 10.13 MBOD to 13.17 MBOD for the year 2000.

As shown in table 12, estimates by the Presidential Study Commission fall right at the mean of the studies cited for both 1990 and 2000. For this reason we have chosen to use the Presidential Study Commission's figures as our projections of the demand for oil in the transportation sector of the United States. Accordingly, we estimate the demand for oil to be 10.48 MBOD in 1990 and 11.55 MBOD in 2000 for the medium-demand scenario. For the low-demand scenario our etimates are 8.79 MBOD and 9.40 MBOD for the years 1990 and 2000, respectively. Under the high-demand scenario we project the demand for oil to be 11.00 MBOD in the year 1990 and 13.30 MBOD in the year 2000.

Similar studies of petroleum demand in the transportation sectors of other countries throughout WOCA are not available, so a different method of projection is necessary. In the rest of WOCA the outlook for petroleum demand in transportation is quite different from the United States. For the past three or four decades the heart of the transportation system in the United States has been the large, high-powered, low-efficiency automobile. One happy implication of this fact is that great improvements in fuel efficiency can be achieved in the coming two decades in the U.S. transportation sector.

Table 12. Projections of demand for petroleum in the transportation sector of the United States (million barrels of oil per day).

SOURCE	1990	2000
a. Presidential Study Commission	10.48	11.55
b. Stanford Research Institute	11.70	13.17
c. Department of Transportation	9.82	
d. Office of Technology Assessment	11.04	12.56
e. Department of Energy	9.82	11.14
f. Data Resources, Inc.	9.88	11.14
g. Exxon	10.08	10.13
h. Pace	11.14	
Average	10.50	11.60

Source: refs. 13, 16 to 22

In the rest of WOCA, however, they have not relied upon the large inefficient automobile. Other countries already use mass transit systems and the smaller automobiles to which the U.S. is now converting. These other countries will not be able to achieve improvements in efficiency comparable to that projected for the U.S. Some improvements, of course, will be made, but they will be more difficult to effect and of smaller magnitude.

Therefore, for the rest of WOCA the authors project that the transportation demand for petroleum will increase. Since transportation is an input in the production process, we can expect the demand for petroleum in transportation to increase roughly in proportion to the level of production. Therefore, in these countries we have increased the demand for petroleum in the transportation sector at the same rate that GNP is projected to grow. These data are presented in table 13 along with figures for the United States and the aggregation for WOCA for the years 1990 and 2000.

This completes our examination of the demand for petroleum in WOCA. In the next section we turn to an analysis of the supply side of the market. Following that, we put demand and supply together to search for price implications.

Summary

The various procedures used to project the demand for petroleum are summarized in table 14. In three sectors of the economy, residential/commercial, electric utilities, and manufacturing, recent price increases and governmental mandate have initiated a process of conservation and conversion that will progressively reduce the demand for petroleum over the next 20 years. Conversion is projected at somewhat different rates in each of the three sectors depending on particular conditions. Identical rates are used for all six geographic areas of WOCA.

In the other industrial sector, substitution of other fuels for oil will be far more difficult, if possible at all. Therefore, the demand for oil in this sector is projected to increase at the same rate

Table 13. Projected demand for oil in the transportation sectors of WOCA (million barrels of oil per day).

AREAS	LOW-DEMAND SCENARIO		MEDIUM-DEMAND SCENARIO		HIGH-DEMAND SCENARIO	
	1990	2000	1990	2000	1990	2000
WOCA	22.31	29.28	25.50	35.71	27.59	42.28
USA	8.79	9.40	10.48	11.55	11.00	13.30
Canada	1.01	1.42	1.17	1.88	1.28	2.20
Europe (Exc. Turkey)	4.34	5.40	4.99	7.04	5.66	8.96
Japan	1.54	2.17	1.71	2.66	2.11	3.96
Developing Economies	6.00	10.06	6.45	11.56	6.73	12.51
Australasia and South Africa	0.63	0.83	0.70	1.02	0.81	1.35

Table 14. Summary of demand projection procedures.

Sector	U.S.A.	Other WOCA
Residential/ Commercial		
Electric Utilities	Conservation and Conversion	Same as U.S.A.
Manufacturing		
Other Industrial	Increased at GNP Growth Rate	Same as U.S.A.
Transportation	Data Projected by Presidential Study Commission	Increase at GNP Growth Rate

as GNP. Separate GNP growth rates are projected for each of the six geographic areas of WOCA.

The demand for petroleum in the transportation sector of the United States is generally expected to decline as the size of the automobile is scaled down and gas mileage is increased. We have used projections made by the Presidential Study Commission.

In the rest of WOCA similiar fuel savings are not likely to be made. Therefore, for the rest of WOCA the demand for petroleum in transportation is projected to increase at the same rate as GNP for each of the five subareas.

Separate projections of the demand for oil have been made for five economic sectors, six geographic areas, two time periods, and three scenarios, for a total of 180 projections. These data are summarized for WOCA and presented in tables 15 and 16. Table 15 also shows a breakdown for each sector, and table 16 shows totals for each subarea.

Table 15. Projected demand for oil in WOCA by economic sectors (million barrels of oil per day).

SECTORS	LOW-DEMAND SCENARIO		MEDIUM-DEMAND SCENARIO		HIGH-DEMAND SCENARIO	
	1990	2000	1990	2000	1990	2000
Residential/Commercial	5.00	2.22	5.96	3.26	6.90	4.45
Electric Utilities	2.91	1.75	3.93	2.63	4.95	3.50
Manufacturing	2.15	0.73	3.22	1.08	4.31	1.44
Other Industrial	13.52	18.96	15.04	23.10	16.82	28.43
Transportation	22.31	29.28	25.50	35.71	27.59	42.28
WOCA	45.89	52.94	53.65	65.78	60.57	80.10

Source: tables 5, 8, 10, 11, and 13

Table 16. Projected demand for oil in WOCA by geographic areas (million barrels of oil per day).

AREAS	LOW-DEMAND SCENARIO		MEDIUM-DEMAND SCENARIO		HIGH-DEMAND SCENARIO	
	1990	2000	1990	2000	1990	2000
USA	15.00	14.00	17.86	18.52	19.69	22.49
Canada	1.80	2.16	2.12	2.90	2.35	3.44
Europe	11.55	11.48	13.87	15.29	16.23	19.63
Japan	4.27	4.82	5.07	6.06	6.30	8.88
Developing Economies	12.13	18.24	13.46	21.25	14.48	23.32
Australasia and South Africa	1.14	1.44	1.29	1.76	1.50	2.33
WOCA total	45.89	52.94	53.67	65.78	60.55	80.09

Source: tables 5, 8, 10, 11, and 13

SUPPLY ANALYSIS

Introduction

For purpose of this study, the principal factors directly affecting the future supply of oil are

(1) the magnitude of proven reserves,

(2) net additions to proven reserves,

(3) the minimum ratio of reserves to production (R/P ratio,)

(4) the rate of oil production that exporting countries permit,

(5) net imports from the Communist countries, and

(6) synfuel production.

These six factors are not the traditional determinants of supply, e.g. product price, technology, and expected future prices, which are the more basic, elementary factors that determine supply. However, for this analysis we have found it more convenient to organize our discussion around the six factors listed above, which more directly affect the supply of oil.

After analyzing each of these factors theoretically and empirically, alternative specific assumptions are made concerning each of these factors over the next 20 years. These specific assumptions are the supply inputs for the three scenarios to be used to project future petroleum prices.

Magnitude of Proven Reserves

Proven reserves of oil are estimated to be economically attractive to produce under current conditions from fields where oil content has been confirmed by drilling and testing. Proven oil reserve figures published at the end of each year are derived from estimates made by oil companies and governments of oil-producing countries. The estimates are stated to be reserves recoverable at current prices and with current technology. They include oil recoverable by primary production methods as well as by secondary or tertiary recovery where the potential has been evaluated and facilities are planned.

Estimates of proven reserves are subject to much uncertainty and can change up or down from year to year as new assessments are made. However, for the past four years estimates published in the Oil and Gas Journal have been fairly stable at about 550 billion barrels of proven oil reserves for the world outside the Communist areas (WOCA). In this analysis we begin with the figures published at the end of 1978. At that date OPEC proven reserves were 445 billion barrels and non-OPEC reserves were 102.5 billion barrels (ref. 23).

Proven reserves for future years are then estimated by adding gross additions for the year and subtracting production for the year. This adjustment gives us proven reserves at the beginning of the following year. Proven reserves for the following year are then estimated in the same fashion.

Additions to Proven Reserves

Introduction

Gross additions to proven reserves result from genuine new discoveries, revised estimates of previously discovered fields, and improved recovery techniques. These sources are discussed in the subsections which follow.

Genuine New Discoveries

How much petroleum was originally in the ground that could eventually be extracted and how much is still there? Since 1960 most estimates of the world's total ultimately recoverable reserves of conventional oil have ranged from 1,800 to 2,200 billion barrels. Cumulative world production in 1979 was 430 billion barrels, and proven reserves were 640 billion barrels. Thus, there remain some 800 to 1,100 billion barrels of recoverable conventional oil yet to be discovered (ref. 4).

The important question for projecting productin over the next 20 years is not how much oil is yet undiscovered, but at what rate it will be discovered. Genuine new discoveries in the past would have been much lower without the discovery of the massive oil reserves of the Middle East. Over half of WOCA oil reserves have been found in an area some 1,287 by 805 km (800 × 500 mi). The chances that such a prolific region will be found again are small.

Since the resource base is finite, the oil remaining to be found must decline as oil is discovered. The most promising areas will be drilled first, and as the search moves into less likely areas, the discovery rate will probably decline. It therefore seems unlikely that genuine new discoveries will be maintained at the rate achieved over the past two decades.

Revised Estimates

Since 1950 revised estimates of previously discovered fields have been quite large. In 1950 the Oil and Gas Journal estimated proven reserves of WOCA to be 72 billion barrels. We now know that those fields actually contained 300 billion barrels, so 230 billion barrels have been added to proven reserves by reassessment of earlier estimates (ref. 4). There are two reasons for the large size of this reassessment. First, prior to 1960 oil was being discovered at a very rapid rate relative to production, and production was being rapidly expanded. Under those conditions there was little pressure to be overly concerned about the exact size of recoverable reserves in a newly discovered field. Second, there was tremendous progress in seismic techniques in the 1960's. This has resulted in a much earlier and more accurate estimate of recoverable oil in a new field. Thus, additions to reserves due to revising estimates of previously discovered fields will probably be much lower in the next two decades than in the past two.

Improved Recovery Techniques

Future additions to reserves are more likely to be obtained by improved recovery techniques. The primary method of oil production uses pressure within the ground to force oil to the surface (ref. 24). This pressure is generally sufficient to force out only about 25 percent of the oil in the ground, depending on the viscosity of the oil and the structure of the surrounding rock.

After the natural pressure has dissipated, enhanced recovery techniques may be used to get more oil out of the well. These include practices such as injecting water or gas into the well to increase the internal pressure and injecting chemicals or heat to reduce the viscosity of the oil and increase the flow of oil to the well. These enhanced recovery techniques hold great promise, but much technology yet remains to be developed for this payoff to be realized.

The average recovery rate in the United States has already risen from 25 to 32 percent (i.e., 68 percent of oil remains in the ground). The increase in oil prices in 1973-74 and again in 1979-80 certainly increased the incentive to use secondary and tertiary techniques and will continue to increase that incentive in the future. If the average global recovery rate could be increased to 40 percent by the year 2000, proven reserves would be increased by 60 percent (based on a present world recovery rate of 25%). It is likely that recovery rates will improve gradually, and annual additions to reserves from enhanced recovery will initially be small, but will increase over the next 20 years.

Historical Review

Figure 4 shows annual gross additions to proven reserves in WOCA from 1950 to 1979. Five-year averages are shown to remove year-to-year variability. The data are obtained from year-end estimates of proven reserves published in Oil and Gas Journal.

The most unusual period in the past 30 years was 1965-70, when gross additions were more than double the average. The large volume of gross additions was due primarily to reassessment of fields previously discovered, particularly in the Middle East. As previously discussed, reassessment on this massive scale is not likely to be repeated in the future.

Omitting the 1965-70 period, gross additions have fluctuated surprisingly little around an average of about 21 billion barrels per year. Gross additions outside the Middle East have been more stable than the total. The greatest variability has been in the Middle East.

Outside the Middle East, gross additions since 1955 have averaged about 10.1 billion barrels per year (omitting 1965-70). The five-year averages have all been within a range of 1.3 billion barrels. Gross

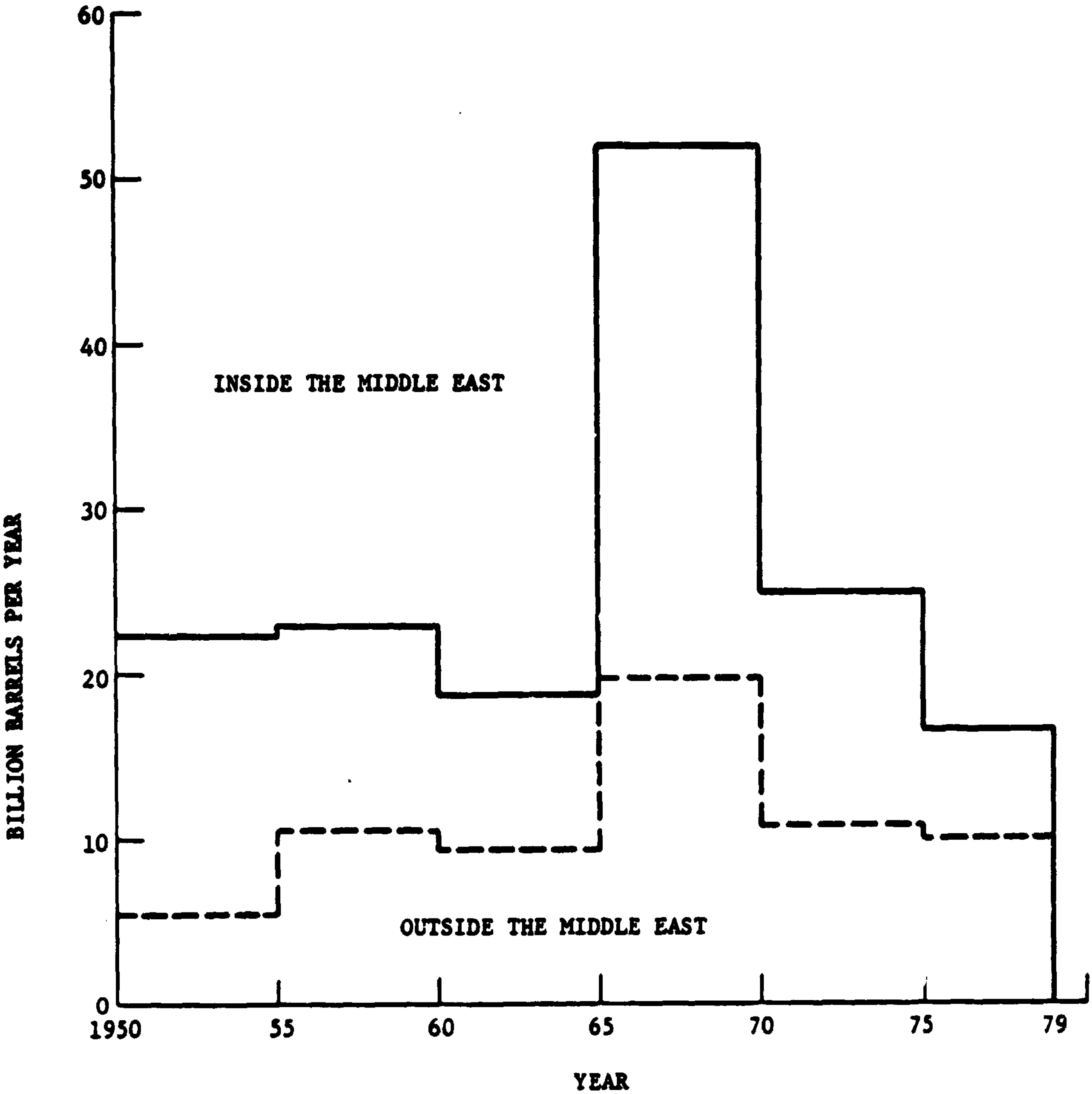

Figure 4. Gross additions to proven oil reserves in WOCA, 1950-79.

Data are five-year averages obtained by comparing year-end estimates published in Oil and Gas Journal.

additions in the last four years were virtually as great as in the late 1950's and somewhat higher than in the early 60's.

Like politics, oil discoveries in the Middle East have been more volatile than elsewhere. Gross additions in this area declined gently from 1950 to 1965, then jumped in 1965 as previously noted. Since then, gross additions have declined dramatically from 32 billion barrels to a mere 6.4 billion barrels annually in the past 4 years.

Scenario Assumptions

Based on the preceding theoretical analysis and historical review, we believe that gross additions to proven reserves in WOCA will average 15 billion barrels annually over the next 20 years. It seems very unlikely that the average will fall below 12 billion, and equally unlikely that it will exceed 18 billion barrels per year.

It is not possible to say how much of this will come from each of the three sources of gross additions. Early in the period most additions to proven reserves will no doubt be from new discoveries and reassessments. As we get closer to the year 2000, relatively more will come from enhanced recovery as the technological problems are gradually overcome.

Since World War II, discoveries in the Middle East have overshadowed those in the rest of the world. This will not be repeated in the future. Undoubtedly there is still more oil to be found in the Middle East. Indeed, proven reserves in Saudi Arabia increased just last year. However, it is extremely unlikely that more giant fields will be discovered in this tiny area. Future discoveries will be considerably more modest.

On the other hand, improvements in recovery techniques will be more beneficial in the Middle East than elsewhere. This is because the Middle East already has large reserves to which the improved techniques can be applied. Thus, gross additions to reserves in the Middle East will continue in the next 20 years, but not at the level of the past.

Based on the foregoing reasoning, we have constructed a supply projection for this study on the assumption that two-thirds of the gross additions will be in non-OPEC countries and one-third will be in OPEC countries.

In summary, our most likely scenario assumes gross additions to proven reserves in WOCA of 15 billion barrels per year. The low-supply scenario assumes gross additions of 12 billion, and the high-supply scenario assumes 18 billion barrels annually. In all three scenarios, two-thirds of gross additions are assumed to be in the non-OPEC areas and one-third within OPEC.

Reserve-to-Production Ratio

Theoretical Analysis

There are several factors that prohibit a newly discovered field from being fully exploited in a short period of time. As discussed previously, the primary method of oil production uses pressure within the ground to force oil to the surface. If the oil is extracted too fast or if too many wells are drilled into the same field, the amount of oil that can eventually be recovered is reduced. Thus, it is in the economic interest of the owner to exploit the field slowly. After the natural pressure has dissipated, enhanced recovery techniques may be used to get more oil out of the well. The use of these enhanced recovery techniques means that more time will be required to exploit the field.

Additional time is required to develop the infrastructure necessary to exploit the field. If the new field is close to existing, producing fields, a new discovery may be brought into production within two years. However, in more remote and inhospitable environments, such as the North Sea or Alaska, 5 to 10 years may elapse between discovery and the beginning of production.

Thus, it takes an average of approximately 15 years to exploit a newly discovered field. This means that, so long as new discoveries continue at the same rate, it would be difficult to increase production so fast that the ratio of proven reserves to annual production (R/P ratio) would fall below 15 to 1 (ref. 6). When new discoveries begin to decline (or cease altogether) production can be maintained but reserves will decline. At that time, the R/P ratio would then fall below 15 to 1. It will eventually reach zero when reserves are exhausted.

Empirical Review

Some recent R/P ratios for selected countries and areas are shown in table 17. Production figures for 1978 rather than for 1979 are used due to the production distortions that occurred in 1979. Highest of all are the 6 OPEC countries in the Middle East with a combined R/P ratio of 49. Reserves in this area are so huge that they do not present any technical limit on production and likely will not within the next decade and perhaps longer. These countries could easily double their production rate if they chose to and if they were willing to invest in the capital facilities necessary to do so.

The remaining OPEC nations face totally different circumstances. For the four African nations the R/P ratio is down to 27. Of these, Libya possesses most of the excess reserves, while the other three are virtually down to their technical limit. For the other three OPEC countries, the R/P ratio has fallen to 20, which is considered very low. This means that these countries have little capacity to increase production unless more oil is discovered.

Among the non-OPEC nations there is considerable diversity. As one might expect the R/P ratio for the U.S. is quite low (8). This reflects the fact that new discoveries in the U.S. have peaked and have been declining in recent years. On the other hand, R/P ratios for Mexico and Western Europe are fairly high - even higher than the African OPEC countries. These high ratios are due to the large recent discoveries in these areas and to the fact that production is not yet up to its full level. The R/P ratio for the non-OPEC portion of WOCA as a whole is 15.

Scenario Assumptions

OPEC countries. - In the seven OPEC countries of the Middle East plus Libya, proven oil reserves are so vast and R/P ratios so high that the availability of reserves does not present a relevant technical limit to oil production at the present time. Nor is it likely to do so within the next decade and perhaps not even in the 1990's. It is much more likely that these nations will establish production limits well below what would be technically possible. This line of thought will be pursued in the following section.

Table 17. Reserve-to-production ratios for selected countries and areas.

AREA	RESERVES 1-1-79 10^9 bbl*	1978 PRODUCTION 10^6 bbl/day	10^9 bbl/yr	R/P RATIO Column (1) ÷ Column (3)
	(1)	(2)	(3)	(4)
OPEC	445.1	30.2	10.87	41
Mid East	365.0	20.7	7.45	49
Africa	50.8	5.3	1.91	27
Other OPEC	29.4	4.1	1.48	20
Non-OPEC	102.5	18.7	6.73	15
USA	28.5	10.3	3.71	8
Canada	6.0	1.6	0.58	10
Mexico	16.0	1.3	0.47	34
West Europe	24.0	1.8	0.65	37
Other Non-OPEC	28.0	3.7	1.33	21

*bbl = barrels

Sources:

Reserves, ref. 23

Production, ref. 25

For the remaining six OPEC members the low and declining R/P ratios could become relevant technical limits on oil production, but even here it is more likely that they will establish production limits below the level that would be technically feasible. Thus, R/P ratio is not considered the relevant factor constraining OPEC oil production for the period under consideration.

Non-OPEC countries. - In the non-OPEC countries matters are quite different. Reserves are already falling in the U.S. and Canada. Even in Mexico and the North Sea reserves are expected to peak within the decade. For the entire non-OPEC area the R/P ratio is down to 15. Thus, the availability of reserves will be a relevant factor limiting oil production.

For this study we assume that the R/P ratio for the non-OPEC area of WOCA remains at 15. In other words, non-OPEC oil production for each year is taken to be one-fifteenth of proven reserves at the beginning of the year (assuming that there is adequate demand for this volume of oil). This same procedure is followed for all three scenarios.

OPEC Production Limits

Political and Economic Nature of OPEC

There is a great lack of understanding among professional analysts concerning the basic nature and functioning of OPEC. There is even greater misunderstanding among the populace. Consider, for example, two statements reported in the Wall Street Journal. On the one hand an aide to PLO chieftain Yasser Arafat says, "Oil is a political weapon for Arabs to use for their ends." At the other end of the spectrum, an OPEC official in Vienna says, "OPEC is not a political organization. We reach our decisions on the basis of economic data" (ref. 26).

The first statement is probably closer to public opinion, but the second seems to be closer to reality. The single overt political action taken by OPEC since its inception was the oil embargo in late 1973.* This action was in response to the Israeli-Egyptian War in which Egypt was being soundly defeated.

*Technically it was OAPEC that established the embargo, not OPEC.

The quadrupling of oil prices at the same time was far more significant than the embargo. This was a distinctly economic action, not political.

Since then there has been a great deal of talk about the politics of oil from every possible vantage point. No doubt there is great potential to use oil policies for political purposes. Nevertheless, since 1973 OPEC has not engaged in another overtly political act.

Even the Iranian cutback in 1979 was not an OPEC action. It was the act of an independent, revolutionary government, and it came in the disorganized period of transition between regimes. This may be considered a political act, but definitely not an OPEC act.

There is no general consensus among professional analysts concerning the economic nature of OPEC at this time (refs. 27-30). For example, in the popular press the term "OPEC cartel" is commonplace. Indeed, there is no doubt expressed that OPEC is a cartel and can set oil prices at any arbitrary level they please. However, a considerable volume of professional literature has arisen concerning whether OPEC is truly a cartel with considerable monopoly power or whether OPEC merely responds to market forces that would operate in its absence. The evidence is by no means obvious and overwhelming. Thus, in the present state of knowledge, any statements concerning projections of OPEC policies as far as 20 years into the future must be shrouded in considerable uncertainty.

A Passive Supply Policy

In spite of this uncertainty, it has become quite clear that the governments of the OPEC nations will not permit oil production to continue to increase passively in response to growing demand from the oil-importing nations. A passive supply policy would lead to rapid growth of production until a peak is reached, then declining reserves would force a decline in production. Such a policy would have several disadvantages. First, increasing production would require the installation of extensive capital facilities which would then become redundant as production declined. Second, it would reduce potential revenue as oil would be sold too soon at too low a price. Third, it would result in a very uneven flow of oil revenue. Thus, there can be no doubt that the

OPEC nations will choose to limit production below the level that would be technically feasible.

At exactly what level they will set production limits, however, is uncertain. In the first place OPEC, as an organization, has absolutely no production policy and no mechanism to enforce one. There is considerable opposition within OPEC to the establishment of any official OPEC production policy. Saudi Arabia in particular has steadfastly insisted that production policies are the sovereign right of each member nation. What can be said regarding likely production policies of these individual nations?

A Dichotomy of OPEC Nations

Describing a simple dichotomy of any group so diverse as the 13 members of OPEC must necessarily be on somewhat shaky logical grounds. However, it is helpful to do so for the purpose at hand: The first group is led by and epitomized by Algeria. Algeria has a poor population of nearly 20 million (ref. 31) and an oil industry that has already started the period of decline to depletion. They have large immediate needs for oil revenues. They ran sizable balance of trade deficits through the late 1970's in spite of the 1973 price increase. They barely squeaked out a surplus in 1979 and will probably return to a deficit by next year. They have every reason for wanting to push the price of oil up as fast and as far as possible. This would permit them to cut production and delay depletion of this valuable resource. Other OPEC nations fitting into this group are Nigeria, Gabon, Venezuela, Ecuador, Indonesia, and Iran.

But every producer doesn't necessarily have the same idea. The second group is led by and epitomized by Saudi Arabia. Saudi Arabia has a small population of only 8 million and enough oil to last 50 or 60 years at current production rates. They were running a $1 billion balance of trade surplus as long ago as 1970. In the fourth quarter of 1979 their balance of trade surplus was running at a $47 billion annual rate. They have virtually no need for additional revenues at the present time. They do, however, have to worry about the future when the wells in Algeria, Nigeria, and Indonesia have gone dry. They know that, as the price of oil goes up, consumers will conserve on the use of oil and substitute other energy sources for oil. More importantly, if the price is driven up too fast and too far, the consuming nations will be stimulated into developing energy substitutes. They do not want to be facing stiff competition from an abundance of oil substitutes such as coal, oil shale, heavy oil sands, nuclear power, and solar power made profitable by the high price of oil. Other OPEC countries in this group are Kuwait, Qatar, the United Arab Emirates and, to a lesser extent, Iraq and Libya.

However, it should not be concluded that this second group of OPEC countries will aggressively increase production even though they may not want the price of oil to rise too rapidly. There is a second force affecting their economic interest and their production policies. That is the question of what to do with their oil revenues. Broadly speaking, there are two uses for these funds: financing imports for domestic consumption or investment purposes and investment abroad.

These six OPEC countries have used their oil revenues to increase imports at a very rapid rate (see table 18). From 1975 to 1979 their combined imports increased 222 percent from $17.5 billion to 56.4 billion. In spite of this increase in imports, their combined balance of trade surplus (i.e. exports minus imports) increased 76 percent from $42.3 billion to $74.5 billion. In the final quarter of 1979 their combined balance of trade surplus was running at an annual rate of $104.5 billion. This is a tremendous sum of money seeking foreign investment outlets.

Some of the OPEC surplus has gone into direct foreign investment; however, there is considerable political opposition abroad to sizable direct investment by the Arab oil sheiks. For example, in the past year three large investment deals by Kuwait in the United States have fallen through, partially due to public opposition. As a result, most of these surpluses have gone into commercial bank time deposits and short-term money market instruments.

Ali D. Johany, a Saudi economist at the University of California, examined the opportunity cost of capital for Saudi Arabia and concluded that, for large sums of money, U.S. Government Treasury Bills appear to represent the most attractive alternative to leaving oil in the ground

Table 18. Combined exports, imports, and balance of trade surplus for six OPEC countries[a], 1975-79 (in billions of dollars).[b]

DATE	EXPORTS	IMPORTS	BALANCE OF TRADE SURPLUS
1975	59.8	17.5	42.3
1979	130.9	56.4	74.5
IV Qtr. 1979 Annual Rate	170.9	66.4	104.5

[a]Saudi Arabia, Kuwait, Qatar, the United Arab Emirates, Iraq, and Libya.

[b]Source: ref. 31

(ref. 32). Treasury Bill rates have fluctuated between 8 and 12 percent--primarily in response to varying inflation rates. After adjusting for inflation, the real rate of return is hardly more than one percent. This is certainly a very poor alternative to leaving oil in the ground.

Some Empirical Evidence

There are some clues regarding probable OPEC production limits. Some relevant data are accumulated in table 19. The second column shows current production capacity in each of the OPEC countries as limited by presently installed facilities. Current OPEC production capacity totals 39 MBOD. This seems to be well above the level of production that will be permitted--at least for several years.

Seven of the OPEC countries have individually announced production limits. These are shown in the last column. Iran has not announced an official limit, but has cut back production and indicated that they intend to keep production well below the level that was reached under the Shah. We have estimated their probable limit at four MBOD.

Of the five remaining countries that have not announced production limits, four are constrained by presently low R/P ratios. Only Iraq has sufficient reserves to be able to increase production to any significant extent, and they have shown no inclination to do so. If the announced production limits are in fact observed, total OPEC production capacity is reduced from 39 to 30.5 MBOD.

Another clue regarding possible production limits is given in column 3 of table 19. In 1979 oil companies were scrambling to build up depleted inventories and to stockpile oil in anticipation of rising prices. This sharp increase in demand put heavy pressure on the producing countries to increase production, and the increasing price provided economic incentive for them to do so. Most of the OPEC countries responded to these circumstances by increasing production, and OPEC production for 1979 was greater than that for 1978 in spite of Iran's cutback. Column 3 shows for each OPEC country the peak level of production that was sustained for at least three months.

A number of countries permitted production to exceed their announced limits. Saudi Arabia, in particular, increased production up

Table 19. Indicators of OPEC production limits (million barrels of oil per day).[a]

COUNTRY	PRODUCTION CAPACITY	PEAK 3-MONTH PRODUCTION IN 1979	ANNOUNCED PRODUCTION LIMITS
Saudi Arabia	11.9	9.8	8.5
Iran	6.7	3.0	4.0[b]
Iraq	3.7	3.5	
Kuwait	3.4	2.6	2.0
United Arab Emirates	2.1	1.8	1.8
Qatar	0.7	0.5	0.5
Libya	2.5	2.1	2.0
Algeria	1.2	1.2	
Nigeria	2.4	2.4	
Gabon	0.2	0.2	
Venezuela	2.5	2.3	2.2
Ecuador	0.2	0.2	0.2
Indonesia	1.8	1.6	
Total	39.3	31.2	
Production capacity if announced limits are observed:			30.5

[a]Sources
Production capacity: (ref. 29)
Peak production: (ref. 10)
Production limits: (ref. 4)

[b]Unofficial but probable limit

to 9.8 MBOD and kept production up to 9.5 MBOD into late 1980. Even they, however, did not increase production up to their capacity of 11.9 MBOD. By this measure OPEC production limits in 1979 were 31.2 MBOD.

These data indicate that OPEC production limits at the present time are in the range of 30 to 32 MBOD. There are indications, however, that these limits will be increased somewhat as time passes. In 1979 Sheik Yamani, the Saudi Arabian oil minister, published an article on the future of OPEC (ref. 33). In one scenario he projected that OPEC production might rise to 36 MBOD in 1987. He referred to this possibility as "normal resource utilization" by the OPEC countries. In another scenario he projected that OPEC production might increase to 47 MBOD by 1995, which he referred to as "strained resource utilization" by the OPEC countries.

Scenario Assumptions

On the basis of the foregoing theoretical analysis and empirical data, we conclude that the OPEC countries will continue to expand oil output in response to increasing demand. They will not, however, do so indefinitely. For our most likely scenario we have assumed that the OPEC countries will limit production to 36 MBOD. It seems highly unlikely that they would limit production to less than 33 MBOD, which is our low-supply scenario assumption. Finally, it also seems highly unlikely that they would increase production beyond 39 MBOD, which we take as our high-supply scenario assumption.

Net Imports from the Communist Countries

The Soviet Bloc

Historical trends. - Oil production and consumption for the combined areas of the USSR and Eastern Europe are shown in figure 5. From 1968 to 1974 both oil production and consumption were growing at very rapid rates. Consumption was increasing somewhat more rapidly, and, if these trends had continued, the Soviet Bloc would have ceased to become a net exporter of oil by 1979. However, beginning in 1975 the growth rate in consumption of oil declined while the previous growth in

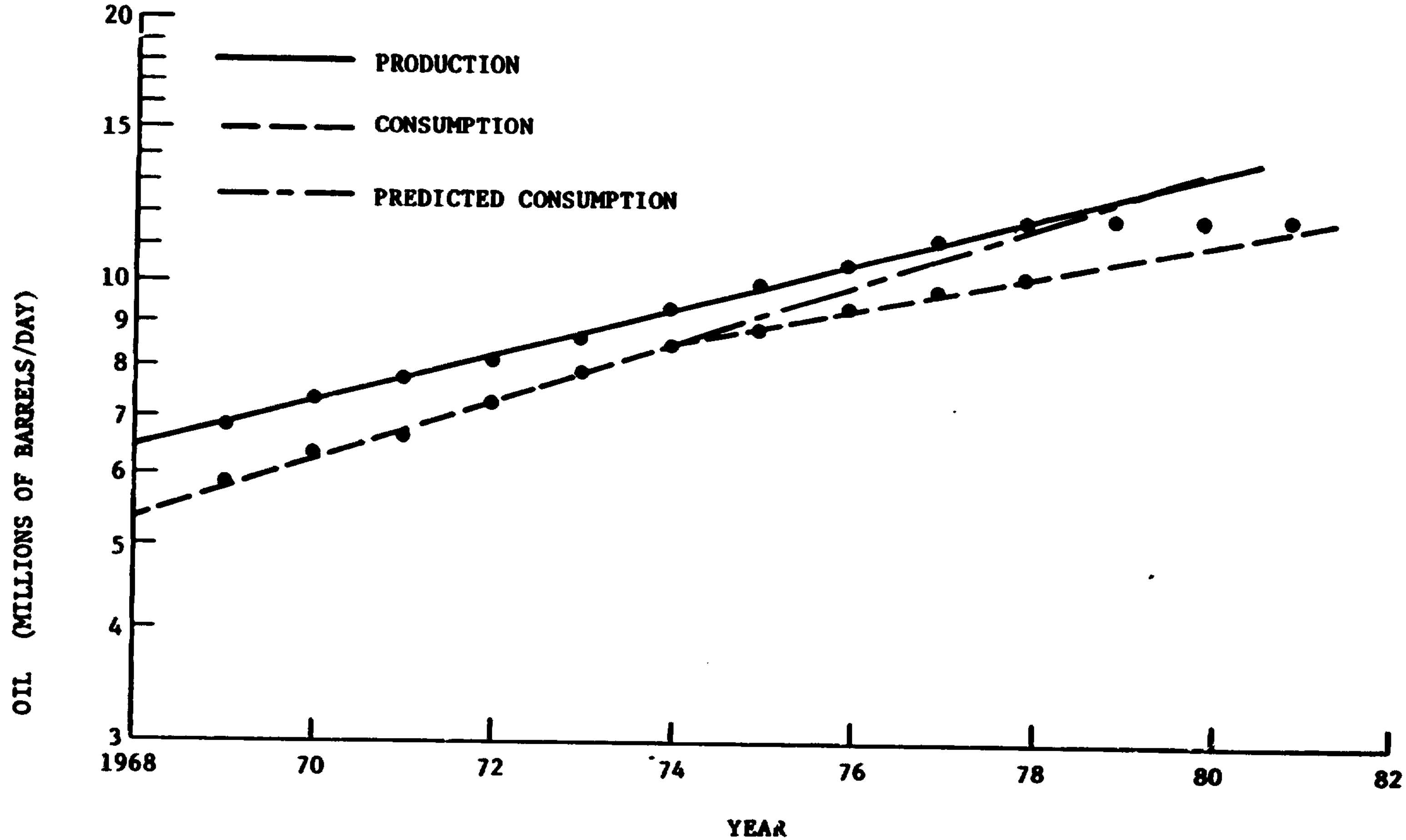

Figure 5. Oil production and consumption: USSR plus Eastern Europe (from ref. 25). 1980 values are estimated. 1981 values represent the planned level of production from ref. 34.

production was sustained. As a result, Soviet Bloc oil exports gradually increased from 1975 through 1978. If these trends were to continue, the Soviet Bloc would continue to be a net exporter of oil to WOCA through the 1980's.

Soviet oil problems. - It appears, however, that these trends cannot be continued. The Soviet Union seems to be reaching a watershed such as the U.S. did in 1970. The most extensive analysis of the Soviet oil problem is that of the CIA, first published in 1977 and updated in 1979 (refs. 35 and 36). According to the CIA, output is now stagnating or declining in all major Soviet oil-producing regions except western Siberia. In that area a single giant field, Samotlor, has accounted for the bulk of the growth in Soviet oil production in the 1970's. The Samotlor field has been worked extensively, and production there will probably peak within a year or two and begin to decline. This will be a momentous event in the Soviet oil industry.

If a decline in total output is to be averted, new fields must be brought into production. The Soviet hierarchy is aware of this problem, and in December 1977 the energy sector was designated a "leading link," meaning that the sector would get priority investment to achieve "maximum rapid results."

There are, however, serious obstacles to rapid achievement of significant results. In the first place, the Soviets' stock of proven reserves has been falling since the early 1970's. In the second place, most of the new areas being developed are in western Siberia. Not only is there a harsh climate to contend with, but the associated infrastructure must be developed. As a result, drilling targets, though substantially increased, are not being met, and the development of new, smaller fields is lagging behind plans.

In time the production decline may be moderated and perhaps reversed, by enhanced recovery techniques and by discovering and developing new areas. These developments are uncertain and subject to long lead-times. They will not affect oil production before the late 1980's.

Recent production developments. - When the CIA study was first published, it was not well received by the oil industry press. Recent events, however, tend to indicate that it is not far off the mark. Soviet oil production increased at a steady 6.3 percent annual rate through 1978. Then in 1979 the increase dropped to 2.3 percent. Moscow has just recently reported that planned production for 1981 is only 0.7 percent greater than that of 1980 (ref. 34). This is a dramatic decline in the growth rate in a very short period of time. The CIA timetable may have been a bit accelerated, but the analysis of basic forces seems quite accurate.

<u>Conservation and energy substitution</u>. - The growth rates of oil consumption in both the USSR and Eastern Europe have been among the highest in the world. After the quadrupling of oil prices in 1973-74, the growth rate of oil consumption in the Soviet Bloc was reduced substantially, although at 5.5 percent it still remains among the highest in the world (ref. 25). If the oil production problems outlined in the previous section cannot be overcome, the growth rate in oil consumption must be sharply curtailed within the next few years. This can be accomplished by (1) conservation efforts, (2) by substituting other energy sources for oil, or (3) by a reduction in the economic growth rate; however, the first two actions will be difficult to achieve.

The pattern of Soviet energy consumption is substantially different from that in Western industrial countries. In the West much oil is used in the residential and transportation sectors, and the potential for conservation in these uses is great. In the USSR many techniques now being discussed and adopted in the West are already employed on a large scale. For example, most urban space heating in the USSR is already provided through cogeneration.

In the transportation sector the bulk of intercity freight is shipped by rail, rather than by truck as in the U.S. and Europe. The Soviets have only one automobile for every 40 to 50 inhabitants, compared with 1 for every 2 in the U.S. and one for every 4 or 5 in Western Europe (ref. 35). Thus, there is substantially less potential for oil savings in these areas. Therefore, major savings in oil consumption must be obtained by upgrading industrial technology. This can, of course, be accomplished, but it is both capital intensive and time consuming. Dramatic short-run results are not to be expected.

Scenario assumptions. - The analysis of the preceding sections leads us to conclude that Soviet Bloc oil production will peak in the very near future and probably decline moderately for perhaps a decade before stabilizing. The growth rate of oil consumption will not likely be much below the economic growth rate, which is projected at about three percent. Given that Soviet net export of oil in 1980 was only some one million barrels per day, it seems inescapable that the Soviet Bloc will cease to be a net exporter at some point in the relatively near term.

This basic conclusion holds over a wide range of specific assumptions concerning the rate of decline in production and the rate of growth in consumption. The only variation is the specific year that exports will cease. For example, if production peaks in 1981 and then declines by two percent per year while consumption increases by three percent annually, exports will end in 1983. On the other hand, if production peaks and then remains at the 1981 level and the consumption growth rate is reduced to just one percent, then net exports would end in 1988. In either case the basic conclusions of this study are unaltered.

Therefore, for our projections of WOCA oil supply, we have assumed for our most likely case that Soviet Bloc oil net exports will gradually decline and become zero in 1988. For our low supply scenario, we assume that exports become zero in 1983 and, for our high supply scenario, 1992.

Communist China

China emerged as a net oil exporter in 1973 just at the time of the oil embargo and quadrupling of prices. Chinese production was increasing by 25 percent each year, and there were astonishing forecasts of Chinese petroleum reserves. Hopes ran high that China would soon challenge Saudi Arabia in the world market. But with the passage of time more sober projections are now being made about China's role as a major oil exporter.

The production growth rate declined from the high level of the early seventies to 13 percent for the 1973-78 period, and in 1979 production increased only 2 percent. Exports have risen only to about 500,000 barrels per day, which would rank China tenth among OPEC nations (ref. 25).

There are some good reasons to expect this slow growth of Chinese exports to continue in spite of large and growing reserves. Future export sales will depend on the Chinese resolution of the perceived trade-off between economic self-sufficiency and the desire to import modern capital equipment financed through oil revenues (ref. 37).

China aspires to become a major industrial power--not a major exporter of raw materials. Crude oil exports would escape China without leaving much of a direct impact on the rest of the economy. Their preference, therefore, is first to use petroleum as an input in the domestic economy, and second to process crude oil and export petroleum products.

If China were to decide to increase crude oil exports substantially, huge outlays for infrastructure would be required. China's harbors, for example, are not presently equipped to handle large tankers. In a capital-scarce economy the opportunity cost of investment in the oil industry is very high. Thus, a policy of export expansion via massive investment in the oil industry appears economically unattractive compared to a policy of moderate investment and restraint on domestic oil consumption.

Moreover, Chinese planners perceive a disruptive nature in a too rapid introduction of foreign technology. Extensive imports of Western technology through potential oil revenues could seriously undermine the fundamental policy of self-reliance. The goal of modernization is important, but so are the means for its realization. This factor militates against the emergence of China as a major world oil exporter.

For purposes of this study, we assume that Chinese oil exports will increase by 5 percent annually for the next 20 years. This will put China's oil exports at only 1.3 MBOD in the year 2000.

Synfuel Production

Introduction

Synfuels are liquids and gases readily substituted for conventional oil products and natural gas in most applications. They can be derived from oil shale, coal, heavy oil, oil sands, and agricultural products. Although the synfuel resource base is several times larger than that for conventional oil and reserves are not presently a limiting factor, there are many barriers which must be overcome, such as technology, high costs, large investments, and environmental problems. As these are surmounted, synfuels will make a significant contribution to energy supplies.

Four countries are expected to produce 90 percent of WOCA's output of synfuels in the next 20 years: the United States, Canada, Venezuela, and Brazil (ref. 21). In the U.S. synfuels will come from oil shale, coal, and to a lesser extent from oil sands. Canada and Venezuela have oil sands and heavy oil. Brazil's primary synthetic will be alcohol from sugar cane.

Technology

Production of synthetic fuels from shale, sands, and coal requires different technologies which are tailored to the characteristics of the raw material and the desired product (ref. 24). Compared to conventional oil, these resources have too much mineral content and too little hydrogen. Mcveral content is of particular concern in shale and sands because large volumes of solids must be handled in order to recover relatively small amounts of oil. This requires large amounts of both capital equipment and manpower.

Oil shale, oil sands, and coal contain less hydrogen than common fuels such as gasoline; therefore, hydrogen must be chemically added to these to produce a suitable final product which is interchangeable with conventional petroleum products. This upgrading is difficult and expensive, but modern refining technologies can perform this task.

A great deal of basic research and development work has been completed for most synthetic resources and processes. For some processes, a significant number of pilot plants has been built and tested; however, for most processes commercial-size plants have not yet been built.

For the United States the most promising synthetic resource in the near term seems to be oil shale. Shale is relatively abundant, and it contains a higher percentage of hydrogen than does coal. Modern mining equipment and methods have been demonstrated satisfactorily in several small projects. They must be scaled up to commercial operations, but they do not require major technical innovations.

Much work has been done on the development of techniques to remove oil from shale once it has been mined, as several pilot plants have successfully demonstrated. No commercial size plants have yet been built, but a number of firms appear willing to proceed to commercial-size plants with technologies which have been tested in large pilot plants (ref. 38).

Coal can be used to produce either gaseous or liquid fuels, and commercially proven processes are now available. In addition to these there are a number of second and third generation processes under development. The technology of coal gasification is generally more advanced than liquification, and commercial-scale coal projects which have been proposed are almost entirely gasification.

Oil sands and heavy oils vary widely from one deposit to another, and no single technology is applicable to all. Virtually all of the ongoing activity in oil sands recovery is taking place in Canada (ref. 39). Pilot plants have been demonstrated, and several large-scale commercial projects are soon to begin construction and should be coming on stream about 1986 and 1987. There has been little interest shown in U.S. oil sands.

Costs

The economics of producing synthetic fuels is a subject of considerable debate and confusion. Many studies have been made and many numbers have been quoted for the costs of plants and the cost to produce a barrel of product.

Some of the variation is due to different assumptions regarding equipment specifications, labor costs, interest rates, debt/equity ratios, and costs of satisfying regulations. Most of the problem, however, is due to the fact that in most cases complete commercial-size plants have not yet been built. Cost estimates, therefore, are based on insufficient data and are subject to a large margin of error.

In 1979 an engineering consulting firm reviewed and evaluated the studies which had been made. Their conclusions are shown in table 20. The use of coal to make liquid fuels would seem to be just marginally profitable at oil prices existing in late 1980. This is no doubt the reason that so few projects for coal liquification have been announced. As the price of oil rises relative to the price of coal, more firms will find investment in coal liquification economically attractive.

Extraction of oil from Canadian sands seem to be quite profitable at current market prices. Two separate large-scale commercial projects are presently seeking licenses to proceed. Each plans to produce 140,000 barrels of synthetic-crude oil per day when they are completed in 6 or 7 years.

Cost estimates for the production of oil from U.S. shale deposits are the most speculative of the three shown since they are based on small pilot plants. It would appear, however, that unless unexpected problems are encountered in scaling up from pilot plants, extraction of oil from shale can be quite profitable at current world oil prices. A number of firms appear willing to proceed.

Table 20. Comparative costs of synthetic fuels (in 1979 prices).

PROCESS	SELLING PRICE ($/barrels)	RELIABILITY OF ESTIMATE	BASIS
Coal liquification	30 - 38	Highest	Complete commercial plant built and operating
Oil sands	26 - 33	High	Extensive pilot plant demonstration
Oil shale	22 - 26	Medium	Retorts must be scaled up and detailed engineering done

Source: ref. 38

Nonprice Impediments

There are many factors which inhibit the rate of development or size of a synthetic fuels industry. Probably most important is the body of laws and regulations which apply to synfuel projects. At least 20 different Federal laws can affect synfuel plants, including the following:

The National Environmental Policy Act

The Clean Air Act

The Federal Water Pollution Control Act

Solid Waste Disposal Act

Resource Conservation and Recovery Act

Federal Land Policy and Management Act

Surface Mining Control and Reclamation Act

These have the effect of drawing out the time schedule required to bring a project on line, and create an air of uncertainty which reduces the willingness to undertake a billion dollar project.

Unfortunately, no synfuel project has yet made it through this maze of regulations, and so it is impossible to assess the total length of time required to bring a project on stream. Many commercial projects which were once active have been scrapped due to uncertainty, law suits, and regulatory delays. Three coal gasification projects and one shale oil project begun between 1970 and 1973 have still not received final approval. Based on this experience and assuming that all of these projects are at least three years away from startup, the project lead times will have ranged from 10 to 13 years. The recently enacted Sythetic Fuels Act has done nothing to reduce these regulatory impediments.

Scenario Assumptions

Although there is virtually no synthetic fuel production in the world today, the technological base for such an industry has been established. The world price of crude oil has risen to a level that makes oil shale and sands economically attractive and liquification of coal marginal. In the U.S. and Canada the Federal governments have enacted policies to encourage the development of synthetic fuel production.

On the other hand, there are some serious impediments which will limit the growth rate of this new industry. Judicious management requires that new processes be tested in large-scale pilot plants for several thousand hours before beginning construction of commercial-size facilities. Construction and break-in of the commercial plant may easily take five years. Add the time necessitated by government regulatory processes in both the U.S. and Canada and the lead time from R & D to commercial operation is easily 10 to 15 years.

We conclude that the production of synthetic liquid fuels by 1990 will be quite minimal. On the low side we expect WOCA production to reach 1.5 MBOD. On the high side, it could hardly surpass 2.5 MBOD. We have taken production of 2.0 MBOD as our most likely assumption.

Between 1990 and 2000 there is a possibility for more rapid growth if some of the more significant restraints can be reduced. Our assumption for the most likely level of output in 2000 is 8 MBOD. With estimates on the low side of 6 MBOD and on the high side of 10 MBOD.

Summary

Specific numerical values assumed for each of the three scenarios for each of the factors affecting the supply of petroleum are summarized in table 21. In the following section, these figures will be used in conjunction with the projected demand figures to examine the implications of the interaction between supply and demand.

Table 21. Summary of assumptions for projecting the supply of petroleum.

SUPPLY DETERMINANT	SCENARIO		
	LOW SUPPLY	MEDIUM SUPPLY	HIGH SUPPLY
Proven Reserves 12-31-78			
OPEC	445 bill. bbl.	445 bill. bbl.	445 bill. bbl.
Non-OPEC WOCA	102.5 bill. bbl.	102.5 bill. bbl.	102.5 bill. bbl.
Annual Additions to Proven Reserves			
OPEC	4 bill. bbl.	5 bill. bbl.	6 bill. bbl.
Non-OPEC WOCA	8 bill. bbl.	10 bill. bbl.	12 bill. bbl.
Production Limits			
OPEC	33 MBOD	36 MBOD	39 MBOD
Non-OPEC WOCA	R/P Ratio = 15	R/P Ratio = 15	R/P Ratio = 15
Net Imports			
Soviet Bloc	Zero in 1983	Zero in 1988	Zero in 1992
China	Increase 5%/yr	Increase 5%/yr	Increase 5%/yr
Synfuel Production			
1990	1.5 MBOD	2.0 MBOD	2.5 MBOD
2000	6.0 MBOD	8.0 MBOD	10.0 MBOD

SUPPLY-DEMAND INTERACTION AND PRICE IMPLICATIONS

Historical Review and Interpretation of Crude Oil Prices

1947-1973

From the mid 1950's to the early 1970's the world price of petroleum drifted steadily downward. From 1954 to 1970 the real price of Saudi light crude, deflated by the United States GNP price index, fell steadily at a rate averaging five percent per year. From 1957 to 1972 the real prices of U.S. produced crude fell 2.1 percent per year (see fig. 6). During this period proven reserves increased year-by-year, production expanded rapidly, and WOCA consumption increased by 9.3 percent per year.

This 15-year trend was brought to a dramatic climax in the early 1970's. Crude production in the U.S. peaked in 1970. The petroleum market tightened, and world crude prices increased sharply in 1971 and 1972. Then in October 1973, in reaction to the Arab-Israeli War came the famous embargo and quadrupling of oil prices by the OPEC nations. The real price of Saudi light increased 230 percent between 1973 and 1974. Production and consumption rates fell sharply in the next two years.

These startling events have generally been taken, particularly in the U.S., as prima facie evidence that OPEC is a cartel acting in typical fashion exercising its monopoly power. The previous low and falling price has been assumed to be a proper, competitive price and the new high price to be an artificial monopoly price. Great attention has been given to the fact that it costs only 50 cents or so to extract a barrel of oil in the rich Middle East fields. It has been widely believed that the cost of extraction should provide a basis for a competitive price.

Under these conditions it was generally believed that the OPEC "cartel" would soon run into the nemesis of all cartels--production quotas. Due to the tremendous, economic, political, and social diversity of the member states, agreement would not be achieved, OPEC would crumble, and the price of oil would fall back to the competitive level.

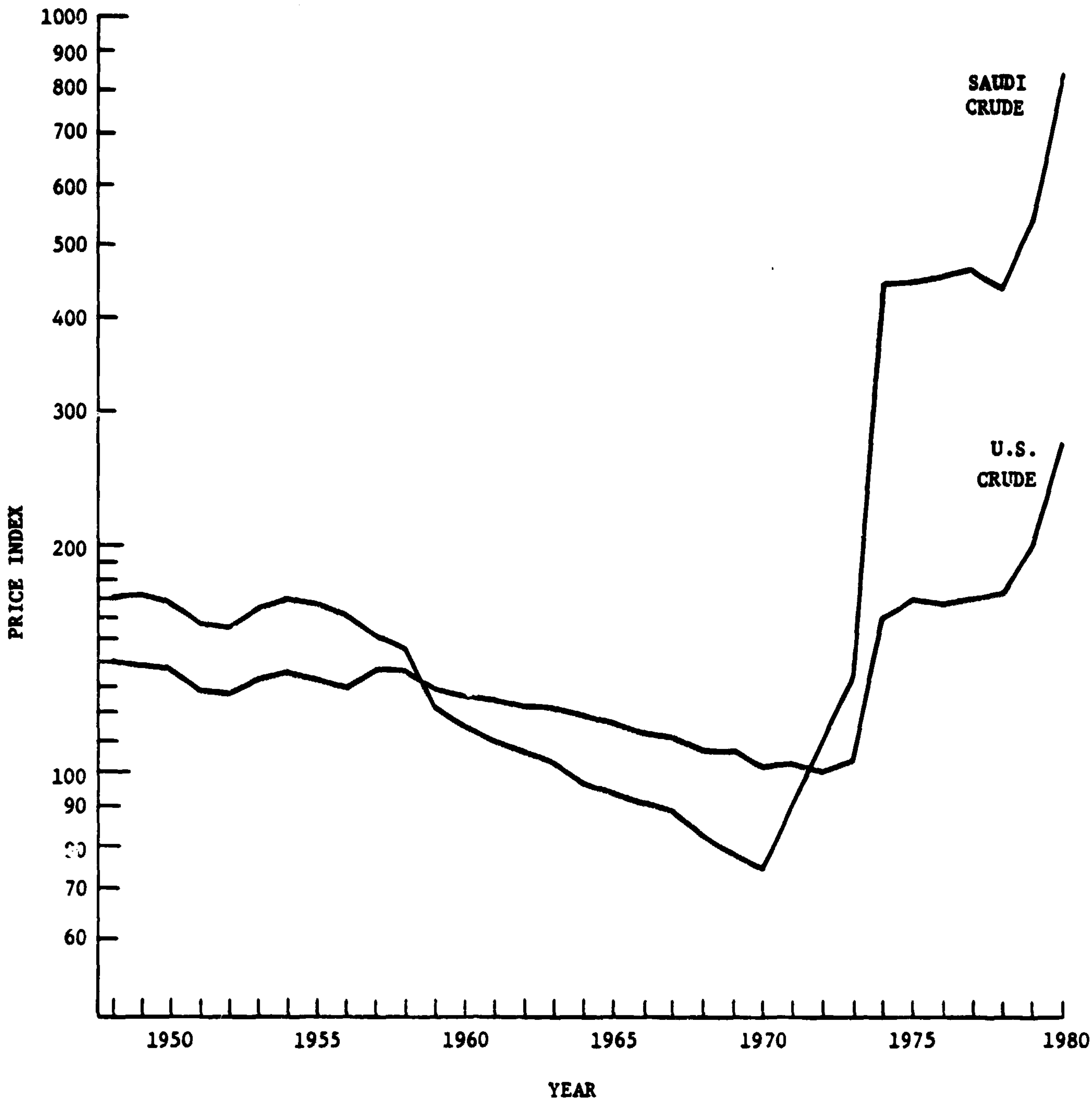

Figure 6. Deflated prices of U.S. and Saudi crude oil, 1948-1980. (1972 = 100).
Sources: Saudi crude, ref. 31
U.S. crude, refs. 40 and 41
GNP deflator, ref. 42

Quite the contrary has happened, however. OPEC has not crumbled, and the price of oil has risen even higher. Many have seen this as the continuing exercise of monopoly power by the OPEC cartel.

The authors do not accept this popular interpretation of events due to one major fact which is inconsistent with the cartel theory. The essence of a cartel is twofold. First, the members must agree to raise the product price above the level that would be determined in the marketplace if each firm acted individually to achieve its own self-interest. Secondly, this higher price necessarily implies that less product can be sold by all firms combined. How much less, of course, depends on the nature of the commodity, but in all cases it will be less. However, the higher price generally means that it is in the interest of each individual producer to expand output. If they do, the cartel will disintegrate. Therefore, the cartel must establish production quotas or require side payments from one producer to another.

OPEC has never been able to establish production quotas even though they attempted to do so as far back as the early 1960's. Venezuela, then the largest producer, wanted to use historical output as the base for quotas. Iran argued for national population. Saudi Arabia and Kuwait selected proven reserves. Agreement could not be reached and attempts to establish production quotas were abandoned (ref. 43).

A far more satisfactory thesis has recently been offered by Johany (ref. 44), who argued that both the falling price of the sixties and the increasing price of the seventies were due to changes in property rights in OPEC oil fields. Prior to World War II the Latin American and Middle East countries granted some of the major oil companies rights to search for and produce oil. The original concessions gave the producing nations a certain royalty per unit of output and granted the companies the right of ownership of crude oil deposits. Most of these original concessions would have expired by the 1990's.

These agreements were repeatedly renegotiated. Each successive agreement resulted in more favorable terms for the countries and less favorable terms for the companies. All the while there was an increasing threat of nationalization.

The significance of these developments was not lost on the oil company executives. Oil sold today at whatever price is worth more than oil left in the ground to be handed over to someone else. They were, of course, aware that increasing output depresses prices, but no company acting alone could raise prices by restricting output. In the absence of collusion, self-interest dictated that each country increase ouput as rapidly as possible. As a result, the price of petroleum fell steadily.

In October 1973 the producing nations decided to determine the price of their oil unilaterally rather than through negotiations with the oil companies as had been done in the past. Once the host countries became the ones to choose how much to produce and how much to charge, the companies became mere production and marketing agencies rather than owners of crude deposits. This amounted to a de facto nationalization of crude oil deposits.

For the producing countries, ownership rights of the deposits were certain and secure. Oil in the ground then became an alternative investment in competition with real capital investment and financial assets that might be purchased with oil revenues. Under safe and secure property rights, oil in the ground is to be preferred if one expects its price to rise faster than the rate of return on real capital or the rate of interest on financial assets.

In most of the oil exporting countries, the rate of return on real domestic investment has been driven to a very low level. The rate of interest on financial assets must be discounted by the likelihood of currency depreciation and expropriation. As a result, discount rates for the producing countries are substantially lower than for the oil companies. It is therefore sensible for each country to reduce output below the rate determined by the oil companies. No collusion or coercion is required for this reduction to take place. Each country acting independently in its own self-interest would reduce output (or output growth rates) below that prevailing prior to 1973.

Although OPEC is not strictly a cartel, there is at least one way that OPEC does significantly affect the price of oil, i.e., by reducing uncertainty. One of the standard characteristics of any oligopolistic market like oil is interdependency. An action by one firm, such as increasing price, will bring forth a reaction by others, but one can never be certain what that reaction will be. OPEC provides a forum for discussion of possible actions and reactions before the event. Uncertainty is thereby substantially reduced, although not completely eliminated. As a result, price changes are now more abrupt than before. No nation acting alone could have quadrupled its price in one move, but all of them acting jointly could do so.

1974-1980

In 1974-75, the United States and most of the industrialized world sank into the most severe recession since that of 1937-38. As a result of reduced production levels, the demand for petroleum fell sharply, and there suddenly developed a glut in the world petroleum market--in spite of the OPEC countries' reduced desires to supply crude oil.

Under these conditions the OPEC nations were unable to increase the price of crude any faster than the general rate of inflation in the United States. The deflated price of Saudi light remained roughly stable through 1978.

Beginning in 1977 the world petroleum market ran through a classical inventory-speculative cycle that practically doubled the real price of crude oil in 1979-80. In 1977 the oil companies added to their inventories at a fairly substantial rate, partially in anticipation of further price increases. Then in 1978, when the market softened and price increases failed to keep pace with general inflation, they reversed policy and reduced inventories by the largest amount within the past decade. This left them with relatively low inventories at the outbreak of the Iranian Revolution in late 1978. Iranian production fell rapidly from six to one-half million barrels per day.

At this point fear became the only relevant factor in the world petroleum market. Other producers responded quickly and increased production. From 1978 to 1979 as a whole, production increased in WOCA, in OPEC, and even in the Middle East (including Iran) (ref. 45).

This fact, however, only served to mitigate developments that were dominated by fear of a shortage and fear of further price increases.

Oil companies began to scramble for oil supplies to build up inventories. Spot market prices were bid up substantially above the official OPEC price level (ref. 46). The spot market is a very thin market, and the price is, therefore, very sensitive to sharp changes in either supply or demand.

Some of the most militant OPEC producers were very quick to follow the spot market by increasing the price of their oil. A few producers, led by Saudi Arabia, were more reluctant to see the price rise and delayed increasing their price. This resulted in a two-tier price market with a substantial disparity among OPEC producers selling the same grade of oil. Eventually Saudi Arabia raised their price to reduce the disparity and the price hawks immediately raised their price again. Prices leapfrogged in this way through 1979 and much of 1980.

Each price increase further aggravated the expectation that prices would continue to rise, which further increased the oil companies' desire to build up inventories before the next price increase. Such a speculative bubble can only come to an end when the companies have managed to increase inventories to a level that they deem satisfactory given their expectations of sales and price increases. This one subsided in the middle of 1980 and prices began to stabilize.

Petroleum Price Projections

Summary of Demand and Supply Projections

The extent to which the OPEC countries are able to increase the price of petroleum over the coming years will depend on the market conditions of demand, non-OPEC supply, and their own willingness to restrict production. Each of these factors has been discussed in detail in earlier portions of this report. The separate demand and supply projections will now be brought together and examined for price implications.

C-2

For each factor affecting supply or demand, three assumptions have been made: a value that the authors feel to be the most likely to occur and high and low ues that are considered possible but not probable. On this basis, three demand projections and three supply projections are made. These could logically be combined to construct nine scenarios; however, only three are presented here. First, there is the mid-level scenario which combines the supply and demand projections deemed most likely to occur. Next, the low demand projection is combined with low supply. The reason for this is that the slower growth of demand would result in a lower price, which in turn is consistent with a slower growth of supply. Finally, high demand is combined with high supply. The greater demand would result in a higher price which would be consistent with a higher level of supply.

These projections are presented in tables 22, 23 and 24. The numbers in columns two and three are constructed as previously explained. OPEC production, in column four, is computed as a residual by subtracting non-OPEC supply from WOCA demand. This is based on the hypothesis that consumers first obtain oil from non-OPEC producers and that OPEC is residual supplier. Column five shows any potential shortfall as a discrepancy between demand and total supply.

Potential Shortfalls

The likelihood of a potential shortfall occurring within the next 20 years appears to be possible but highly unlikely. In our mid-level, most likely scenario, OPEC production only gets as high as 31.7 MBOD. This is well below even the lowest OPEC production limit of 33 MBOD which is considered likely. In the low demand-low supply scenario, OPEC production is continually lower than the 1979 level of production. Only in the high demand-high supply scenario at the end of the 20 years is there a potential shortfall, when the demand for OPEC oil reaches 39.5 MBOD.

In the event that such a potential shortfall should occur, we would expect events to follow closely what happened in 1979-80. There would be a scramble among oil companies to obtain sufficient supplies

Table 22: Projected WOCA demand and supply for petroleum based on midlevel scenario (in million barrels of oil per day).

YEAR	DEMAND	NON-OPEC SUPPLY	OPEC PRODUCTION	POTENTIAL SHORTFALL
1980	51.0	21.3	29.7	--
1981	51.3	21.7	29.6	--
1982	51.5	22.2	29.3	--
1983	51.8	22.5	29.3	--
1984	52.1	22.9	29.2	--
1985	52.3	23.3	29.0	--
1986	52.7	23.7	29.0	--
1987	52.8	24.1	28.7	--
1988	53.1	24.7	28.4	--
1989	53.3	25.4	27.9	--
1990	53.6	26.3	27.3	--
1991	54.7	26.8	27.9	--
1992	55.8	27.4	28.4	--
1993	57.0	28.1	28.9	--
1994	58.2	28.8	29.4	--
1995	59.4	29.6	29.8	--
1996	60.6	30.5	30.1	--
1997	61.9	31.4	30.5	--
1998	63.2	32.5	30.7	--
1999	64.5	33.2	31.3	--
2000	65.8	34.8	31.0	--

Table 23: Projected WOCA demand and supply for petroleum based on low demand-low supply scenario (in million barrels of oil per day)

YEAR	DEMAND	NON-OPEC SUPPLY	OPEC PRODUCTION	POTENTIAL SHORTFALL
1980	50.3	20.7	29.6	--
1981	49.9	20.6	29.3	--
1982	49.4	20.6	28.8	--
1983	49.0	20.4	28.6	--
1984	48.5	20.6	27.9	--
1985	48.1	21.0	27.1	--
1986	47.6	21.2	26.4	--
1987	47.2	21.5	25.7	--
1988	46.8	22.0	24.8	--
1989	46.3	22.3	24.0	--
1990	45.9	22.9	23.0	--
1991	46.6	23.2	23.4	--
1992	47.2	23.6	23.6	--
1993	47.9	24.0	23.9	--
1994	48.6	24.4	24.2	--
1995	49.3	25.0	24.3	--
1996	50.0	25.6	24.4	--
1997	50.7	26.2	24.5	--
1998	51.4	26.9	24.5	--
1999	52.2	27.6	24.6	--
2000	52.9	28.6	24.3	--

Table 24: Projected WOCA demand and supply for petroleum based on high demand-high supply scenario (in million barrels of oil per day)

YEAR	DEMAND	NON-OPEC SUPPLY	OPEC PRODUCTION	POTENTIAL SHORTFALL
1980	51.6	21.7	29.9	--
1981	52.5	22.4	30.1	--
1982	53.3	23.4	29.9	--
1983	54.2	24.1	30.2	--
1984	55.0	24.9	30.1	--
1985	55.9	25.6	30.3	--
1986	56.9	26.2	30.7	--
1987	57.8	27.0	30.8	--
1988	58.7	27.8	30.9	--
1989	59.6	28.7	30.9	--
1990	60.6	29.9	30.7	--
1991	62.3	30.7	31.6	--
1992	64.1	31.3	32.8	--
1993	65.9	32.5	33.4	--
1994	67.8	33.3	34.5	--
1995	69.7	34.3	35.4	--
1996	71.6	35.3	36.3	--
1997	73.7	36.6	37.1	--
1998	75.8	37.9	37.9	--
1999	77.9	39.3	38.6	--
2000	80.1	41.0	39.1	0.1

in anticipation of the shortage. This would rapidly bid the price up as happened in 1979. It is impossible to anticipate just how high the price would go due to the crucial importance of the psychological factor in such an event. It is certainly reasonable to expect the price to double, and not surprising if it might triple before demand is reduced sufficiently to clear the market.

Price Projections for 1990

The more problematical analysis regards the price implications of the projections in the absence of a shortfall. The authors have discovered no objective technique to determine the pricing implications other than the exercise of informed judgment.

In our midlevel, most likely scenario, WOCA demand for petroleum increases from 51 MBOD in 1980 to 53.6 MBOD in 1990. However, non-OPEC supply increases at such a rate that the residual demand for OPEC oil actually falls over the decade from 29.7 to 27.3 MBOD. This decline in the demand for OPEC oil might tempt some to say that the price might fall or, at least, not rise. We believe that this is not the case, although the declining demand will certainly make it more difficult for OPEC to raise the price of oil.

Some further data on the forces impinging on the pricing decision are presented in table 25. Under our midlevel scenario assumptions, WOCA's proven reserves will fall from 545 billion barrels in 1980 to 507 billion barrels in 1990. Within OPEC the decline is even more dramatic--from 439 to 378 billion barrels.

Reserve-to-production ratios will also be falling, especially in OPEC. In spite of the decline in OPEC production, the aggregate R/P ratio for all of OPEC will fall from 40.5 to 38. This is perhaps not dramatic, but it is certainly a significant drop for a decade and contrary to all prior experience.

Synthetic petroleum production is another matter that must be considered when the OPEC countries price their oil. One strategy that could be followed by OPEC and the other oil producers would be to

Table 25. Midlevel scenario of conventional petroleum production, additions to reserves, and reserves for WOCA and OPEC in 1980, 1990, and 2000 (in billions of barrels).

AREA	PERIOD	BEGINNING RESERVES	PRODUCTION	GROSS ADDITIONS	ENDING RESERVE	BEGINNING R/P RATIO	ENDING R/P RATIO
WOCA	1980-1990	545	203	165	507	30.5	27.5
WOCA	1991-2000	507	200	150	457	27.5	22
OPEC	1980-1990	439	116	55	378	40.5	38
OPEC	1991-2000	378	110	50	318	38	27.5

increase production as necessary to keep the price of oil low enough to prevent entry of synthetic oil producers. The OPEC countries have already shown that they are not willing to do this. Therefore, we project that synfuel productions will gradually increase and be 2 MBOD in 1990 or about 3.7 percent of WOCA oil consumption.

Constituting such a small share of the market, synfuel producers would be price takers and accept the market price determined by conventional oil. The output of synfuel would merely be one addition to the WOCA supply of oil, which together with demand determines price.

Consideration of these factors leads to the conclusion that the price of petroleum will rise over the decade, though at a fairly moderate rate in comparison to the 1970's. An annual real price increase on the order of four percent would seem reasonably consistent with both the supply and demand conditions contained in our midlevel scenario. This would raise the price of petroleum from an approximate $35 per barrel in 1980 to about $52 per barrel in 1990.

In our low demand-low supply scenario, WOCA demand declines from 50.3 MBOD to 45.9 MBOD in 1990. The residual demand for OPEC oil falls from 29.6 to 23.0 MBOD--a decline of 22 percent. Such a decline in demand would put substantially greater strain on the OPEC organization. Reaching agreement on cutbacks in production would be more difficult than in the midlevel scenario case.

As a result the increase in price would be less--perhaps in the area of two percent per year increase in the real price. This would bring the price of petroleum to about $43 per barrel in 1990.

In our high demand-high supply scenario, WOCA demand increases from 51.6 MBOD to 60.6 MBOD in 1990. Non-OPEC supply increases substantially, and the residual demand for OPEC oil increases moderately from 29.9 MBOD to 30.7 MBOD. Such conditions would permit a more rapid in-crease in price in the nature of six percent per year. This would raise the price to $63 per barrel in 1990.

Price Projections for 2000

In all three scenarios WOCA's demand for oil increases more rapidly in the decade of the 90's than in the decade of the 80's. The reason for this is that the process of conversion to other fuels in the electric utility, residential-commercial, and manufacturing sectors will be substantially completed within a decade. After that, the demand for petroleum will more closely follow the level of aggregate production and increase with GNP.

In all three scenarios the residual demand for OPEC oil increases in the decade of the 90's, whereas it fell during the 80's in two of the scenarios. As a result, we can expect the price of oil to increase more rapidly during the 90's in each scenario. Table 26 summarizes the changes in WOCA demand and OPEC production over each of the coming two decades.

In the midlevel, most likely scenario, WOCA demand increases from 53.6 MBOD in 1990 to 65.8 MBOD in 2000. The demand facing OPEC increases from 27.3 to 31.0 MBOD. Although this is only slightly above their production level in 1990, it is nevertheless an increase of 3.7 MBOD over the decade. Considering the fact that by that time some OPEC countries will have passed their peak production and be on the decline, this is a substantial increase in production.

Synfuel will be substantially more significant in the market by this time, and production of synfuel is projected to hit eight MBOD by the year 2000. This figure has been subtracted from WOCA demand to calculate the demand for OPEC oil. Even in the year 2000 the output of synfuel will not be great enough to limit the price of petroleum to the cost of producing synthetic petroleum.

Proven reserves of convential oil will fall from 507 billion barrels at the beginning of the decade to 457 billion at the end. The R/P ratio for all of WOCA will fall from 27.5 to 22. Within OPEC proven reserves will decline from 378 to 318 billion barrels. The R/P ratio will fall from 38 to 27.5.

Table 26. Summary of changes in WOCA demand and OPEC production: 1980-1990 and 1990-2000 (in million barrels per day).

PERIOD	WOCA DEMAND	OPEC PRODUCTION
	Midlevel Scenario	
1980-1990	+ 2.6	- 2.4
1990-2000	+12.2	+ 3.7
	Low Demand-Low Supply Scenario	
1980-1990	- 4.4	- 6.2
1990-2000	+ 7.0	+ 1.3
	High Demand-High Supply Scenario	
1980-1990	+ 9.0	+ 0.8
1990-2000	+19.5	+ 8.4

Calculated from tables 22, 23, and 24.

These conditions will put greater pressure on raising the price of oil in the 90's than in any of the three scenarios for the 80's. In the midlevel scenario the price of crude should increase by an average of at least seven percent per year. This would raise the price from $52 in 1990 to $102 in 2000.

In the low demand-low supply scenario, WOCA's demand increases from 45.9 to 52.9 MBOD. After subtracting non-OPEC supply, the demand facing OPEC rises from 23.0 to 24.3 MBOD. This is an increase over the decade of 1.3 MBOD, compared to 3.7 in the midlevel scenario. Thus, market conditions are only slightly less expansive than in the midlevel scenario. As a result the price of oil should increase by about 6 percent annually from $43 to $77 a barrel.

In the high demand-high supply scenario, WOCA demand increases from 60.6 to 80.1 MBOD over the decade, and the demand facing OPEC rises rapidly from 30.7 to 39.1 MBOD. This would require an increase in OPEC production of 27 percent over the decade. Such pressure would increase the price at a rate of at least 10 percent per year. This would increase the price of oil from $63 a barrel in 1990 to $150 in 1999 just before the point that a potential shortfall is projected.

All of these price projections are summarized in table 27.

Historical Review and Interpretation of Jet Fuel Prices

Figure 7 shows the real price of kerosene products, including jet fuel, in the United States (deflated by the GNP price deflator) for the period 1948-1980. Also shown are the deflated prices of U.S. crude and Saudi crude. All prices are indexes with 1972 equal to 100.

Examination of these graphs indicates that the price of kerosene products follows the price of crude quite closely. From 1948 to 1972 the price of kerosene products tracks the price of domestic crude more closely than it does the price of Saudi. This is consistent with theoretial expectation. The relevant cost for price determination is marginal cost. During this period the price of Saudi crude was less than the price of demestic crude. During much of the period the United

Table 27. Crude petroleum real-price projections for 1990 and 2000 (in 1980 dollars per barrel).

YEAR	LOW DEMAND - LOW SUPPLY SCENARIO	MIDLEVEL SCENARIO	HIGH DEMAND - HIGH SUPPLY SCENARIO
1980	\$ 35	\$ 35	\$ 35
1990	\$ 43	\$ 52	\$ 63
2000	\$ 77	\$102	\$150[a]

[a] projected price for 1999 immediately preceding a projected shortfall

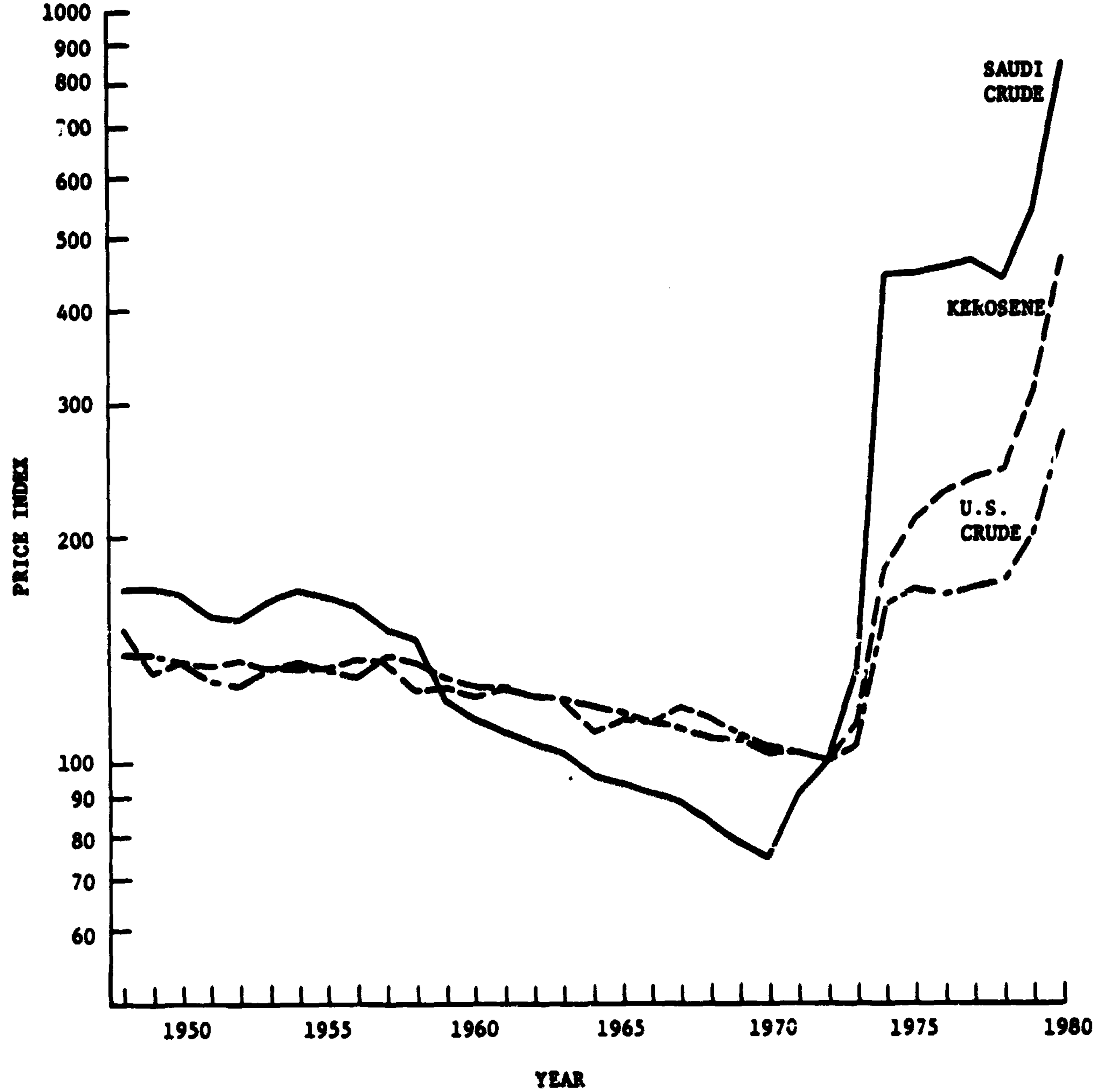

Figure 7. Deflated prices of U.S. crude, Saudi crude, and U.S. kerosene products, 1948-1980 (1972 = 100).

Sources: Saudi crude, U.S. crude, and GNP deflator, fig. 6
Kerosene, refs. 40 and 41

States restricted imports of crude oil in order to support the domestic price. Therefore, the marginal cost of crude to the refiner was the higher priced domestic crude.

In the 1970's, conditions changed dramatically. Domestic production peaked and began to fall, the United States became a net importer, the world price of oil increased dramatically, and the United States imposed price controls on domestic crude and refined products. Under these changed conditions the marginal cost of crude became the world price of imported oil. Theory would lead us to expect that the price of refined products should then follow the world price of oil rather than the domestic price.

Examination of the graph indicates that, indeed, this is what happened, although not so closely as in the earlier period. Beginning with the increase in the price of Saudi crude in 1973, before the quadrupling and embargo, the price of kerosene products began to track the price of Saudi crude more closely than the lower priced domestic crude.

These observations are crucial to a proper interpretation of these events. First, the price of kerosene products increased substantially less than the price of Saudi crude from 1972 to 1978. Second, the price of crude leveled off in the 1974-78 period, while the price of kerosene products continued to increase by decreasing amounts. Third, in 1979-80, the price of kerosene products increased in line with the price of Saudi crude.

We conclude that 1972-78 was a distinct and unique period in the relationship between the price of crude and the price of kerosene products, including jet fuel. This may have been due to the price controls which were imposed in late 1971 and removed on jet fuel in February 1979. There is some doubt concerning this explanation because many refiners had unrecouped costs and legal authority to raise the price of refined products above the actual level (ref. 45).

Another explanation is that the combination of quadrupling of the price of crude and the ensuing recession was so dramatic and unprecedented an event that it took the industry four years to return to something of an equilbrium. Whatever the reason, it is clear that the period from 1972-78 was unique and does not provide a proper basis to project into the future.

In 1979-80 with price controls removed from jet fuel and having recently experienced a dramatic price increase, the price of kerosene products closely followed the increase in Saudi crude.

To summarize, the price of kerosene products closely followed the price of U.S. crude prior to 1972 and Saudi crude after 1972, with a disruption of the relationship between 1972 and 1978.

Econometric Analysis

To measure more precisely the relationship discussed in the previous section between the price of crude and the price of jet fuel, an econometric analysis was performed. The dependent variable in the regressions is:

DEKERO = Index of wholesale price of the kerosene product group excluding taxes and deflated by the U.S. GNP price deflator (1972 = 100).

The principal independent variable is:

DEMCCRUD = Deflated marginal cost of crude oil. This variable is constructed by splicing the price of domestic crude for 1948-72 and the price of Saudi crude for 1972-80. It is an index with 1972 = 100.

Additional independent variables are:

DUMMY = A dummy variable to capture the disturbance in relationship between DEKERO and DEMCCRUD previously discussed. It is equal to zero for 1948-71 and 79-80 and for projecting into the future. For 1972-78 it is equal to DEMCCRUD.

OPRATIO = Operating ratio or the percentage of refinery capacity being utilized; and

KEROSHRE = Kerosene product group share (%) of the total market for petroleum products.

. All data are annual figures for the period 1948-1980. Price of U.S. crude, refinery operating ratio, quantity of kerosene products produced, and total petroleum products produced are from references 40 and 41. Price of Saudi crude is from reference 31. GNP deflator is from reference 42.

As a first approximation, DEKERO is regressed on DEMCCRUD alone. The relationship is given in table 28 in both linear and natural logarithmic forms. Numbers in parentheses are t values for the coefficients of the variables. Coefficients of determination and Durbin-Watson statistics are also shown.

Coefficients of determination for both equations (1) and (2) are above 0.9 and are highly statistically significant. In both equations the coefficient of DEMCCRUD is statistically significant at a very high level and confirms the visual observation of a close correlation between the two variables. The low value of the Durbin-Watson statistic indicates the presence of the statistical problem of autocorrelation, which tends to bias the coefficients of the variables. Equation (3) shows the regression results when the remaining subsidiary independent variables are included in the regession. The R^2 is increased by a significant amount. Coefficients of all the variables are statistically significant at the five percent level or better. The Durbin-Watson statistic indicates that the equation is reasonably free of the problem of autocorrelation. In short, this equation shows highly respectable statistical properties. On this basis it is acceptable for projecting the price of jet fuel.

Jet Fuel Price Projections

The regression results form the previous section provide the essential basis for projecting the price of jet fuel for the years 1990 and 2000. For the projections, the refinery operating ratio is set equal to the average value for the 1948-80 period. The kerosene product share of the market is set equal to its 1980 value. Prices of crude oil are those previously projected and reported in table 27.

Table 28. Regression results with DeKero as the dependent variable.

EQUATION NUMBER	COEFFICIENTS ON DEMCCRUD	DUMMY	OPRATIO	KEROSHRE	INTERCEPT	ADJUSTED R^2	D.W.	FORM
(1)	0.40 (19.4)[a]				0.71	0.92	0.5	Linear
(2)	0.55 (18.1)				0.22	0.91	0.5	Log
(3)	0.48 (33.1)	-0.13 (-9.8)	0.80 (1.6)	-367.2 (-2.7)	18.5	0.98	2.1	Linear

[a] Numbers in parentheses are t values.

With these inputs, the price index for the kerosene product group is calculated. The percentage increases thus determined are then applied to the 1980 price of jet fuel to calculate projected prices of jet fuel for 1990 and 2000 for each of our three scenarios. These projections are shown in table 29.

Table 29. Projected price of jet fuel in the United States in 1980 prices (dollars per gallon).

	SCENARIO		
YEAR	LOW DEMAND-LOW SUPPLY	MIDLEVEL	HIGH DEMAND-HIGH SUPPLY
1980[a]	$ 0.92	$ 0.92	$ 0.92
1990	$ 1.11	$ 1.32	$ 1.57
2000	$ 1.89	$ 2.46	$ 3.56[b]

[a]ref. 45

[b]Estimate for 1999 preceding a projected shortfall in 2000.

CONCLUSIONS AND RECOMMENDATIONS

The doubling of the price of petroleum following the Iranian Revolution initiated a set of responses that will revolutionize the petroleum market over the next 20 years. Principle among these is the substitution of other fuels (especially coal and natural gas) for petroleum. This process of interfuel substitution cannot be accomplished in short order but will require a considerable period of time. We hypothesize that the full adjustment will take some 20 years, but most conversion will occur during the 1980's. After that, the demand for petroleum will more closely follow the growth of total world production of goods and services.

From this analysis, it follows that during the 1980's the demand for petroleum will increase slowly or decline, depending on the exact rate of conversion and the rate of economic growth. The conversion process being discussed should not be construed as the sole cause of the soft market in the winter of 1982. The current low level of demand is due primarily to the general economic contraction throughout most of the industrialized world. With the economic expansion which is expected over the next few years, the demand for petroleum should increase back to the trend level projected, while the conversion process continues.

With the major portion of the conversion process completed, the demand for petroleum will increase more rapidly during the 1990's. This conclusion holds regardless of which demand scenario comes to pass.

On the supply side of the petroleum market, the recent price increase will stimulate supply through new discoveries and improved recovery techniques. Gradually at first, then gaining momentum in the 1990's, there will be an increasing supply of synthetic fuels--particularly from oil sands and shale.

With these rather favorable and optimistic developments on both sides of the market, the price of petroleum should rise somewhat slowly through the 1980's. However, with the tightening of the market in the nineties, the price can be expected to rise at a significantly higher rate.

Note that all of this assumes a relative tranquility and political stability in the Middle East. Obviously, this is a rather shaky assumption to make for a 20-year projection.

Based on these conclusions, we recommend that the government take the following actions:

1. The government should pursue various techniques to stimulate research and development in additional ways to conserve in the use of petroleum without reducing the standard of living. Much of this R&D can and should be performed by the private sector; however, R&D can be expected to yield external benefits that accrue to society at large. This portion should properly be performed by government.

By its very nature R&D involves extensive lead times--measured in decades--before it comes to fruition in the marketplace. Therefore research today must be looking to the needs of the mid-nineties and beyond.

2. The government should pursue varios policies to stimulate the establishment of a sound, viable, synthetic fuel industry--particularly shale oil. The principle economic incentive, the price of petroleum, seems to be in place. The main impediment appears to be the maze of governmental authorities that must grant permission before projects can go forward. The entire process for reviewing projects should be thoroughly examined and streamlined so that projects can be either approved or rejected in much less time than is now required.

3. Some difficult decisions must be made concerning how much environmental pollution is to be permitted. Zero pollution is simply not the answer if we are to continue to raise the average standard of living. Consequently, some rational trade-off must be made between environmental pollution and energy production.

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