WORLD ENERGY SUPPLY AS A PRICE DEPENDENT VARIABLE

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Introduction

In the area of energy resource management, more uncertainties have developed in the last five years than in the previous twenty. In Figure 1, the posted price (real and current) of world crude oil is shown from 1960 through 1978. After a long period of relative stability, this price rose from $2.59 per barrel to $11.65 per barrel in one year (1973). A strong cartel (OPEC) developed that now asserts control over a large fraction of petroleum traded in international markets. This development has substantially affected the price outlook for other fuels as well. International energy markets and other segments of world economies have been changing rapidly in the past five years in a still emerging response to the formation of the cartel.

A common perception of the future[1,2] is that there will be increasing disparity between growing demand and dwindling non-OPEC supplies and ever rising energy prices. In this view, the United States and other major industrial nations are confronted with the likelihood of a growing need for oil imports and greater dependence on foreign supplies. The resulting political and economic problems impel government and business planners to consider alternative responses.

In a recently completed two-year study of world energy supply and demand at SRI International, a somewhat different picture of the likely developments in future world energy balances has been obtained.

Summary

The principal conclusion of our analysis of world energy supply and demand is that there are adequate opportunities for increasing conventional supplies of hydrocarbon resources on a worldwide basis, diversifying the sources of supply, and substituting among fuels to allow an orderly development of alternatives through the remainder of this century and for some time into the next without large price increases. This conclusion is based on the following series of observations and estimates:

- The conventional techniques used to make estimates of resource availability in terms of a single number representing reserves are not adequate information to determine future supply/demand balances. Resource availability should be discussed in terms of recovery costs and market prices.

- There is no long-term condition of imbalance in supply and demand where "gaps" occur. In the absence of artificial price controlling regulations, prices respond well in advance of this impending situation to prevent just such a possibility.

- International energy supply and demand price elasticities have been broadly underestimated.

- Current estimates of proven oil reserves do not accurately reflect the long-range impact of higher petroleum prices. Higher oil prices are encouraging exploration and the application of advanced recovery techniques so that future additions to proven reserves will be greater than they would have been at lower oil prices.

- The opportunities for fuel substitution are greater than has generally been recognized.

- There will be an expansion of the class of major oil exporting nations to include some new members in the next few years (Mexico, the United Kingdom, Norway, China, etc.). The disparity of national interests will cause highly varied responses to changing supply/demand situations in the world markets. Those who join OPEC will increase the diversity of cartel membership and the complexity of production allocation and pricing decisions to be settled.

This view of world energy availability has not been the consensus. As mentioned earlier, many other analyses anticipate serious supply/demand imbalances in the 1980s. These different viewpoints arise principally from certain features of the present analysis described below that are not usually considered in this kind of study. These features do not eliminate the substantial uncertainties inherent in this kind of analysis from unanticipated political, social, or technological developments (e.g., wars, embargoes, a major depression, or a breakthrough in photovoltaic cell economics, etc.), but they do provide a powerful tool for evaluating the potential sensitivity of the results to these changes.

<u>The Analytical Structure</u>

It has been customary for energy analysts to hypothesize a "scenario" price or set of prices for some reference energy source, usually Middle East oil, and then try to determine how the demand for oil will grow and what supplies will be produced at this price. In that approach, demand is growing exponentially and supplies are relatively static. It is not surprising then that at some point demand exceeds the supply, creating an "energy gap."

The procedure outlined above simplifies the analysis by ignoring the feedback among energy supply, demand, and prices, and the effects of prices on interfuel substitution. That approach is not complete, however, because it ignores the dynamics of energy pricing through time.

Energy prices respond not only to the instantaneous supply/demand balance but also to producers' and consumers' perception of the future. If a producer perceives that his resource is growing scarce because of depletion of the reserves, he will demand higher prices now for incremental production. How much he can raise his price depends upon a variety of time dependent variables including:

- The rate at which the resource is being depleted now and what rate might be expected in the future

- That producer's potential loss of market share to other producers of the same resource or to competing substitutes or to declining demand

- The impact that higher prices would have on the stimulation of new technology to replace future demand for the product

- The individual producer's preference for present income versus deferred, perhaps higher, income at some future time.

Therefore, at any given time in energy markets, a variety of individual decisions are being made by producers and consumers that rebalances the supply/demand equations.

The quantitative analysis here has centered around the development of a world energy model[3] built in two parts and called ENDEM and FUELCOM, respectively.

ENDEM (Energy Demand Model) is a representation of our analysis of energy demand development on a regional basis for 15 different end-use categories (steelmaking, chemicals, residential/commercial space heat, transportation, etc.) as a function of assumptions about macroeconomic variables such as population, GNP per capita, and trade balances. FUELCOM (Interfuel Competition Model) represents our analysis of the competition among different fuels (oil, coal, gas, nuclear, hydro, and others) for each of the end-use markets in each region. FUELCOM calculates market clearing prices for each fuel in each region based upon obtaining supply/demand balances at each point in the energy network from resource production, through conversion and transportation links, to end-use consumption in each of the demand markets used by ENDEM.

The approach used in this study to integrate the demand and supply work is an iterative process. At first a tentative economic projection (GNP growth rates, trade flows, industrial production, consumption) is used to calculate tentative energy demand projections by end-use category for each region (at the highest level of regional aggregation) in ENDEM. These projections are used in FUELCOM to obtain an overall energy demand/supply balance at a market clearing price for each fuel in each region over the entire time horizon. This tentative energy balance is compared by the analyst with the assumptions on energy prices and trade flows implicit in ENDEM. If they are consistent and reasonable in the judgment of the analyst, a converged solution is assumed. If they are not consistent, a somewhat revised economic outlook is made to take into account the new information on energy prices and trade flows, and the process is repeated until a converged solution is obtained. When this process is completed at the first level of regional disaggregation and a satisfactory convergence obtained, a further regional disaggregation is begun using the larger region results as constraints on the more detailed analysis.

The principal outputs of the energy model are projections of the regional market clearing prices for fuels over time, associated production quantities, flows through transmission links, capacities of conversion processes, and demands for distributed fuels. Clearly, the projections can be sensitive to the inputs to the model. By varying the key model inputs and assumptions over reasonable ranges of uncertainty, the sensitivity of the projections to these inputs are determined.

Results--Demand

Long-range projections of world energy demand have been changing substantially in recent years. Today's estimate for total primary energy demand for the year 2000 is more than 20 percent lower than earlier estimates.[4] For example, Exxon's recent estimate of world energy demand for the non-Communist world in 1985 of 125 million barrels of oil equivalent per day is down 24 percent from estimates of 165 million barrels of oil equivalent per day made in 1973 for the same region. These differences are related to changing views of the future growth of regional macroeconomic indicators such as GDP and population, as well as to changes in the relationship of energy consumption to these variables and to price. The quadrupling of world oil prices since 1973 (shown in Figure 1) has had an important impact on all of these estimates. Even if demand often appears to be somewhat inelastic to price changes in the short term, long-term effects of the increases shown in Figure 1 are making big changes in year 2000 projections.

The regional variation in anticipated primary energy consumption obtained in this analysis is shown in Table 1. Although OECD nations still account for nearly half of world energy consumption in year 2000, in general, developing nations will show higher growth rates of energy consumption than developed nations because they are starting from much lower absolute values, have higher population growth rates, less room for improvements in the efficiency of consumption, and are expected to make considerable effort to "narrow the gap" in GDP per capita.

The changing relationship anticipated between energy and GDP is most dramatic in the United States. In 1970, a barrel of oil equivalent energy was used to generate about $140 in gross domestic product (in constant 1978 dollars). By the year 2000, it is expected that the same amount of energy will generate about $191 in GDP or a 37 percent increase in economic efficiency in energy use. These efficiency improvements are achieved despite the fact that electricity consumption is expected to grow faster than total energy, and average electric power efficiencies are lower than for the direct consumption of fuels. Such changes are occurring worldwide, although not so dramatically in nations that have historically not had access to the same abundance of relatively low-cost energy as the United States.

Table 1

PRIMARY ENERGY CONSUMPTION
(Millions of Barrels of Oil Equivalent per Day*)

	1960	1970	1980	2000
United States	20.7	31.7	38.9	58.6
Canada	1.8	3.0	4.5	7.3
Western Europe	12.5	22.0	27.3	46.3
Japan	1.8	5.6	8.8	17.9
Mexico/South America	2.2	4.2	7.5	20.9
Africa	1.0	1.8	3.4	7.6
Middle East	0.7	1.4	3.3	10.5
Centrally Planned Economies	18.2	27.1	42.9	87.5
Remainder	2.2	4.6	7.6	19.1
Total	61.1	101.4	144.2	275.7

* For most of this paper, the units of energy demand will be expressed in oil equivalent barrels to evaluate how changes in forecasts or assumptions can affect world oil trade--oil being the "swing fuel" in international energy forecasting.

The results of the FUELCOM interfuel competition analysis corresponding to the ENDEM regional energy demand of Table 1 is shown in the highly aggregated curves of Figure 2. There are no dramatic surprises shown in this figure. World demand for all forms of primary energy is expected to continue to grow to the end of the century but at considerably lower rates than for the most recent 25-year historical period. The average historical growth for 1950 to 1975 was about 5 percent, whereas for the forecast period the analysis indicates world average demand growth of about 3.4 percent.

Oil, coal, natural gas, and nuclear energy are all expected to play major roles in supplying the increased energy consumption, while hydroelectric energy supplies will become increasingly important in some of the less developed areas.

Worldwide, nuclear power generation growth rates, although still considerable, will be substantially lower than most projections of the recent past because of previously unanticipated political, social, and economic problems. Gas consumption, on the other hand, will probably grow more rapidly than expected.

Primary Resource Economics

One of the most difficult and important considerations in analyzing energy supply and demand balances is to quantify the long-term economics of primary resource production. In the classical economic sense, a long-term dynamic supply curve that specifies a price-volume relationship across a 50-year time horizon or longer is required for each resource. The key issues that must be considered with regard to primary resources are: depletion, reserves, lease cost, production, development, exploration, technological change such as enhanced oil recovery or advanced mining techniques, and wellhead or mine-mouth price.

The main shortcoming of most published resource estimates is that price is not explicitly included; only quantity if considered. Differences among estimates can thus be due to differences among assumptions and definitions as well as to differences of opinion or uncertainty about the resource base itself. To analyze strategic energy decisions and to estimate resource availability, considering resource volume estimates alone is not sufficient; joint price-volume relationships for each resource must be estimated and made explicit.

Resource supplies represented in FUELCOM on a regional basis are crude oil, natural gas, coal, nuclear fuel, hydroelectricity, oil shale, and tar sands in specific regions. Each of these is described in each resource basin by a different supply curve giving the marginal cost of incremental production of that resource as a function of total cumulative production in that basin. Probable in-place resources, past discovery and development histories, and expected future finds are defined in the analysis. In estimating the costs of reserves, price-dependent costs such as lease bonus payments, royalties, and production taxes are distinguished from ordinary exploration, development, and production costs.

Specifically excluded from the marginal cost is economic rent (lease bonus payment and additional profits above the 15 percent return on investment). The marginal cost of a resource is the minimum acceptable price at which the supplier would be willing to develop and sell that resource. Economic rent, reflected in a price higher than the minimum acceptable price, is computed by FUELCOM as a function of the prices of other energy sources and the dynamic characteristics of the market. For OPEC producers, a specific cartel pricing algorithm is used.[3]

FUELCOM uses regional marginal cost estimates including 26 oil resource curves, 26 gas resource curves, 22 coal curves, and 13 miscellaneous resource curves, including estimates of the costs of hydropower, nuclear fuel, shale oil, and tar sands in different regions. As an example of this type of curve, Figure 3 illustrates the marginal cost curves for world cumulative supplies of crude oil, natural gas, and coal. These world total curves are much too aggregated for use in FUELCOM, but are valuable to illustrate several important points. As shown, coal is available in vast quantities at low recovery cost. Recently,[5] the estimated in-place coal resource base of the world was increased over 18 percent above the 1974 estimates at the 1978 World Energy Conference. Similar modifications in estimates of traditional supplies of oil and gas are being made showing increases in production potential from old and new areas, e.g., Mexico, China, Canada, the North Sea, etc.

From the results shown in the curves of Figure 2, the cumulative world consumption of oil anticipated from 1975 to 2000 is 700 billion barrels. For natural gas and coal, the cumulative consumption is 340 and 460 billion barrels of oil equivalent, respectively. Although there is not sufficient information in the curves of Figure 3 to calculate a year 2000 market clearing price for each resource, it is apparent that world supplies of these resources are by no means exhausted at the end of the century. In fact, there is considerable uncertainty as to whether the market prices of conventional supplies will even reach the levels required to make sources of synthetic hydrocarbons commercially competitive by that time. Superimposed on the marginal cost resource curves of Figure 3 are the minimum cost estimates found in the literature[6] for synthetic crudes from coal, synthetic natural gas (SNG), and oil from shale. The early 1978 posted price of OPEC marker crude oil is also shown for comparison. In this economic environment, because of price competition from conventional supplies, it is not likely that any unconventional supplies of energy will become commercially available on a global scale before the end of the century. However, in specific locations, shale oil, heavy oils, and synthetic fuels from coal may contribute a measurable fraction of regional energy supplies.

As an example of evolving trade patterns, Figure 4 shows how petroleum production patterns have changed since 1950 and are expected to change in the future. In 1950 there were four significant production areas in the world--North America, Central and South America, the Middle East, and the Soviet Union. By the end of the century, according to this analysis, there will be several more. The Middle East, of course, remains a major supplier of oil to the world, although its share of world markets will be smaller in the future. An important result of this analysis is the growing role of producers that are not presently in OPEC--Mexico, the United Kingdom, Norway, China, and several nations in Africa and Asia. Each is faced with the need to develop supplies and to market them to provide capital for economic development. In addition, considerable development of coal and nuclear resources displaces oil and gas from utility and industrial markets. Since OPEC must continue to function as the marginal supplier of petroleum to maintain control over international oil prices, all of these development impact strongly upon cartel production growth rates and together suggest that--for a time--the organization will find itself in the passive position of attempting to preserve its gains. Future growth in world demand for oil will very likely be significantly slower than the pace that was seen in the years prior to 1974. Non-OPEC oil production will continue to grow, probably at a rate higher than many observers expect. If the organization is to continue to set and maintain the world price of oil, it must also support the price for all producers of oil moving in international trade. Many of the newer oil exporters such as Norway, the United Kingdom, and China are not likely to become part of OPEC because of their history, politics, or because--for one reason or another--they do not view membership in the cartel as in their best interests. A special problem for the cartel is that non-OPEC producers can take advantage of the cartel price without assuming any of the burdens associated with withholding production to support prevailing price levels. As mentioned previously, it is expected that those who do join OPEC will increase the diversity of cartel membership and the complexity of production allocation and pricing decisions to be settled. The combination of these factors is likely to place pressure on OPEC's market share and--at least over the near term--continue to reduce the ability and willingness of cartel members to make higher real prices stick.

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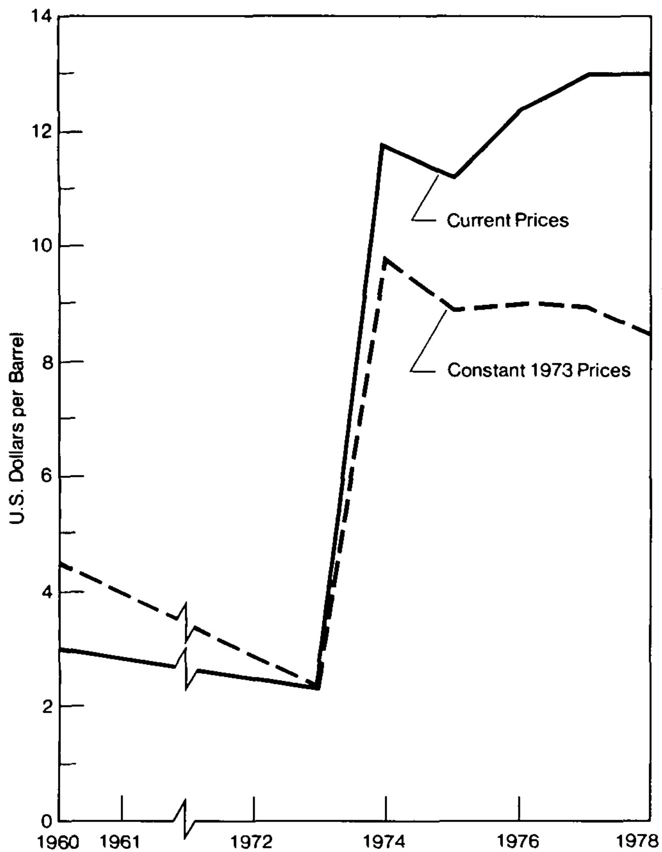

Figure 1. OPEC Prices of Oil

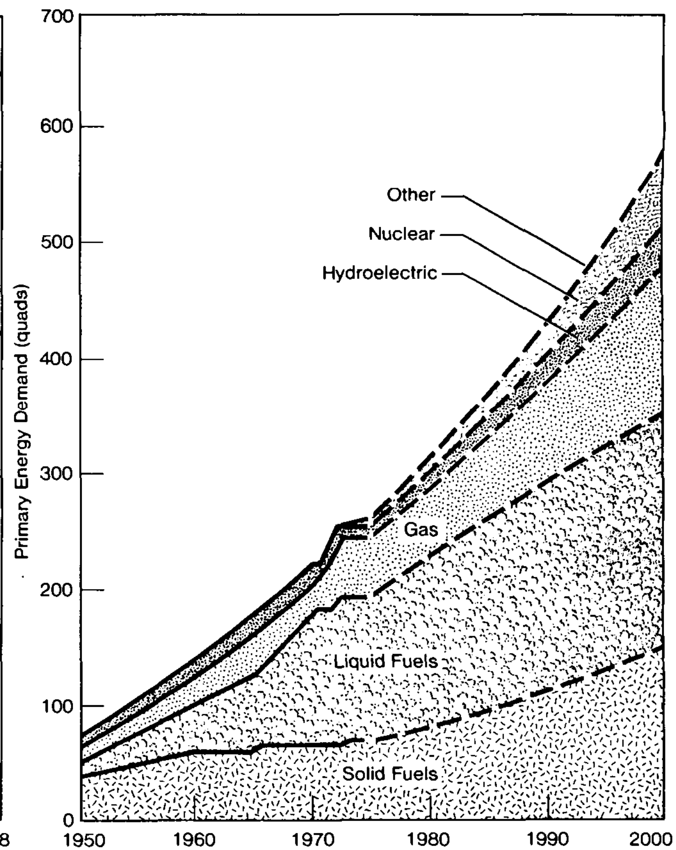

Figure 2. World Energy Consumption

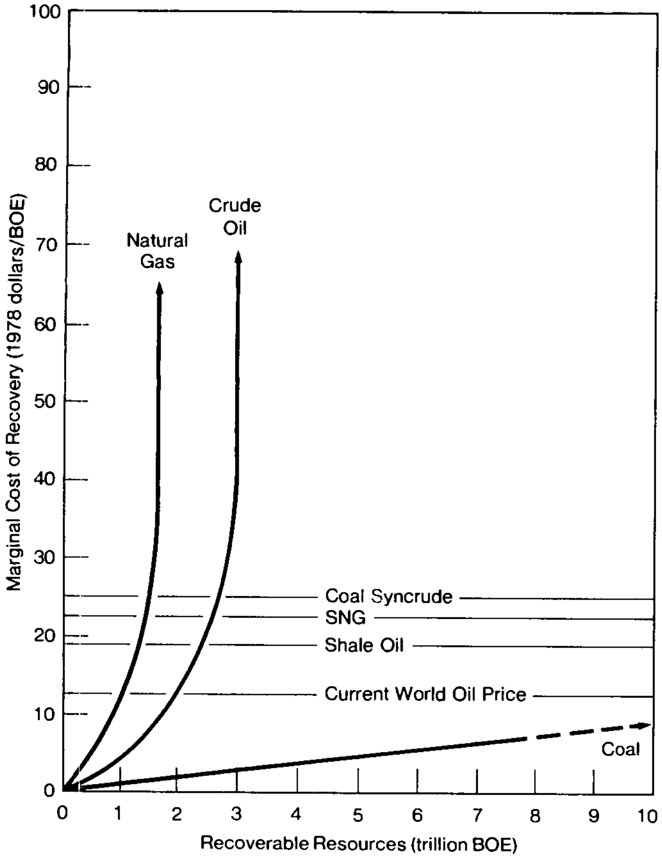

Figure 3. World Hydrocarbon Resources in 1975

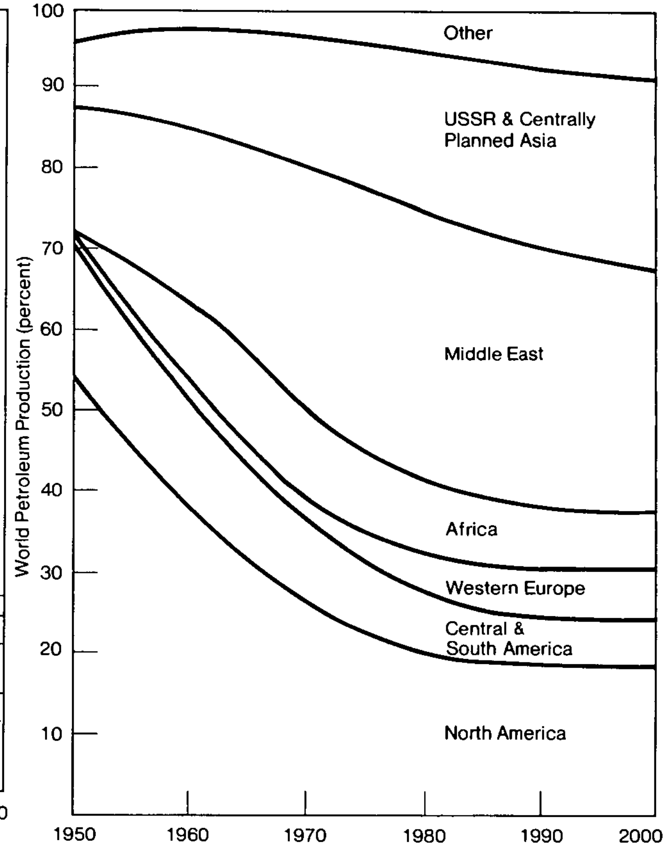

Figure 4. World Petroleum Production