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SYNTHETIC FUELS SUMMARY

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The Engineering Societies Commission on Energy, Inc.
444 North Capitol Street, N.W.
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PREFACE

The Engineering Societies Commission on Energy, Inc., (ESCOE), is a non-profit corporation established in 1976 by the five Founder Engineering Societies to provide independent and objective technical and engineering economic assessments for the federal government. Pursuant to this goal, ESCOE has prepared a primer for technically-oriented government and business officials who seek to become more informed about synthetic fuels.

This present report examines the federal government's experience in synfuels, the market potential of synfuels, the U.S. energy resources base, and the numerous technologies available. Technologies and energy resources are reviewed and compared to provide the facts needed to understand existing energy-related problems.

This introductory manual is an overview of synfuel technologies, and markets. It is not meant to be the sole source of information on which multi-billion dollar investment decisions for specific synfuel plants would be based.

This report was published originally in August 1980, bearing control number FE-2468-82. The report has been revised to incorporate appropriate corrections and clarifications, and it bears a new control number, FE-2468-82A. The intent behind these revisions is to present the best technical and programmatic information available as of the original publication date. <u>It is beyond the scope of this report to reflect new public policies or to include data based on new information obtainable after August 1980</u>.

The original report included certain information about the relative costs of selected synfuels technologies. Economics are especially sensitive to recent events and updated information, and it would possibly be misleading to restate the original cost data in this report. It was felt that the original cost data needed major updating and reconcilation due to differences in project scope, basic assumptions, and costing methodologies. ESCOE believes that reliable economic comparisons require timely data and a recognition of any major differences in scope or methodology. Therefore, ESCOE, in a separate task, is undertaking an updated commercial scale economic comparison of selected synfuel processes, on a normalized basis. The results of this task will be published as a separate ESCOE report.

SUMMARY

During 1980, major federal government actions were undertaken to initiate a large domestic synfuels industry. It was especially important that the 96th Congress enacted, and President Carter signed the Energy Security Act of 1980.

This Act defines "synfuel" as any gas, liquid, solid, or combinatiion of these, which can be used as a substitute for petroleum or natural gas produced by chemical or physical transformation of:

- i) coal including lignite and peat
- ii) shale
- iii) tar sands, including certain heavy oil resources
- iv) water, as a source of hydrogen only through electrolysis.

Mixtures of coal with combustible liquids including petroleum are included in the definition of a synfuel. Fuels from biomass sources are not included.

The Act establishes a national goal of achieving a synthetic fuel production capability from domestic resources equivalent to at least 500,000 barrels per day of crude oil by 1987, and of at least 2,000,000 barrels per day of crude oil by 1992. The newly-created U.S. Synthetic Fuels Corporation is given the authority to provide financial assistance to achieve this goal.

This report is a comprehensive review and comparison of the various combinations of domestic energy resources and emerging technologies that have the potential to significantly displace foreign oil, either directly or indirectly, with synthetic fuels by 1992. The domestic energy resources consist of coal, oil shale, tar sands, and heavy oil. The technologies encompass gasification, liquefaction, pyrolysis, enhanced oil recovery, and special techniques. Petroleum is not a synfuel so this resource is not covered in comprehensive detail in this report. Heavy oils and coal-oil mixtures are covered because of their treatment as synfuels by the Energy Security Act.

ENERGY IN THE FUTURE

One cannot be optimistic concerning domestic petroleum production in the year 1990 and beyond. Some energy experts predict a small increase in production over the next decade, while others expect a decline. However, no one is predicting that the number of new discoveries will triple to match current production, or a five-fold increase in production to match consumption. No conceivable level of effort will enable domestic resources to replace foreign oil and meet the nation's total need for petroleum in the future.

In addition to the continuing shortfall in domestic petroleum production, the nation's economic plight is exacerbated by the tremendous drain of U.S. dollars going for foreign oil. Domestic substitutes to meet the country's energy requirements are needed.

An aggressive program to develop and produce synfuels can help meet this need. Use of synfuels can reduce oil imports, as well as replace petroleum and natural gas in the future as these natural resources diminish and approach exhaustion.

MARKETS

Success for the U.S. synfuel program is keyed to the market penetration of synfuel products that displace foreign oil. However, the production and sale of synfuel products may not always displace foreign oil. For example, the use of synthetic boiler fuel for an existing oil-fired power plant that would otherwise convert to domestic coal would not displace foreign oil nor would the use of synthetic natural gas in a pipeline system that does not expand its sales beyond available domestic natural gas production.

The question for individual synthetic fuels in the U.S. energy system is not <u>can</u> the fuel displace foreign oil but <u>will</u> it? The U.S. energy system is complex — the answer is not simple.

The U.S. energy market at the consumer level depends heavily — critically in the transportation sector — on liquid or gaseous fuels. In

1978, gasoline, used mainly for private passenger automobiles, constituted 47% of all petroleum products, with heating oil, at 21%, in second place. Gasoline, jet fuel, kerosene, and heating oil, together commonly referred to as transportation fuels constituted slightly more than 75% of all petroleum products in 1978.

DOMESTIC ENERGY RESOURCES

The report contains an examination of those U.S. energy resources — primarily fossil energy resources — best suited for synthetic fuels. For comparative purposes, some other forms of energy are also briefly examined. The table summarizes available U.S. fossil energy resources. Clearly coal and oil shale are the major U.S. fossil energy resources available to displace foreign oil.

Oil shale is a hard rock which contains a minor fraction of an organic material called kerogen. There are significant formations containing oil shale in Colorado-Utah-Wyoming, Michigan and the Tennessee-Kentucky areas. The richest deposits in the U.S. are in the Green River Formation in Colorado-Utah-Wyoming. The amount of oil in place in the form of U.S. oil shale has been estimated at perhaps 26 trillion barrels. The amount of this oil which is recoverable with realistic economic constraints is far less but cannot be stated with any accuracy since there is no real commercial shale production experience.

Coal-bearing strata underlie approximately 13% of the land area of the United States. The thickness of coal-bearing strata varies considerably. Although coal is found in 37 of the 50 states, only 26 have significant production.

The composition of coal varies considerably from region to region and within any given field. The wide variations in coal composition require that some coal conversion processes be designed for a particular coal. The very large coal conversion plants needed to displace foreign oil economically will require extensive site specific design.

U.S. Energy Supply
(Billion barrels oil equivalent) (Ref. 32, 98)

	Estimated Resources	Proven Reserves
Crude Oil	50 - 370	28
Natural Gas	56 - 210	36
Unconventional Gas		
- Coal seams	70	—
- Tight sands	—	38
- Devonian shale	—	2.9
- Geopressured brine	570 - 17,000	—
Tar Sands	26 - 37	2.5
Heavy Oil	55	1.8
Coal	4,500 - 17,000	1,200
Peat	29 - 250	—
Shale Oil	26,000	418

CONVERSION TECHNOLOGIES

The report also briefly reviews the technologies by which abundant U.S. sources of fossil energy, primarily oil shale and coal, can be converted to liquid and gaseous fuels. Fundamental concepts inherent in all anticipated synfuels plants are discussed and the basic techniques for producing synfuels are qualitatively described — pyrolysis, gasification, direct and indirect liquefaction.

Synfuels technologies involve many operations already established commercially. Typical steps are grinding, drying, mixing, preheating, reacting, ash separation, flashing, hydrotreating, distillation, and storing. In addition to these steps in the main processing sequence, there are auxiliary operations such as hydrogen generation, removal of sulfur and nitrogen compounds, wastewater processing, and electric power production. In most synfuel processes, there are only one or two processing steps which are difficult to accomplish with known technology. These difficult steps dominate R&D activities for that synfuel technology. However, the remaining steps for the routine operations dominate the costs.

COMPARISONS

Although costs for synfuels are frequently estimated, conclusions are elusive. Unproven technologies, changing inflation rates, and dramatic uncertainties in primary energy prices preclude definitive cost estimates for new synfuels.

A process cost estimate reflects many assumptions about parameters such as site conditions, project scope, feedstock characteristics, by-product values, technological status, inflation rates, and financial parameters. Different assumptions made by different engineering teams mean that the resulting estimates can vary significantly — even for the same process. Misleading conclusions may occur when different estimates are compared without an understanding of the assumptions upon which they are based.

A meaningful cost for a new plant and process requires extensive engineering study. Many of the costs which have been published are based on rule-of-thumb estimating. Very few high quality cost studies have been published. Additionally, there is a variation in the quality factor involved with the people. Some companies insist on higher quality design standards for their manufacturing plants. Some companies are more or less conservative in the use of contingency factors for cost estimating.

As a separate task, ESCOE is undertaking a comparative analysis of the commercial-scale economics of selected synfuels processes. This analysis focuses upon those coal gasification and liquefaction processes that are receiving financial support under DOE Fossil Energy Demonstration Program. DOE's support is helping to ensure the public availability of detailed technical and economic studies. ESCOE is reviewing these studies with regard to the uniformity of project scopes and the comparable handling of major capital and operating costs elements. ESCOE is using a common set of financial parameters to recompute the economic performance of each process over its useful lifetime. The results of this task will be published as a separate ESCOE report, in a form to facilitate economic comparisons.

It must also be recognized that a lower cost per gallon or per Btu does not mean a particular synfuel is best. Some fuel forms are more valuable and thus command a higher price in the market-place. For example, gasoline is more valuable and costs more than boiler fuel.

Most synfuel costs are capital intensive which makes the plant cost estimate a very important input for any level of economic study. In addition, to verify completeness and accuracy for the capital estimate, it must be determined whether costs such as start-up, interest during construction, and royalties or license fees are being capitalized or expensed. Any comparison between competing technologies must be based on consistent financial treatment.

The emergence of a synthetic fuels industry has been accompanied by many comprehensive assessments of health and environmental impacts. The common message of these assessments and statements is encouraging. The environmental effects of synthetic fuels plants are sufficiently well understood so that the nation can move prudently to initiate a synthetic fuels industry. The preponderance of expert opinion is that the environmental impacts have been adequately identified and that methods are available to meet the necessary standards of environmental performance.

Synthetic fuels projects are subject to a large body of laws and regulations promulgated to protect human health and the environment. They cover the major concerns: clean air, clean water, solid wastes management, toxic substances control, worker protection, mining, land policy, and the list goes on. There is no significant area in which the impacts of synthetic fuels plants would go unregulated. The existence of so many different laws and regulations creates uncertainties as to the time and steps required to satisfy the various administrative requirements. The uncertainty is compounded because environmental regulations are continually evolving and expanding.

Market needs will dictate the generic processes which best suit national requirements. A healthy future U.S. synfuels industry will likely make some use of most of the available synfuel technologies. Prices of synfuels will be directly affected by environmental factors. Choices of synfuels will be dictated by market price.

1.0 INTRODUCTION

Debate has raged since 1973 as to the causes of, and the solution to the international energy problem. Following years of uncertainty, some major elements of the U.S. response are emerging — conservation, fossil energy, and renewable energy.

While we must continue to significantly improve the efficiency of energy use (i.e., conservation) it is also recognized that we must attack the excessive oil importation problem directly by significantly increasing the use of our abundant indigenous fossil energy resources.

President Carter proposed — and the ninety-sixth Congress approved — the initiation of a new synfuels industry during the 1980's. However, to create this new synfuels industry, many government and private organizations must be created, expanded, or redirected. The keystone is the U.S. Synthetic Fuels Corporation, established by the Energy Security Act of 1980, which has the responsibility to judiciously use taxpayers money to seed this new industry.

The Energy Security Act set goals of 500,000 barrels of oil equivalent per day by 1987 and 2,000,000 by 1992. The U.S. energy resource base of coal and oil shale is sufficient to support an even much larger synfuels industry and the conversion technology is available.

This report is a comprehensive review and comparison of the various combinations of domestic energy resources and emerging technologies that have the potential to significantly displace foreign oil, either directly or indirectly, with synthetic fuels by 1992. The domestic energy resources consist of coal, oil shale, tar sands, and heavy oil. The technologies encompass gasification, indirect liquefaction, direct liquefaction, pyrolysis, enhanced oil recovery, and coal-oil mixtures.

2.0 ENERGY FUTURE

2.1 HISTORICAL PERSPECTIVE

In the course of developing a technological society, man has made three major changes in the energy base. In 1850, wood supplied nearly all of the U.S. energy needs. By 1900, coal was the dominant energy source, whereas by 1950 petroleum moved into the forefront. Not only is petroleum the largest source of U.S. energy today, but nearly one-half of it is now imported.

The change from wood to coal was forced by growing shortages of wood supplies close to the important markets, but the conversion to oil and gas resulted from the superiority of these fuels over all competitors. The convenience in handling, storage, and use, combined with the low cost of oil and gas, resulted in the adoption of a very energy-intensive way of life and a rapid growth in total energy consumption. Figure 2.1 shows both the growth of U.S. energy since 1850 and the shift from wood to coal to petroleum and natural gas.

We are now faced with another conversion away from petroleum and natural gas which will be far more difficult to manage than those of the past. Three factors make the problem more difficult:

- we are now using more energy than ever before and have a tremendous investment in the capital goods associated with the extraction, processing, distribution and consumption of oil and gas,
- past transformations have been to an energy form both better and less expensive than the one being replaced, whereas the coming transformation will be to forms that are initially less adaptable and convenient and may well be more expensive, and
- environmental and health aspects of future energy technologies, as well as public's increased perception of these factors, must be resolved in an economic and socially acceptable manner.

The only candidates in sight as potential replacements for petroleum and natural gas are nuclear energy, solar energy in all its forms, oil shale and a return to coal. For the long-term, to the end of the next century and beyond, only nuclear energy, through the breeder or fusion, and solar energy in all its forms will remain as relatively inexhaustable energy sources.

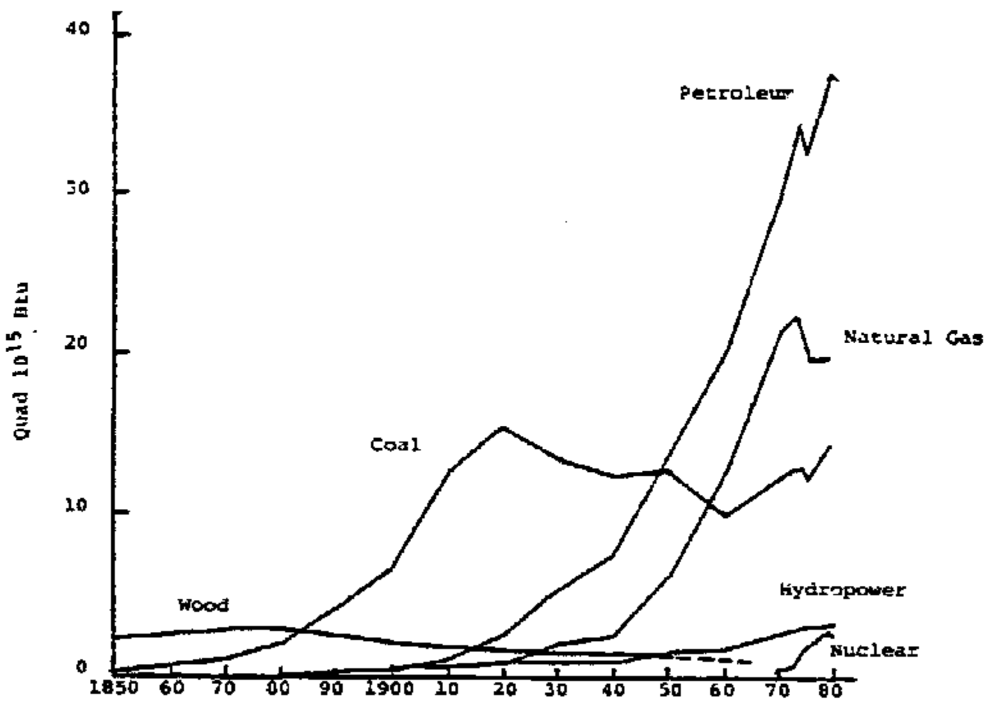

Figure 2.1: U.S. Energy Consumption Patterns, 1850-1979 (Ref.1&2)

Even with an all-out effort it will be a long time before nuclear and solar energy can satisfy a major share of the nation's energy needs. Thus, coal and oil shale must pick up the major load as we reduce our dependence on foreign oil in the years ahead. Fortunately, coal was bypassed, rather than exhausted, and large resources still exist. However, even the immense U.S. oil shale and coal resources will probably be facing depletion within another several hundred years, a very short time in human history. Clearly then, even as we prepare to meet much of our immediate needs by the use of coal and synfuels, we must continue to hasten the day when nuclear and solar energy can begin to carry an appreciable and growing share of the load.

Early in the course of the development of the technological society, man began to experiment with and use synthetic fuels and related products. Wood and other biomass materials, as well as animal products, were the source of turpentine, alcohols, sealants, adhesives and similar solar-derived products. The first major synfuel industry, the production of gas from coal for lighting, developed in England early in the 19th century. By-products of coal pyrolysis such as coke, tar and pitch found wide use in industry and commerce. By the middle of the 19th century, coal oil began to replace whale oil as a liquid fuel for lighting and other uses. Both were displaced by kerosene after the discovery of petroleum in Pennsylvania around 1860. A small shale oil industry also developed in several countries at about the same time. More recently, the Bergius process for the destructive hydrogenation of coal to produce motor and aviation fuels was developed in Germany before World War I. By World War II, The Bergius process, the Fischer-Tropsch indirect liquefaction process, and pyrolysis were producing synthetic gasolines and diesel fuels for the German war effort.

The current U.S. synfuels effort is directed toward accelerating the development of an industry capable of producing the large quantities of fuel needed to reduce our dependence on imported oil.

2.2 PETROLEUM AND NATURAL GAS RESOURCES

To assess future supplies of liquid and gaseous fossil fuels we must consider both the total known and presumed resources, and their relative rates of discovery, production, and consumption. Figure 2.2, plotted from American Petroleum Institute (API) data, provides the historical basis for a look ahead at liquid fuel supplies for the coming decade.

Figure 2.2 shows U.S. production, consumption, and new discoveries since 1947. Before 1950, production and consumption were essentially equal at approximately 2 billion barrels per year, while new discoveries averaged about 3 billion per year; hence, reserves were increasing. After 1950, consumption rose rapidly and the gap between production and consumption, filled by increasingly expensive imports, has become very large. The trend line of new discoveries has been falling for three decades and the rate of decline increased in the 1970's in spite of an increase in drilling rate from approximately 26,000 wells in 1971 to 48,000 in 1978. Clearly, this increase in drilling has not prevented a continued drop in the rate of finding new oil.

The curve of new discoveries also shows the remarkable nature of the discovery at Prudhoe Bay on Alaska's North Slope. This field, discovered in 1968, is the largest ever found on the North American Continent, yet at current rates of consumption it holds only 1½ years supply of petroleum.

Domestic production peaked in 1970 and has been declining since then, due to the low rate of discovery. A slight upturn in 1978 resulted from the beginning of flow through the Alaskan pipeline. With this line now essentially up to capacity and supplying over 15% of domestic production, the decline will undoubtedly continue.

It is clear that a continuation of the trends shown in Figure 2.2 to the year 1990 would produce a catastropic situation. Since future production depends on future discovery rates, only a substantial change in the latter can alter the future.

What is the probability that a major increase in the discovery rate can be brought about? Although there are many conflicting opinions concerning this question, the weight of evidence seems to indicate that it is small indeed. Root and Drew,(3) energy analysis with the U.S. Geological Survey, studied the patterns of petroleum discovery rates and summarized their findings in two general statements: "First, most of the oil and gas discovered in a region is contained in a few large fields; and second, most of the large fields are discovered early in the exploration of a region." In the U.S., for example, over 20,000 oil fields have been discovered; however, the 275 largest contain over 90% of the total proven reserves, and most of these were discovered by 1950, when the high rate of discovery in the U.S. ended.

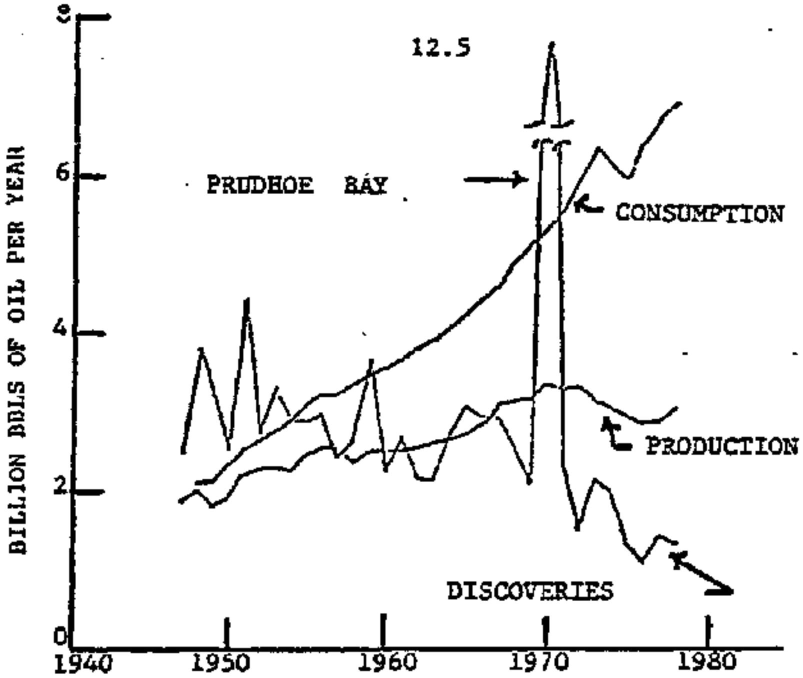

Figure 2.2: HISTORICAL PETROLEUM DATA (Ref. 24, 68)

A low rate of discovery has now persisted for the approximately 300,000 exploratory holes drilled since 1951.

In order to assess the significance of new field discoveries or potential fields, their capacity should be compared with the annual U.S. consumption of nearly 7 billion barrels. Thus, the recent announcement that seismic studies have indicated the possibility of finding up to 7 billion barrels of oil in the Navarin Basin (lying in 1500 to 2000 feet of water about 300 miles north of the Aleutian Islands and 400 miles west of the Alaskan coast) must be put in the context of the 10 to 15 years that would be required to explore the field and bring it into production (if it does indeed contain oil) and the fact that it may hold only a one-year supply. Similarly, the entire Atlantic offshore area, on which so many hopes have been pinned, has been estimated to hold up to 4 billion barrels, about a seven-months supply.

In view of this history, it is difficult to be optimistic concerning domestic petroleum production in the year 1990 and beyond. There are estimates which predict a small increase in production over the next decade and others which expect a decline. None, however, is predicting a tripling of new discoveries to match current production, or a five-fold increase to match consumption. It seems clear, therefore, that no conceivable level of effort will permit domestic resources to replace foreign oil and meet the nation's total need for petroleum over the coming years. Assuming continued high and rising world oil prices, expanded exploration and drilling, increased production of heavy oils, and enhanced recovery from existing fields, it may be possible to arrest the decline in domestic production during the next decade. By 1990, however, even the Prudhoe Bay field is expected to peak and begin to drop in output, and it will probably not be possible to delay the inevitable decline in U.S. production.

The situation with respect to natural gas differs substantially from that for oil since the U.S. is not dependent on imports in a major way. A significant portion of the new gas discoveries are the by-product of oil exploration. There are also unconventional gas sources that have been roughly defined but not verified or developed. In addition, increased incentives to produce and increased costs of consumption will result as natural gas prices climb due to deregulation. There have also been legal restrictions placed on the industrial use of natural gas in recent years.

The uncertainty regarding both U.S. oil and gas resources, and future rates of discovery with accelerated exploration and drilling, makes predictions of future supplies difficult and possibly subject to large errors. It would, however, be extremely dangerous to pin the economic health and military security of the nation on the expectation that a field the equivalent of Prudhoe Bay would be found every one or two years.

2.3 PROJECTIONS OF ENERGY USE

The drastic changes in the energy picture since 1974 have made old projections of future energy use obsolete, and the accuracy of new projections open to serious question. However, some of the fundamental trends of future energy demand are reasonably well understood.

The serious overestimations of future requirements, which were being made prior to the 1973 embargo, are illustrated by a report of the National Petroleum Council.(4) This report, typical of most projections published in 1971, predicted a total domestic energy consumption of 83 quad* in 1975, whereas the actual consumption in 1975 was 71 quad. The report also projected total consumption of 103 quad in 1980 (versus an actual in 1979 of 78 quad), and 125 quad in 1985. More recent predictions, which take into account the changed situation since 1974, cover a wide range, depending on estimates of future economic growth, future energy prices, and how much effort the government and the people put into energy conservation.

In 1975, the Energy Research and Development Administration estimated demand in the year 2000 at between 122 and 165 quad,(5) whereas a 1976 study by the Institute of Energy Analysis of the Oak Ridge Associated Universities(6) indicated a consumption between 101 and 126 quad in 2000. The Second National Energy Plan (NEP II)(7) of the Department of Energy, issued in 1979, gave estimates of total U.S. consumption of 117 to 123 quad in 2000 based on assumptions of high to low world oil prices.

In 1979, the Demand and Conservation Panel of the National Academies of Science and Engineering Committee on Nuclear and Alternative Energy Systems (CONAES) evaluated a range of scenarios from very aggressive conservation policies and energy cost increasing by a factor of four in real dollars to business as usual and energy prices increasing only at the inflation rate. Based on these assumptions, CONAES concluded that the 2010 U.S. consumption could be as low as 63 quad or as high as 137 quad.(8)

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* quad = quadrillion Btu = 10^{15} Btu. One quad/year = 0.5 million barrels oil/day.

A recent ESCOE study[9] analyzed U.S. energy consumption in 1978 and projected the energy production flow and use patterns in 1990 based on expected U.S. energy resources, the National Energy Act of 1978, the new energy initiatives announced by President Carter on July 15, 1979, and the energy growth projections in NEP II. Although changes in the law and in federal initiatives will undoubtedly occur to meet new conditions as they arise, the projections based on current laws and directives are plausible. Increasing prices and other market forces could easily denigrate these forecasts. Table 2.1 shows the primary energy sources for the U.S. energy system in 1978 and as projected for 1990. Table 2.2 shows energy used by consumers in 1978 and as projected for 1990. Here the term "consumers" includes residential, commercial, transportation and industry users but excludes energy used by the energy industry to produce, transform and transport energy to the consumers. The 31.6 quad difference between the 98.7 quad of primary energy projected to be supplied and the 67.1 quad projected to be used by consumers in 1990 would be absorbed by the energy industry — mostly in electric power generation, but some in synthetic fuel production.

Table 2.1: U.S. Energy Sources (quad) (Ref. 9)

	1978	1990
Coal	14.1	34.0
Natural Gas		
Domestic	18.9	20.0
Import	0.9	0.9
Petroleum		
Domestic	21.0	21.8
Import	17.0	9.5
Nuclear	3.0	8.5
Hydropower	1.2	1.2
Solar/Other	1.1	2.8
Totals	77.2	98.7

Table 2.2: U.S. Energy Uses (quad) (Ref. 9)

	1978	1990
Coal	3.7	6.1
Natural Gas	13.1	18.0
Liquid Fuels	31.8	30.3
Electricity	6.6	10.1
Solar/Other	1.0	2.6
Totals	56.2	67.1

According to the study[9] for which the results are shown in Table 2.1 for 1990, 0.8 quad of the petroleum would be synfuel from oil shale and 5.7 quad of the coal would be used to produce another 3.2 quad of synfuels. However, of the 34.0 quad of primary energy from coal, 65% would be used as boiler fuel to produce electricity, 18% would be for direct industrial use, and 17% for synfuels.

It is clear that estimates of future U.S. energy consumption cover a very wide range. An encouraging aspect of these studies is the indication that conservation will play a major role in permitting continued economic growth without large increases in energy consumption. The degree of conservation will be influenced by energy prices. Given a free market, energy price increases will usually foster decreased demand leading to conservation of the product. The interrelationship between the impact of prime changes upon supply and demand is called "elasticity."

Economists have long observed that changes in price motivate people to adjust the amounts of products and services they buy and can sell. Economists have found it useful to measure the rate at which these adjustments take place by using the concept of "elasticity." An elasticity coefficient is the ratio of two percentage changes. For example, if the price of a product changes by 10% and people adjust their purchases by 1%, the product is said to have an elasticity of 0.1.

The key reason that people are often able to adjust to changing prices — and therefore display elastic behavior — stems from the several choices that most people have. Consumers are offered a wide variety of products and services. When the price of one of these rises relative to the others, it becomes less attractive than before. The tendency of the consumer is to reduce the amount bought of the product or service that has become more expensive and to increase the purchases of other products and services that have not increased in price. Producers, for their part, usually can choose among several ways of making a product or service. Therefore, if an input becomes more expensive than before, producers can use less of that input and more of other inputs and still make the product or service.

Even in those cases where people must achieve a particular objective, they usually can choose among several different ways of reaching that objective. The choice that people make among these alternatives is heavily influenced by the relative cost of each. For example, although people "must get to work" it does not mean that they will buy a constant amount of gasoline regardless of its price. People can reduce the amount of gasoline they buy and still get to work by driving a more fuel-efficient car or by reducing their driving speed. They can lessen their demand for gasoline by forming car pools or taking public transportation. Over the long-term, they can make decisions affecting housing or employment by considering the distance between home and work.

It is not easy to predict energy elasticities in the absence of actual data on how consumers modify their behavior in response to increased fuel prices. Surveys which ask hypothetical "what if" questions about how consumers would adjust their patterns of energy consumption in the face of higher prices are often misleading. On the one hand, prior to a price increase, individuals may not have thought much about their options for reducing energy consumption. They may believe that they have little choice but to continue energy consumption at a constant level. On the other hand, the suggestion of significant price increases may be perceived as threatening and may evoke heated emotions rather than a deliberative, rational answer.

Thus elasticity values are best determined by observing how actual consumption changes when price changes occur within a certain range. Elasticity coefficients are reliable within the range in which they have been observed. Significant extrapolations of elasticity values to much different price ranges are, at best, uncertain.

The decades of the 50's and the 60's were periods of relatively stable energy prices, measured in constant dollars. This stability, although quite desirable for consumers, was a disadvantage to energy economists and forecasters. It precluded opportunities to make reliable measurements of energy elasticities. Furthermore, stability contributed to a planning environment in which energy supply and consumption forecasts were made, under the implicit assumptions of constant prices or essentially zero elasticity.

Prior to the 1973 oil embargo, forecasters predicted very large increases in future energy demand. Because energy supply at pre-1973 prices could not keep up with demand, there were large hypothetical "gaps" between supply and demand. Energy planners and economists knew that such gaps would not actually occur in an unrestrained market, and that the market clearing price would rise to balance supply and demand. Nonetheless, in the absence of reliable elasticity data, economists could not agree about the market clearing price or the level of energy at that price.

After 1973, energy prices have behaved in a complex fashion. There have been periods of rapid escalations and periods of stability. Witness the behavior of the refiner acquisition cost of crude oil, as reported by the Energy Information Administration.[99] The average cost per barrel was constant in 1977 and 1978 at $14.53 and $14.57, respectively. It rose rapidly thereafter to $21.67 in 1979 and $33.89 in 1980. Petroleum consumption responded appropriately: first, by rising from 37.1 quad in 1977 to 38.0 quad in 1978; and then, dropping back to 37.1 quad in 1979 and 34.2 quad in 1980. Such behavior while reflecting multiple economic factors does provide important insights into the relationships between energy price and consumption.

Energy forecasting models have grown much more sophisticated and use elasticity coefficients. Forecasts made today predict much lower levels of future energy consumption than the forecasts of a decade ago. Often, modern energy forecasts give a range of future energy requirements to reflect different assumptions about energy costs.

The concept of demand elasticity can be illustrated for transportation fuels. Using motor gasoline as an example, a short term (over the next 12 months) price increase of 10% translates into a demand reduction of 1.6%.[100] On this basis, over the longer term, a 10% increase in price can result in demand reductions of 4.2%, 4.9%, and 4.8%, respectively for the years 1985, 1990 and 1995. These longer term figures apply to the transportation sector and include aviation fuel.[101]