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MASTER

STRATEGY ANALYSIS FOR ENERGY CONSERVATION

Task 1 - Economic Studies

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EXECUTIVE SUMMARY

This report is the first step of a study whose overall purpose is to provide the Division of Power Systems (DPS) with a basis for the analytical evaluation of its RD&D program options. These efforts, ranging from basic research to technology development and demonstration, are directed toward energy conservation through improved conversion efficiency or alternative fuel utilization. These objectives support the overall Department of Energy (DOE) goal of achieving an orderly transition from oil and gas to more abundant energy sources. This report documents the results of Task 1 which is aimed at identifying the basic requirements in each energy consuming sector of the U.S. economy which these RD&D efforts must address.

To accomplish the objectives of Task 1, historical data on U.S. energy consumption have been compiled for the period 1950-1975, and broken down by consuming sector (industrial, transportation, residential/commercial, and electric utility) and by fuel. The trends derived from this data base have been extrapolated to yield "no action" case projections of fuel consumption for the years 1985 and 2000, in which the conditions affecting energy consumption remain much as they have been over the last 25 years. In order to identify the general conservation requirements in each sector, the trends projected in the "no action" case must be compared to energy consumption goals. For Task 1, the basic goals stated and derived from the National Energy Plan (NEP) were used.

The historical analysis reveals that the economic growth the U.S. has enjoyed since 1950 was accompanied by a parallel growth in energy consumption. At the same time, consumer preferences have tended toward higher grade fuels, resulting in increased dependence on oil and gas to heat and light buildings, transport people and freight, and power factories. Consumption of coal, our most

abundant fossil fuel resource, has increasingly been restricted to primary industry (e.g., steel) and to utilities where it is used to produce the highest grade fuel of all--electricity. The cleanliness, ease of handling, and low cost of oil and gas have so encouraged their use, that while energy consumption more than doubled, coal use hardly grew at all. More than 95% of all fuel requirements outside the steel and utility industries are now satisfied by oil, gas, and electricity. Of the four consuming sectors, industry has experienced the slowest growth, and electric utilities the fastest. Consumption in the transportation and residential/commercial sectors has been at the same rate as the growth in GNP and total energy use.

However, during this period, domestic oil and gas production has failed to keep pace with demand, leading to increased reliance on imported oil. Those imports have actually increased since the 1973 embargo, when the price quadrupled, and the U.S. now pays over \$30 billion a year for foreign oil.

Under NEP projections of economic growth, energy demand would increase substantially by 1985, and the results of the "no action" case indicate that U.S. dependence on oil and gas will continue to grow, and that the need for oil imports could be twice as great as it is now. Achievement of overall goals will require substantial reduction in fuel consumption in the U.S., 15 quads per year below the "no action" case in 1985, 40 in 2000. Much greater reliance on coal is necessary through the end of the century, but achievement of goals for 2000 would also reduce total energy consumption through conservation, increase reliance on nuclear power, and require development and utilization of other non-fossil fuel sources.

The majority of the analysis of this Task 1 report deals with the comparison of projected "no action" energy consumption in each sector to NEP-derived goals. The results of this analysis for each sector are as follows:

- Industry - Energy efficiency has improved, but many processes still waste most of the energy they use. Further, fuel preferences for process heat have increasingly tended toward natural gas and away from coal, because gas was clean, cheap, and convenient, and because gas burning equipment is unusually cheaper. Oil use, as a percent of sector consumption, has remained about the same, but has been increasingly allocated to non-fuel uses such as chemical feedstocks, paving materials, etc. Electricity has filled a greater share of energy requirements as more processes were automated. Energy consuming machines have been substituted for labor, as real energy prices declined while labor costs increased.

The cost of energy has doubled since 1970, however, and most sources predict further increases. In addition, natural gas shortages in some areas have caused halts in production. Industry has thus been made aware of the limited supply of premium fuels. The "no action" case results indicate that, even if oil and gas use as a percent of sector consumption does not increase, demand could grow by 50% before 1985, but the cost or even availability of these fuels is subject to question.

NEP goals for the industrial sector do not require large decreases in energy consumption, but imply much greater utilization of coal. Under the NEP, oil and gas would increasingly be reserved for the transportation and residential/commercial sectors, where fuel-switching potential is not as great.

• Transportation - Energy consumption in the transportation sector has grown at the same rate as GNP, but while coal once supplied a sizable portion of fuel requirements, U.S. transportation is now totally dependent on oil. Furthermore, the more energy-intensive modes of transport, i.e., cars, trucks, and planes, have increasingly dominated the sector. Population and industry have dispersed and have become heavily dependent upon highway passenger and freight carriers. Cars, the dominant mode of passenger transport, have grown steadily less efficient. The speed with which airliners can cover long distances cannot be rivaled by land-based carriers, but planes consume enormous quantities of fuel.

With the oil embargo of 1973 came large price increases, and sector fuel consumption declined for a time. However, recent figures show consumption rising again. Recently enacted mileage standards for new automobiles will serve to slow this rise, but the "no action" case estimates show energy consumption increasing 25% by 1985. Stated goals require slower growth in the near term, and an actual decline after 1985, necessitating a 50% efficiency improvement by 2000.

• Residential/Commercial - Growth in energy consumption in this sector, as in transportation, has closely paralleled GNP growth. A similar trend in fuel choice has also been observed--in this case to natural gas and electricity. Coal, which once accounted for one-third of sector requirements, has virtually disappeared, and oil consumption, as a percentage of sector consumption, has declined slightly. Fuel costs have been, and remain, a small fraction of building and homeowners' expenditures, so convenience and cleanliness came to be valued over economy. Rising population and per capita GNP have resulted in more and bigger homes and offices. Natural gas has become the preferred heating fuel, and the widespread use of air conditioners and work-saving appliances has produced dramatic growth in electricity demand.

Recently, natural gas has been much less available to new customers, and a trend toward electric heat has been encouraged. Thus, electricity growth is expected to continue at a high level, even though population growth is slowing. The "no action" case predicts that most future growth will be in electricity consumption, but increased availability of gas could produce different results. The NEP goals require a large increase in sector fuel efficiency, (e.g., 50% by 2000), but it is recognized that dependence on premium fuels will continue.

- Electric Utilities - Utility energy consumption has grown the fastest of all sectors. Electricity demand has historically expanded at 7% per year, or doubled every ten years. Efficiency improvements kept fuel consumption growth below that level for a while, but since 1965, power plant efficiency has remained almost constant.

Coal has been, and still is, the dominant fuel, but its share of sector fuel demand has declined. The combined effects of low prices and environmental regulations have encouraged utilities to burn oil and gas. Nuclear power, virtually non-existent before 1970, currently makes up 10% of all sector fuel requirements.

The "no action" case projections show electricity demand growing even faster than it has historically until 1985, this growth coming about through the combined effects of high growth of industrial production, and increasing residential use of electric space heat and air conditioning. Coal and nuclear power, being constrained by environmental and safety considerations, cannot satisfy this growth alone, and the "no action" case shows oil and gas use continuing to fulfill over one-fourth of utility energy requirements through the turn of the century.

The NEP, however, states as an objective the elimination of oil and gas use from powerplants by 2000. The conservation goals imply greatly reduced growth in electricity demand in the industrial and residential/commercial sectors, greater utilization of nuclear power, and consumption of two quads per year of "other" sources (e.g., solar, geothermal, and wind power) by the end of the century.

The conservation goals and energy usage requirements implied by these goals (i.e., efficiency improvements and fuel switching) identify those areas where Federal RD&D efforts are needed to effect the transition in the U.S. energy economy. Future efforts under Tasks 2 and 3 will concentrate on development and implementation of an analytical methodology to evaluate alternative programs to satisfy these requirements.

I. INTRODUCTION

A. BACKGROUND

This report documents the results of Task 1, Economic Studies, of Contract No. EC-77-C-1430 for the Division of Power Systems (DPS) of the U.S. Department of Energy (DOE) entitled "Strategy Analysis for Energy Conservation." The objective of the total study effort is to develop and implement an analytical methodology to evaluate alternative research, development, and demonstration (RD&D) projects to be undertaken by the Division. Use of the methodology will enable DPS management to allocate Federal funds in a manner consistent with overall DOE and National Energy Plan (NEP) goals.¹ This report documents the first step toward addressing those goals.

The Task 1 report traces historical consumption and efficiency of energy usage in the U.S. Based on a variety of sources and assumptions, a set of "no action" projections of energy consumption through 2000 was developed. These projections were then compared to national goals derived from the NEP and other sources to identify specific requirements for energy conservation through efficiency improvements and fuel switching. These requirements will form the basis for development and implementation of the analytical methodology as part of Tasks 2 and 3. The following paragraphs discuss the methodology concept in greater detail.

¹The National Energy Plan, Washington, D.C., April 29, 1977.

B. METHODOLOGY DEVELOPMENT

1. General

The mission of the Division of Power Systems is the development of technically and economically feasible technologies which can facilitate a transition away from dependence on oil and gas to increased reliance on alternative energy resources. Specifically, the DPS program consists of development efforts aimed at (1) more efficient use of oil and gas and (2) substitution of alternative fuels (e.g., coal) in energy conversion processes. The scope of these efforts ranges from initial conceptual studies to fabrication and testing of prototype demonstration units.

The basic problem facing DPS managers is the formulation of a program strategy to achieve these dual objectives. Formulation of alternative program strategies involves allocation of DPS RD&D funds among a set of alternative projects to develop and introduce fuel-efficient and alternative fuel technologies into each of the basic four energy-consuming sectors of the U.S. economy: industrial, residential/commercial, transportation, and electric utilities.

Figure I-1 shows the hypothetical impact of alternative conservation strategies for consumption of oil and gas. A base case, corresponding to no RD&D, government regulations, or economic incentives (i.e., the "no action" case) represents the pattern of consumption in the face of the limits of existing reserves. One approach toward conservation is to emphasize programs which improve conversion efficiencies for existing fuel sources and processes. This approach, which acts over the near and mid-terms, has the effect of extending the time interval over which oil and gas will be available to all end-use sectors, particularly in those areas in which the transition is more difficult. This extension is realized through energy savings as the result of improved conversion efficiencies for oil and gas.

FIGURE I-1
HYPOTHETICAL

Future Patterns of Petroleum
and Natural Gas Consumption

OIL AND GAS AS
PERCENT OF TOTAL
ENERGY CONSUMPTION

A second approach shown in Figure I-2 emphasizes fuel substitution in addition to improved conversion efficiency for oil and gas. This approach relies heavily on new technology development and can be realistically implemented by utilizing alternative fuel sources and conversion processes to achieve significant reductions in oil and gas usage. Over time, as implementation in all usage sectors becomes technologically and economically feasible, further savings in conventional fuels usage will be realized. The net impact of this approach will be to assure the availability of oil and gas resources during the period required to develop and produce technically and economically feasible energy alternatives for all energy end-use sectors.

In terms of specifying technology objectives, a resource allocation problem exists. For some end-use sectors, reductions in oil and gas consumption are projected to be easier than others. In this context, "ease" refers to technical complexity, risk, capital requirements, time delays, and institutional factors. A logical approach as shown in Figure I-2 is to first emphasize those programs which target end-use sectors where significant savings can be achieved relatively quickly in an economically and technically feasible manner. Then, in the longer term, petroleum and natural gas will be available to be consumed in those end-use sectors where alternative fuel and processes will be most difficult to implement. Thus, as Figure I-2 shows, immediate priority might be made in the electric utility sector where improved conversion efficiency (e.g., bottoming and topping cycles) and alternative fuel use (e.g., coal) can realize large savings in a short period, thus diverting reserves for future consumption in the transportation sector, where the lead time to implement alternative fuels and conversion processes is likely to be longest.

FIGURE I-2

MARKET SECTOR ALLOCATION OF HYPOTHETICAL
FUTURE PATTERN OF PETROLEUM AND
NATURAL GAS CONSUMPTION

OIL AND GAS AS PERCENT
OF TOTAL ENERGY CONSUMPTION

In order to develop such an analytical framework, it is necessary to analyze energy end-use sector components and assess the potential for savings in oil and gas consumption achievable through RD&D in various program alternatives. The evaluation must consider factors including:

- Capital Requirements
- RD&D Lead Times
- Market Penetrability
- Institutional Factors.

This analysis, to be conducted under Tasks 2 and 3 of this effort, will provide an approach to evaluate several alternative RD&D programs by DPS decision makers and to illuminate the establishment of overall conservation goals.

2. Task 1 - Economic Studies

The first step in the development of the methodology is the derivation of specific requirements for efficiency improvement and/or fuel switching in each end-use sector. This analysis has been performed by fuel type and consists of the following elements:

- Development of historical energy consumption and productivity profiles (output per unit of energy input) for each fuel type in each sector for the period 1950-1975
- Projection of energy service demands for each fuel type in each sector for the period 1975-2000 assuming no government action
- Identification of goals for reduced energy service demand by sector and fuel type
- Derivation of efficiency improvements and fuel switching requirements in each sector.

The output of Task 1 is a set of requirements which the DPS RD&D program must address. Tasks 2 and 3, Methodology Development and Methodology Application, respectively, will address the analysis of specific DPS projects in terms of their ability to satisfy the requirements developed in Task 1.

C. DATA SOURCES

Data for the historical analysis have been taken from various government and private sources, primary among them were the Bureau of Mines' "Minerals Yearbook"; Energy Statistics, a Department of Transportation publication; the American Gas Association; and Edison Electric Institute figures on the utility industry. The sources are identified, and data from these sources are displayed in the Appendix.

Several studies were canvassed for projections of population, service demands, economic forecasts, etc. These included: the Department of Energy's Market-Oriented Program Planning Study (MOPPS); Brookhaven National Lab "Reference Energy System"; MIT's "World Alternative Energy Strategies" (WAES); Federal Energy Administration "Project Independence Evaluation Study" (PIES), and the Ford Foundation's energy policy project entitled, "A Time to Choose." These and other sources are listed in the Appendix.

Base year consumption figures were taken from FEA "End Use Consumption Data Base" for 1974, adjusted for 1975, the base year chosen for this study.

D. REPORT ORGANIZATION

The remainder of this volume consists of the following sections:

II - ENERGY CONSUMPTION AND PRODUCTIVITY (1950-2000)

A description of historical (1950-1975) and projected (1975-2000) energy usage and productivity by fuel type in each end-use sector for the "no action" case.

III- ENERGY OUTPUT REQUIREMENTS: 1975-2000

A description and comparative analysis of projected energy consumption patterns versus energy consumption goals; and the derivation of efficiency improvements and fuel switching requirements necessary to satisfy the goals for each end-use sectors.

IV - SUMMARY

A discussion of the conclusions of the Task 1 effort and planned activities under Tasks 2 and 3.

II. ENERGY CONSUMPTION AND PRODUCTIVITY: 1950-2000

A. GENERAL

Energy consumption in the United States rose approximately 3.5% annually during the period 1950-1975. This increase paralleled the rise in the Gross National Product (GNP). Industry was expanding, new technologies were being developed and the general public became accustomed to the benefits of an energy-intensive standard of living (e.g., automobiles, electric appliances). Yet during this time, the use of coal, the most abundant fuel source (90% of domestic reserves), fell from supplying 38% of all energy needs in 1950 to supplying only 18% in 1975. The shares supplied by the other two major sources of fuel, natural gas and petroleum, rose from 18% to 30% and from 39% to 46%, respectively. The inordinate growth in consumption of these two fuels threatens to exhaust the domestic supply and force the United States to rely increasingly on imported fuels which have been and, again, may be cut off arbitrarily.

Figure II-1 depicts this total energy growth and Figures II-2 and II-3 display in bar graph form historical energy consumption by fuel type and end-use sector, respectively. The following paragraphs address the data displayed in these figures.¹

¹ These figures and all others express energy usage in quads, an amount equal to one quadrillion, or 10^{15} , BTUs.

Electricity consumption is not shown as part of total U.S. consumption of fuels, as it is not a primary fuel, and the fuels consumed in its production are included in the other fuel consumption curves. Where consumption is broken down by sector, as in Figure II-3, utility consumption is a net consumption, that is, fuel burned in power plants less electricity produced, and the other sector totals include electricity consumption. In figures dealing with only one sector, electricity counts toward total sector consumption.

FIGURE II-1

TOTAL US ENERGY CONSUMPTION BY FUEL TYPE
1950-1975

FIGURE II-2
TOTAL U.S. ENERGY CONSUMPTION BY FUEL TYPE
1950-1975

FIGURE II-3
TOTAL US ENERGY CONSUMPTION BY SECTOR
1950-75

Coal is a plentiful, low-cost source of energy. But, since 1950, its use outside the electric utility sector has fallen off drastically. It has almost disappeared from use in the residential/commercial and transportation sectors, where, during the early 1950s, it accounted for over five quads annually. Its use in the industrial sector has fallen to 70% of its 1950 level, despite growth of the steel industry. A major factor which led to the decrease in the use of coal was changing technology. The costs of acquiring and maintaining equipment which burned gas and petroleum were lower than for similar coal-burning equipment. These lower initial costs offset the higher operating and fuel costs for gas and oil and thus made gas and oil more attractive than coal. This decrease in the use of coal can also be partially accounted for by the rise of environmental concern in the United States in the 1960s. The high ash and sulfur content of coal combustion products became a health hazard, especially as United States industry grew rapidly. Regulations were passed which forced coal consumers to install costly anti-pollution equipment, which was not necessary if oil and gas were burned.

In the 1950's, there was a surplus of oil production capacity in the U.S. This surplus led oil companies to give bulk rate discounts, engage in advertising campaigns, and take other measures to stimulate demand. This effort proved to be successful. Oil exploration and production techniques improved rapidly in that period, raising the average rate of recovery as well as increasing reserves. In 1950, the Oil and Gas Journal estimated proven world reserves at 72 billion barrels, but we now know that reserves in fields discovered before 1950 were about 300 billion barrels.²

² Estimates of proven reserves as published in Oil and Gas Journal, quoted in "Energy, Global Prospects 1985-2000", 1977, MIT Press.

The geographical distribution of new discoveries, however, has increasingly favored countries other than the U.S., notably the Middle East. By the end of 1975, 80% of the world's proven reserves of 555 billion barrels were held by OPEC nations, some 65% in the Middle East alone.³

The rate of discovery has fallen off since 1970. Additions to worldwide reserves averaged about 22 billion barrels per year between 1950 and 1965, increased to over 50 billion barrels per year from 1965 to 1970 (30 billion in the Middle East), but have fallen off to around 25 billion barrels per year since 1970. Furthermore, 10 billion barrels per year since 1970 have resulted from reevaluation of reserves in existing fields, not from new discoveries.

These additions to reserves have failed to keep pace with consumption. In the U.S., discoveries have declined since 1965 and consumption has increased, leading to increased imports. From just over 2 million barrels per day (4 quads per year) in 1965, oil imports increased to over 6 million barrels per day in 1973.

Though U.S. oil consumption declined from 1973 to 1975, somewhat reducing the level of imports, 1976 figures show consumption exceeding its 1973 peak. Domestic production has not recovered to previous levels, however, and the U.S. actually imported more oil in 1976 than in 1973 (roughly 14 and 12 quads, respectively). The U.S. balance of trade has thus gone from a modest surplus to a deficit of over \$25 billion per year in 1977. If consumption continues to outrun production, this figure could increase significantly by 1985. The NEP estimate of U.S. oil production in 1985, with no government incentives, is slightly over 23 quads. The "no action" case projection of consumption in that year is over 20 quads higher. The resulting imported oil bill, even with no further price increases, would be over \$50 billion, assuming that producers are willing to continue to expand their production.

³Ibid.

Even if enough oil could be produced to sustain historical increases in consumption, recovery costs would almost certainly be so high as to render such a course infeasible. World oil prices have gone from \$4 per barrel in 1973 to over \$13 less than 4 years later. (Average U.S. prices have only risen to around \$8, due to price-controlled domestic production). Even with further increases in price, some sources predict a serious supply shortfall in the late 1980s. Only the most optimistic researchers place it after the turn of the century.

As easily recoverable reserves are exhausted and prices rise further, oil will be increasingly reserved for those purposes for which it is most valuable, probably industrial raw material uses and the less energy-intensive forms of transportation. Continued economic growth may well depend on the orderliness of the transition, and the degree to which the economy can be made less dependent on cheap oil.

Natural gas, once only a by-product of oil production, has become a critical fuel source to the residential/commercial and industrial sectors. Gas consumption has been the fastest growing of any fossil fuel, expanding at over 6.5% annually between 1950 and 1970, compared to 4% for oil and 3.5% for total energy. The increasing supply, low price, convenience and cleanliness of gas all contributed toward this growth. The retail price to residential customers has been competitive with that of heating oil, and the bulk discounts available to industrial users have rendered gas less expensive per BTU than even low-grade petroleum or coal in many areas.

Since 1970, however, the consumption of gas has decreased. Consumption in 1975 was 10% below its 1972 peak. One contributing factor has been rapid price increases, from an average of about \$1.00 per thousand cubic feet (mcf) to residential customers in 1970 to over \$2.00 today, and from \$0.40 to over \$1.50 to industrial users. Even so, the recent decline in consumption is more often

attributed to lack of supply rather than of demand. New residential natural gas hookups were simply unavailable in many parts of the U.S., and large industrial customers and regional gas utilities found their supply contracts being interrupted.

New discoveries did not keep pace with even this decreased consumption. The ratio of known reserves to yearly production decreased from 17 to 1 in the late 1960's to 11 to 1 in 1975. This relative decline in reserves makes production less flexible, and makes suppliers less able to cope with extraordinary demand conditions, as witnessed by the gas shortage during the winter of 1976-1977. It has been estimated that a loss of \$4 billion of GNP resulted directly from that shortage, and that excess demand of over 7 quads per year will still exist in 1985, even if the user taxes and production incentives proposed in the NEP are put into effect.⁴

U.S. electricity consumption has increased dramatically since 1950. Historic demand growth has been at an average annual rate of 7%, leading to the "double in a decade" rule in the utility industry. In 1975, electricity satisfied 12% of industrial sector energy needs and 22% in the residential/commercial sector, up from 5% and 6% respectively in 1950. This conversion has increased overall energy consumption, as 3 BTUs of fuel must be burned in the power plant to provide 1 BTU of electricity to the end-user.

Utility consumption of oil and gas increased sharply during the 1960's and early 1970's due to the combined effects of price controls, environmental regulations, and the lower cost and easier maintenance of oil and gas burning generating equipment.

⁴Pindyck, Robert S., Options for U.S. Energy Policy." Prices and Shortages: Policy Options for the Natural Gas Industry." Institute for Contemporary Studies, San Francisco, California, pp. 143-177.

While electricity can be generated from virtually any fuel, there are serious environmental and safety concerns restricting the use of coal and nuclear power. Conversion to electric power thus cannot solve the fuel crisis in the near future without major technical breakthroughs in the clean, efficient utilization of coal and alternate fuels.

The remainder of this section discusses both historical and projected energy consumption by end-use sectors.

B. INDUSTRIAL SECTOR

1. Historical Consumption

Industry is the only sector under study in which energy consumption has grown slower than GNP and total energy usage since 1950. Its annual growth, as shown in Figure II-4, was 2.6% versus the 3.5% overall energy growth up to 1973. These data reflect the overall trend away from coal to petroleum and natural gas and, indeed, support the conclusion that natural gas has been directly substituted for coal. Figures II-5 and II-6 display the historical pattern of consumption by each type of fuel in quads and percent of total consumption, respectively.

Natural gas use has grown rapidly and presently over 40% of all gas is consumed in industry. This growth at least partially reflects the historical low price. Despite the substantial contribution still made by coal (mainly to the steel industry), the fact remains that oil and gas currently supply more than two-thirds of all energy used by the industrial sector. About two-thirds of that energy is converted to heat that could be supplied by other, more abundant, fuels. As illustrated by Figures II-7 and II-8, petroleum consumption has increasingly been for non-fuel uses while growth in natural gas usage has been mostly for fuel. One-third of industrial oil input is currently used as raw material, rather than as fuel. Where possible, fuel uses have been separated from non-fuel uses (e.g., chemical feedstocks, lubricants and waxes) in the analysis.

The share of fuel uses filled by electricity has grown at around 4% per year, as more machine drive and high-grade energy came to be needed for advanced processes. Industry currently consumes roughly 40% of utility-generated electricity, plus small amounts of self-generated power. As the utility system became larger and better able to supply power to remote locations, industrial generation has declined.

FIGURE II-4
INDUSTRIAL ENERGY CONSUMPTION
1950-1975

quads. per year

FIGURE II-5
INDUSTRIAL ENERGY CONSUMPTION BY FUEL TYPE
1950-1975

quads per
year

25

20

15

10

5

0

elec

gas

oil

coal

FIGURE II-6
PERCENTAGE OF INDUSTRIAL ENERGY CONSUMPTION
BY FUEL TYPE - 1950-1975

percent

100

80

60

40

20

0

elec

gas

oil

coal

FIGURE II-7
INDUSTRIAL OIL CONSUMPTION
1950-1975

FIGURE II-8
INDUSTRIAL GAS CONSUMPTION
1950-1975

The industrial sector is also unique in that during an era of falling real fuel prices, overall energy efficiency, as measured by industrial output divided by energy consumption (as fuel), has actually increased. That growth has been at an annual rate of about 1.75%, as shown in Figure II-9. There is still room for a great deal of improvement though, as the energy efficiency of many industrial processes is still very low (e.g., 10-15% in some direct heating furnaces). The falling relative prices of energy sources compared to labor costs have discouraged industrial consumers from taking fuel-conserving measures where energy-consuming machines can substitute directly for labor.

One factor contributing to the increased substitution of oil and gas for coal is the lower acquisition cost of the oil- or gas-burning equipment. From the industrial decision maker's point of view, any investment in production capacity has associated with it certain non-recoverable (sunk) capital costs, and a certain amount of risk. If the capital outlay is minimized, the potential loss is also minimized. While spending more for equipment in return for expected lower fuel costs may seem economically feasible, if the venture fails the expected savings will never occur. In addition, the price of natural gas or oil has historically been low, and the extra handling and maintenance costs inherent in burning coal have often offset its lower cost per BTU. This situation appears to have changed, however. The industrial sector spent a total of \$12 billion for energy in 1972; but, in 1975, even though consumption was slightly less, that bill had risen to over \$20 billion.

The incentives are thus present for American industry to use its energy much better than it has in the past. The previously cited historical improvement in energy-efficiency has to be partially attributed to the switch to higher grade fuels. Current DOE studies estimate that for direct heat and steam-raising, oil is presently utilized 20% more efficiently, and natural gas 40% more efficiently, than coal.

FIGURE II-9

INDUSTRIAL EFFICIENCY INDEX (1967 = 100)
1950-1975

INDUSTRIAL PRODUCTION $\div$ ENERGY CONSUMED AS FUEL

2. Projected Consumption

One of the basic assumptions underlying the NEP is that continued high economic growth depends on continued satisfaction of industrial sector energy demand; while large decreases in energy consumption could be achieved in the residential/commercial and transportation sectors with no loss of services, and would have less direct effect on economic stability. Accordingly, the NEP economic growth target of a 46% increase in GNP by 1985 (4.3% per year) implies substantial growth in industrial fuel consumption. MOPPS estimates that if this high rate of GNP growth is achieved, expansion in industrial output will be over 5% per year until 1985, and around 3% thereafter. Projections of total demand for this sector are found in Figure II-10.

For the purpose of estimating fuel requirements in the "no action" case, sector energy demand was broken down by nature of the end-use (i.e., steam, direct heat, etc.). Service demand, that is, the amount required of each form of energy in each industry, was projected for 1985 and 2000 assuming that NEP economic goals are met. Fuel mix was then derived from the FEA Energy Consumption Data Base. The service demands and fuel mix were then combined for 1985 and 2000 to yield estimates of fuel consumption.

Analysis of historical trends yielded two significant results which were incorporated into the projections. First, a 1.75% annual growth in sector energy efficiency (industrial output/fuel used) was observed (see Figure II-9) so all fuel uses for 1985 were decreased by 16% (1.75% per year for 10 years). The annual efficiency improvement was decreased to 1% from 1985 to 2000, to reflect greater uncertainty in long-range estimates, so that projected fuel consumption was reduced by 28%. The resulting annual growth in energy consumption is slightly over 4.8% until 1985, and 2.2% thereafter, as shown in Figure II-10. Somewhat lower energy demand would be expected from the industrial output growth and efficiency increase cited above, but greater expansion is expected in the more energy-intensive industries, i.e., chemicals and aluminum.

The other historical trend included was the 4% annual increase in the consumption of electricity as a percent of total fuel uses during the period 1950-1975. The percentage of estimated fuel use made up by electricity was increased by 50% in 1985, and doubled in 2000. (Four percent for 25 years would yield 2.66 times greater consumption, but this study reduced the figure to 2 to reflect less confidence in a long-term estimate). Electricity was assumed to substitute equally well for all fossil fuels. Projected fuel mix is shown in Figure II-11.

Other assumptions included in the analysis include:

- The fuel mix for each end-use was assumed to remain constant, (except electricity as noted above), reflecting the use of price and/or limitations on supply to prevent further conversion to natural gas.
- Non-fuel uses of oil and gas, use of coal for coke production, and electricity for electrolysis would not be affected by the trends cited above.
- Consumption for agricultural and construction vehicles, asphalt and road oil, lubes and waxes, and oil and gas extraction, were included in the "no action" projections, adding 2.7 quads in 1985 and 5.3 quads in 2000 to estimated oil consumption.

The rapid growth projected for industrial energy consumption from 1975 to 1985 is primarily the result of the assumed high rate of economic growth. The 4.3% annual expansion of GNP sought by the NEP is considerably above the average 3.5% from 1950 to 1973, and would be the highest sustained growth in the history of the United States.

Of the three end-use sectors, industry has perhaps the greatest potential for fuel-switching, as most energy service demands can be filled by a variety of fuels. Decision criteria in industry are almost always economic, so that prices

FIGURE II-10
INDUSTRIAL ENERGY CONSUMPTION BY FUEL TYPE
1950-1975 ACTUAL
1985-2000 PROJECTIONS

FIGURE II-11
PERCENTAGE OF INDUSTRIAL ENERGY CONSUMPTION BY FUEL TYPE
1950-1975 ACTUAL
1985-2000 PROJECTIONS

and other financial incentives would effectively encourage conservation and conversion to more abundant fuels. These characteristics contrast with those of the transportation and residential/commercial sectors where many uses (i.e., vehicles) are not amenable to conversion, and where economic considerations are often not the primary basis for fuel choice.

If industry is to reverse the trend toward conversion to oil and gas, however, more efficient technologies are just as vital as alternate-fuel technologies in order to avoid more rapid growth in energy consumption than in the "no action" case. Since coal is dirty, hard to handle, and presently utilized considerably less efficiently than oil or gas, total energy requirements must be reduced if capital outlays to cover the increased costs for handling equipment, compliance with environmental standards, and production capacity of the coal mining industry are not to constrain increased coal utilization.

Due to the assumption of continued sector efficiency growth, the final projections incorporate substantial penetration of new, more efficient technology. As most advanced technology will be more capital-intensive and have lower fuel operating costs, economic factors unique to each of possibly numerous applications, such as yearly load factor (hours of operation per year), required rate of return, and payback period in the particular industry, will be of primary importance to the marketability of the new device. The most efficient or fuel-flexible device cannot save fuel unless it is widely utilized.

The need to devise new systems to make more efficient industrial use of premium fuel, and to substitute lower-quality fuel, is imminent. A capital base designed originally to function on high quality fuels, the prices of which have been held down artificially by regulation, cannot continue to function as fuel costs increase. The U.S. economy must adapt to cope with the future era of high energy costs.

C. TRANSPORTATION SECTOR

1. Historical Consumption

U.S. energy consumption for transportation grew at a rate of about 3.5% annually from 1950 to 1973, roughly the same rate as total energy use. Sector petroleum consumption expanded at almost 4.5% annually, however, due to the virtual disappearance of coal use, which accounted for half of sector energy requirements in the late 1940's. Except for less than one quad per year of natural gas used to power pipeline compressors, all transportation now depends on petroleum. Figures II-12 thru II-14 show the historical trends in oil and coal use in the transportation sector.

Several factors underly this trend. Both passenger and freight transportation have become increasingly decentralized. Except in some specific cases (e.g., New York City), people have grown to prefer cars to buses or other mass transit for intra-city, and even a good deal of inter-city transport. Fuel costs have been low enough that in most cases it has proved cheaper (as well as faster and more convenient) to drive than to ride a bus or train, even though automobile transport requires anywhere from 1.5 to more than 5 times as much fuel per passenger-mile, depending on passenger loadings.

The purchased inter-city passenger transportation market has become increasingly dominated by air travel, which typically requires more than 5 times as much fuel per passenger-mile than bus or rail transport. During the decade that ended in 1973, the result of these changing preferences was that while energy consumption for buses remained virtually the same, and for passenger trains actually declined; fuel use in cars grew at 5.5% per year. This increase was due to increased usage of automobiles and the fact that average fuel economy declined between 1950 and 1975 as shown in Figure II-15. During the same period, energy use for air travel expanded at an annual rate of over 12%.

FIGURE II-12

TRANSPORTATION ENERGY
CONSUMPTION: 1950-1975

quads per year

FIGURE II-13
TRANSPORTATION ENERGY CONSUMPTION
BY FUEL TYPE - 1950-1975
quads per year

FIGURE II-14
PERCENTAGE OF TRANSPORTATION ENERGY
CONSUMPTION BY FUEL TYPE - 1950-1975
percent

FIGURE II-15

AVERAGE AUTOMOBILE ENERGY EFFICIENCY
1950-1975

miles per gallon

Freight handling has also grown much more energy-intensive. The convenience of door-to-door pickup and delivery that trucking firms can offer their customers, and the fact that they, unlike the railroads, have their roads built out of public funds, have outweighed the fact that fuel requirements for truck freight transport are 5 to 10 times greater than for rail or water transport. In the 10 years ending in 1973, fuel use by railroads and shipping remained constant while consumption by trucks expanded at the rate of 5.5% per year.

The oil embargo in 1973, and the subsequent doubling of average petroleum prices in the U.S. (while world prices quadrupled), had a very strong effect on the transportation sector. From 1973 to 1975, gasoline consumption experienced a slight decline, (as did consumption of diesel fuel and heavy fuel oil), and then recovered to its previous level. The rapid growth of the airline industry had come to a halt in the late 1960s. By 1975, cars, trucks and planes still accounted for over 90% of sector fuel consumption.

The price increases affected some consumers more than others. While gasoline prices did not quite double, the prices of jet fuel and some grades of heavy fuel oil quadrupled. Refining costs make up a greater percentage of the cost of gasoline than of other fuels, so the rise in crude oil prices had a less than proportional effect on consumer gasoline prices.

More recent figures show, however, that when fuel prices stabilized and the economy recovered, many former fuel consumption patterns resumed as if they had never been interrupted. Consumption of gasoline and fuel oils has risen since 1975, and the air industry is expanding once more. For these and other reasons, many sources speculate that economic recession and expectations of further price increases were more responsible for the decline in consumption than higher prices. If this view is correct, U.S. dependence on relatively scarce fuels and unreliable foreign supplies seems more likely to increase than to decline in the near future.

2. Projected Consumption

To estimate future fuel consumption for transportation, several studies were reviewed for service demand projections. Where the estimates conflicted, those studies which assumed the same economic growth and price structures as in the NEP were relied upon. Where similar assumptions led to differing estimates, the figures most consistent with historical trends were chosen. The overall projection of energy consumption in the transportation sector is shown in Figures II-16 and II-17. Among the sources used were MOPPS, Brookhaven National Laboratory's Reference Energy System (BNL), MIT's Workshop on Alternative Energy Strategies (WAES), FEA's Project Independence Evaluation Study (PIES), Ford Foundation's Energy Policy Project (FEPP), and various government agency estimates.

The following paragraphs delineate the assumptions behind the "no action" case estimates for each transportation mode:

- Automobiles - estimates of growth ranged from 3% (BNL, MIT) to 4% (MOPPS) thru 1985; all sources project 2.3% thereafter. The growth rate of 4% until 1985 was chosen to represent the most conservative estimate, as there was no clear reason to choose one figure over another. In addition, the Congressional standards for new automobile mileage of 20 mpg in 1980, and 27.5 mpg in 1985 are assumed to be met, resulting in fleet average efficiencies of 22.5 mpg in 1985 and 27.5 mpg in 2000 as shown in Figure II-18.

- Trucks - for annual service demand growth in ton-miles of freight hauled through 1985, the various estimates ranged from 2% (PIES) to about 5% (MOPPS). In view of the high economic growth forecast for that period, and the historical tendency for truck usage to grow faster than GNP, the 5% figure was chosen. By similar reasoning, the high (3%) estimate for growth from 1985-2000 was also chosen. The 1975 fuel mix of 2/3 gasoline and 1/3 diesel fuel was assumed to continue.

FIGURE II-16
 TRANSPORTATION ENERGY CONSUMPTION BY FUEL TYPE
 1950-1975 ACTUAL
 1985-2000 PROJECTIONS

FIGURE II-17
 PERCENTAGE OF TRANSPORTATION ENERGY
 CONSUMPTION BY FUEL TYPE
 percent 1950-1975 - ACTUAL 1985-2000 - PROJECTIONS

FIGURE II-18

AVERAGE AUTOMOBILE FUEL EFFICIENCY
1950-1975 ACTUAL
1975-2000 PROJECTION

Non-freight trucking, which accounted for an estimated one quad of gasoline consumption in 1975, was assumed to grow at 6% annually until 1985 and at 3% from 1985 until 2000. An average efficiency of 10 mpg was assumed to apply to all years.

- Bus - The MOPPS estimates of 6% annual growth until 1985 and 4% thereafter were used. The same fuel mix as in 1975 was assumed, roughly half gasoline and half diesel. Buses consumed only one-tenth quad of fuel in 1975.

- Rail - Demand growth estimates range from 2% (BNL) to over 3% (MOPPS) for all years. In view of the nearly constant fuel usage in this mode, the lowest rate of growth was chosen for the "no action" case, 2% for all years. Railroad fuel consumption is virtually all diesel oil.

- Ship - Service demand estimates range from 2% (PIES) to 7% (MOPPS) from 1975-1985; all estimates were close to 2% thereafter. In view of historical declines in U.S. shipping, the lowest rate of growth was used, 2% for all years. Water freight fuel consumption is all heavy fuel oil. One-tenth quad each of gasoline and diesel fuel was consumed for private and recreational boating in 1975; this consumption was assumed to grow along with GNP.

- Air - Industry sources estimate 6% growth in passenger volume until 1985, but only 4% growth in fuel consumption due to the planned production of more efficient engines. Beyond 1985, the industry and all sources used (Ford Foundation, ERDA, BNL), project 5% growth except MOPPS, which assumes 4%. The higher figure was chosen for the "no action" case, by the same reasoning used in the automobile projection.

- Pipeline - Fuel consumption in pipelines, mostly natural gas, was assumed to grow in proportion to oil and gas consumption.

Reliable, historical data on energy efficiency were not available for all modes of transport, but what there are indicate that efficiency has, in general, declined since 1950. (It must be understood that efficiency, as it is used here, refers not to the thermodynamic heat input/work output relationship, but to BTU's per passenger-mile or per ton-mile. Thus, while the thermal efficiency of a small car may not be greater than that of a large car, it may be able to provide more miles on a gallon of fuel and is more efficient by the definition used here). To take into account some response to higher fuel prices, and to simplify the estimating process, the 1975 efficiencies were assumed to apply to all years for all modes of transport, except automobiles as noted above.

There is a significant potential to reduce fuel consumption without cutting back on either passenger travel or freight hauling. Buses, airlines, and other mass passenger transporters typically operate at less than 50% of available seating. Average urban automobile passenger loading is considerably less than 2 passenger-miles per vehicle-mile. Just by filling available empty seats, a sizable portion of the fuel consumption for passenger transport could be eliminated. To cite an extreme case, a full bus requires less than 5% as much fuel on a given trip than if each person on the bus drove a large car. A bus also requires only 15% as much fuel per passenger-mile as a wide-body jet when each is loaded to the same percent of capacity.

According to MOPPS, in 1975 over 50% more ton-miles of freight were hauled by railroads than by trucks, but in that same year trucks consumed seven times as much fuel as did trains. Under the "no action" case assumptions, the number of ton-miles carried by trucks will exceed the number carried by trains, and trucks will consume more than 10 times as much fuel as trains by the year 2000.

These statistics are not meant to suggest that there is a simple way to avoid the consequences of any future fuel shortage. Consumption habits have been built up over a long period of time and for a variety of reasons, such as:

- Automobiles have become heavier, more powerful, and more numerous
- Many suburban and exurban areas are not accessible by any other means
- Much of American industry has become decentralized and dependent on transportation of raw materials, workers, and finished projects
- Workers live further away from their jobs, and will not easily surrender their ability to select where they want to live.

Also, any large shift of freight hauling from highway to rail would require an immense capital investment in railroad beds and equipment, and the relocation of many industries near rail lines.

As pointed out in the previous section, historical trends in fuel consumption for various modes of transport seem to have resumed after the 1974-75 recession, despite the large increase in oil prices since 1973. It is therefore difficult to predict the effect that economic incentives and more efficient technology would have on fuel demand in this sector.

D. RESIDENTIAL/COMMERCIAL SECTOR

1. Historical Consumption

Energy consumption in the residential/commercial sector, as shown in Figure II-19, grew at about 4.2% per year between 1950 and 1973, but declined from 1973 to 1975, bringing growth to 1975 down to 3.6%. Several mild winters and the impact of quickly rising fuel prices contributed substantially to that decline, but recent figures show that the larger annual growth rate has resumed. Figures II-20 and II-21 show the amount and percent of residential/commercial energy consumption by fuel type for the period 1950 through 1975.

While growth in oil consumption has closely paralleled sector growth, natural gas and electricity have increasingly become the fuels of choice, currently satisfying two-thirds of sector requirements, up from one quarter in 1950. Lower oil consumption in 1974 and 1975 was wholly responsible for the decline in total sector consumption, while consumption of natural gas and electricity remained relatively constant. Since virtually all sector oil consumption is for space and water heat, and most is consumed in the Northeast, oil demand is strongly dependent on the severity of the winter weather. The leveling off of natural gas consumption in the 1970's can be attributed to a large degree to decreased availability rather than to increased price. The continuing decline in coal consumption and increased use of electricity for purposes which do not require high-grade energy (i.e., space heat) indicate that consumer and builder/developer preferences are more sensitive to convenience, and the initial cost of the energy-using equipment, than to fuel cost.

The combined effects of economic recession and rising fuel prices raised residential expenditures for energy as a percentage of total residential consumption expenditures from 3.5% in 1973 to 4.1% in 1975. Commercial energy costs as a percentage of sector output rose from 2.6% to only 2.8%. The cost of energy thus has been, and remains, a small fraction of total sector expenditures and output.

FIGURE II-19

RESIDENTIAL/COMMERCIAL ENERGY
CONSUMPTION: 1950-1975

quads per year

FIGURE II-20
RESIDENTIAL/COMMERCIAL ENERGY
CONSUMPTION BY FUEL TYPE:
1950-1975

FIGURE II-21
PERCENTAGE OF RESIDENTIAL/COMMERCIAL ENERGY
CONSUMPTION BY FUEL TYPE: 1950-1975

Many factors have driven the expansion in residential energy consumption since 1950. Chief among them are rising personal income, declining real energy prices, and the combination of rising population and decreasing household size, greatly increasing the number of households. The average size of dwellings also increased as personal income grew. There has been a marked trend toward raising fewer children and spending more money on building and furnishing--and heating--houses. Cleanliness and convenience have come to be valued over economy.

The recent trend toward all-electric homes has been further encouraged by the moratorium on new natural gas hookups in many areas. Electricity demand has been further stimulated by increased use of air conditioners and "convenience" appliances. For these and other reasons, residential electricity consumption expanded at 9% per year from 1950 to 1973.

Large shifts in the U.S. economy from employment in agriculture and manufacturing to employment in services have greatly increased the proportion of the work force in the commercial sector. This proportion rose from 45% in 1950 to over 60% in 1973. Combined with a 40% average increase in floor space per employee, this trend tripled commercial floor space between 1950 and 1975. During this period, sector productivity (constant dollar output per employee) increased by more than one-third, at least partially from increased use of energy to improve employee performance (e.g., air conditioners, computers) and to reduce the time and effort needed to perform service tasks (e.g., electric typewriters, copying machines, powered tools).

The residential/commercial sector has come to depend on heavy consumption of increasingly scarce and expensive fuels. It is certainly not desirable to reverse the large increases in productivity and standard of living that have occurred, yet an effective strategy to reduce energy consumption has to be defined in the very near future.

2. Projected Consumption

Projections of the expected additions to the number of housing units and number of square feet of commercial floor space, as well as the choice of heating fuel in new construction, were taken directly from the MOPPS analysis (Part 2, Section 3). The projections as to heating fuel choice assume continuation of current trends in construction; that is, new residential construction is assumed to be 50% electrically heated, 40% gas, and 10% oil. New commercial space is assumed to be 64% gas heated, 28% oil, and 8% electric. The resulting mix of fuel usage in the housing and commercial building stocks in 1985 and 2000 is illustrated in Figures II-22 and II-23. Amounts of heating fuel required are then derived using the same number of BTU's per housing unit, or per square foot, as were used in 1975 for each fuel type. The energy consumption projection for this sector is shown in Figures II-24 and II-25.

The "no action" case thus assumes no major shift of population from a colder (warmer) geographical area to a warmer (colder) climate will occur. The MOPPS and ORNL residential studies both project no significant change in the proportions of the housing stock that are made up of single family and multi-family housing.

FIGURE II-22

RESIDENTIAL UNITS BY HEATING FUEL:
1975 - ACTUAL 1985 & 2000 PROJECTION

FIGURE II-23

COMMERCIAL SPACE BY HEATING FUEL:
1975 - ACTUAL 1985 & 2000 PROJECTION

FIGURE II-24
RESIDENTIAL/COMMERCIAL ENERGY CONSUMPTION BY FUEL TYPE
1950-1975 ACTUAL
1985-2000 PROJECTIONS

FIGURE II-25
PERCENTAGE OF RESIDENTIAL/COMMERCIAL ENERGY CONSUMPTION BY FUEL TYPE
1950-1975 ACTUAL
1985-2000 PROJECTIONS

In addition, increased market penetrations for other uses of electricity were taken from MOPPS and the Brookhaven study. These estimates include:

- Residential air conditioning increases twice as fast as the number of houses until 1985, 33% faster from 1985 to 2000.
- Residential use of lighting and appliances increases 40% faster than the housing stock until 1985, 33% faster thereafter.
- Commercial air conditioning increases 40% faster than floor space until 1985, 33% faster thereafter.

It was also assumed that coal consumption would continue to decline, and would be insignificant by 1985.

It should be noted that the projections in the "no action" case assume a continuation of current moratoria on new natural gas hookups in many areas, thereby greatly increasing the use of electric heat. Should more gas hookups be made available, a large shift in fuel requirements from the projections would probably occur, increasing gas consumption at the expense of electricity (and increasing overall energy consumption since gas is utilized less efficiently than electricity).

The major increases in consumer gas and oil prices anticipated for the near future, however, would tend to increase electricity use. As all fuel prices rise, electricity becomes more competitive, as its price rises proportionately less (being initially higher). Also, most electric power is still generated using coal or nuclear fuel, the prices of which, not currently under government controls, are not expected to rise nearly as much as those of oil and gas.

The basis of the "no action" case is that decisions as to heating fuel in new buildings will continue to be influenced primarily by convenience and (in houses) the initial cost of heating equipment, subject to constraints on availa-

bility of preferred fuels. With the economic conditions assumed by the NEP, demand for air conditioners and convenience appliances will continue to grow.

The projected fuel demands should thus not be construed as a probable future, but as a scenario in which all conditions continue as they are. New buildings will probably be more efficient than old, but builders' and homeowners' attitudes toward fuel use could have a substantial effect. If people build bigger houses and buy the cheapest (and least efficient) furnaces and appliances, fuel use could well be higher. On the other hand, the heating requirements of even many old buildings could be substantially reduced by improvement of insulation, installation of storm windows, etc. The residential/commercial sector is perhaps the biggest market for retrofit equipment, since an estimated 60% of the building stock in the year 2000 is in existence today. Few decision-makers in this sector have considered life cycle costs in choosing equipment, and the market penetration of many products (i.e., storm windows, electric heat pumps, insulation) is below the economically justifiable level. Many homeowners, and some commercial building owners, are not aware of many cost-effective steps they could take to significantly reduce fuel costs. The market penetration of any new technology will thus be difficult to estimate, as the factors determining that penetration are not well understood.

Though each residential/commercial unit (home, office building, store, etc.) can generally undergo technological change relatively rapidly, the sector as a whole tends to change slowly. Sector-wide changes thus require long lead-times for their impacts. In this sector, perhaps more than any other, decisions and policies enacted in the next few years will fundamentally effect energy use for the rest of the century.

E. ELECTRIC UTILITY SECTOR

1. Historical Consumption

Electric power is indispensable to the factory, the commercial establishment, the home, and even most recreational facilities. It is such an accepted part of our way of life that it is newsworthy only when it is not available. It was introduced in the late 1800's and has grown very rapidly, until today very few people in the United States do not have electricity in their homes and places of work.

Growth in energy consumption in the utility sector, shown in Figure II-26, was by far the fastest sector growth. Sector output, in kilowatt hours (KWH) of electricity, has historically grown at over 7% per year, or doubled every 10 years. Consumption in the utility sector alone did not decline following the 1973 oil embargo.

Fuel mix in the utility industry has changed less than in the other sectors, as illustrated in Figures II-27 and II-28.⁵ Coal, which accounted for 55% of all consumption in the early 1950's, now fills around 45% of requirements, a level that has been stable since 1970. Utility consumption of oil and natural gas increased five-fold from 1950 to 1973, at least partially due to low equipment prices and stricter environmental regulations. The use of oil and gas peaked in 1973 at over 37% of all requirements and has dropped to around 30% more recently. Nuclear power, virtually nonexistent before 1970, now accounts for almost 10% of all electricity production. Growth in hydroelectric power paralleled demand growth until the mid-1960's, at which time most of the better sites for such installations had been developed. Few sources foresee any further significant growth in hydro-electricity production in the U.S.

⁵ Figures II-27 and II-30 were drawn to show both total and net energy consumption. While the entire length of the bar represents total fuel consumption, each bar has been moved down through the zero level by an amount equal to energy output, or electricity produced, in that year. The part of the bar that remains above zero thus represents net sector consumption.

FIGURE II-26
ELECTRIC UTILITY ENERGY CONSUMPTION
1950-1975

quads per year

FIGURE II-27
ELECTRIC UTILITY CONSUMPTION BY FUEL TYPE
1950-1975

FIGURE II-28
PERCENTAGE OF ELECTRIC UTILITY FUEL CONSUMPTION BY FUEL TYPE
1950-1975

Utility fuel efficiency has also increased since 1950, as a result of improvements in steam turbines and heat recovery systems. Technical constraints in handling of high pressure and temperature steam have slowed improvements in the past decade, however, and average efficiency has leveled off at 30-35%, as illustrated in Figure II-29. It cannot be said that the utilities have not sought further improvements, as this leveling off occurred during a time in which expenditures for primary energy were becoming more significant to the industry. Fuel costs, 37% of total operating expenses in 1975, accounted for less than 20% as recently as 1969. That fraction jumped from 27% to 37% in the space of one year--1973 to 1974. Between 1973 and 1975, real coal prices rose by almost 90%, gas prices by 100%, and oil prices by 264%. The weighted average real cost of all fossil fuels used in electricity generation more than doubled. There are, however, large differences between costs in different geographical areas. Average fuel costs per million BTUs in 1975 were between \$1.50 and \$2.00 in most Northeastern and Pacific states, and only \$0.60 to \$0.70 in most of the Midwest, with extremes ranging from less than \$0.30 in Wyoming to over \$2.00 in Connecticut and Oregon. Corresponding electricity prices were 4¢ per KWH in New England, and 2.5¢ in the Midwest.

At least part of this discrepancy comes from environmental restrictions on burning of high-sulfur coal in New England, and the difficulty of transporting coal to Pacific Coast states. While oil makes up less than 20% of total sector fuel requirements, 58% of all electricity in New England is generated by oil. In the West Coast, oil accounts for 21% of all generation, but 53% of fuel requirements, because in those states hydro-electric power accounts for over 60% of all electricity production. (This accounts for the low cost of power in Washington and Oregon - 1¢ per KWH in 1975).

FIGURE II-29

ELECTRIC UTILITY ENERGY EFFICIENCY*
1950-1975

*ELECTRICITY PRODUCED/FUEL CONSUMED

Even with these increases in fuel costs, the utility industry is still the most capital-intensive in the world. Average equipment life is exceeded only in the residential/commercial sector, where the capital stock consists of buildings. Planning horizons are the longest of any industry, as growth must be accomplished prior to growth of demand, with no service discontinuity, and with maximum economy and minimum air and water pollution. Unlike most businesses, the utility must create its product simultaneously with its use. This requires a system capacity able to meet the load demand whenever it occurs. Thus a maximum or peak load of only a moment's duration will require the necessary equipment to be in place the entire year.

In many kinds of business the gross annual income is several times the amount invested in the business, but for the reasons cited above, the reverse is true of the utility. The typical utility will have four dollars invested for every dollar of annual revenue, the railroads under three, and total manufacturing under thirty cents for each dollar of sales. This comparison reflects the high investment cost in a utility; so that in 1975, little over 34% of the average 2.7¢ per kilowatt hour paid by all electric power customers was spent on the fuel needed to generate the electricity. This fraction has increased substantially in the last decade, from 17% in 1968, and from 24% as recently as 1973. Thus, the utilities have become much more conscious of fuel costs in recent years, and are taking active part in research and development of new technologies for the clean, efficient generation of electric power.

2. Projected Consumption

Summing electricity demand projections from the industrial and residential/commercial sectors yields annual demand growth of 8% from 1975-1985 and 3.2% from 1985-2000. Fuel efficiency in the "no action" case was assumed to remain

constant, so primary fuel requirements grow at the same rate as demand. Projections for consumption in this sector are illustrated in Figures II-30 and II-31.

Projected consumption of each fuel type was derived as follows:

- Nuclear - the MOPPS 'best guess' estimate of 123 plants on-line in 1985 was used, yielding a primary equivalent fuel consumption of 5.6 quads (assuming the same average size and load factor as in 1975). For 2000, the MOPPS study considers two cases, low and high uranium availability. The 'best guess' estimates of fuel usage were 11 quads for the low case, and 19 quads for the high case. The median value of 15 was incorporated into the "no action" case estimates.

These figures translate into 12% growth to 1985, and 6.8% thereafter, roughly twice the rate predicted for growth in electricity demand. The "no action" case thus predicts that the percentage of electricity generated from nuclear fuel will increase from 9% in 1975 to 17% in 1985, and to over 20% in 2000.

- Coal - Coal has always been the largest single source of power plant fuel, even though its share has declined, and is no longer greater than half. As illustrated, an almost constant 45% of fuel requirements have been filled by coal since 1970. This share was assumed to remain constant until 2000 in the "no action" case. Utility coal consumption is thus predicted to expand at 8% until 1985, a rate above the NEP goal for growth in total coal consumption.

- Other - In this sector, this component includes hydro, geothermal, solar, and wind power. The NEP goals of 3.4 quads (primary equivalent) of hydro and geothermal power in 1985, and 3.5 quads in 2000, were assumed to be met. While geothermal and hydro-electricity generation do not involve the consumption of fuel, "primary equivalent" consumption is derived from the actual amount of power generated, using national average fuel efficiency for all utilities, and so is the amount of fuel that would be required to generate the same amount of

FIGURE II-30
ELECTRIC UTILITY ENERGY CONSUMPTION
BY FUEL TYPE 1950-1975 ACTUAL 1975-2000 PROJECTIONS
quads per year (net)

FIGURE II-31
PERCENTAGE OF ELECTRIC UTILITY ENERGY CONSUMPTION
BY FUEL TYPE
1950-1975 ACTUAL
1975-2000 PROJECTIONS

power. Primary equivalent consumption in 1975 was 3.2 quads, so the real meaning of the figures is that production of geothermal and hydro-electric power is expected to increase at less than 1% annually. Under the conditions assumed for the "no action" case, no significant utilization of solar or wind power is anticipated.

- Oil and Gas - Since coal consumption is assumed to grow along with demand, and hydro and nuclear power were projected independently of demand, oil and gas usage is a residual and is thus strongly dependent on demand growth.

The "no action" case projections do not consider the implementation of hydro-electric and nuclear technologies to be constrained by electricity demand, but by siting and, in the case of nuclear power, safety and waste-disposal considerations.

If the proposed expansion of coal production takes place, the upper limit on how much coal is burned by utilities will not depend on demand for electric power, but on how fast the coal industry can expand without massive environmental degradation. If the utilities are to continue to meet expected demand for electric power through the end of this century, consumption of oil and gas must continue. Unless constraints on expansion of hydro, coal, and nuclear capacity can be relaxed, and new technologies made commercially viable, the U.S. will continue to rely on oil and gas for part of its electricity requirements.

Under "no action" case demand projections, somewhat lower than some industry estimates, the utilities must build twice as many new power plants as are already in existence by the year 2000. Even if prices of new power plants do not increase, this represents an investment of well over \$500 billion, a market large enough to absorb a wide variety of new technologies.

III. ENERGY OUTPUT REQUIREMENTS

A. CONSERVATION GOALS

In developing consumption goals for 1985 and 2000, the results of several studies were analyzed. Those goals chosen for the analysis came primarily from the NEP and, in those instances where greater detail was required, from other DOE studies (e.g., MOPPS).

The NEP presents three estimates of fuel consumption for 1985. The first and highest is labeled "Without (National Energy) Plan," and corresponds roughly in its assumptions and results to the "no action" case. In the second case, labeled "With Plan," fuel consumption is projected assuming that the economic incentives and pricing policies proposed by the President are put into effect. The third and lowest, estimate, "Plan plus additional Conservation," differs only from the second in its approximately 2.5 quads lower oil consumption. This third case was not specific, however, as to the source (sector) of these extra savings.

The third set of estimates was chosen to represent 1985 consumption goals. The "With Plan" estimates of residential/commercial and transportation sector oil consumption were each adjusted downward 1.25 quads to yield the lower total oil demand. The choice of these two sectors for the additional cut in consumption is consistent with the text of the NEP, in which industrial sector fuel consumption was seen as more critical to economic growth, and thus received priority.

The NEP does not, however, list any specific targets for the various sectors in the year 2000. The only goal stated is the reduction of the rate of total energy growth to below 2% per year. Therefore, the consumption goals for 2000 were taken from the MOPPS base case.

The MOPPS study presents a reference case, corresponding roughly in its assumptions and results to the "no action" case, and a base case which assumes significant market penetration of new conservation technologies, as well as the NEP pricing structure and economic incentives.

The conservation goals by fuel type and by sector are illustrated in Figures III-1 and III-2, respectively. The goals call for total annual energy savings of around 15 quads in 1985, and 40 quads in 2000, over the "no action" case. The goals imply a shift from reliance on gas and oil to much greater use of coal in the near term (1985), and substantial reduction in total energy consumption in the last part of the century. The year 2000 goals more than satisfy the NEP target of an annual energy growth rate of less than 2% after 1985. In fact, a level of consumption 10 quads higher in 2000 would still fall within that growth constraint.

B. EFFICIENCY REQUIREMENTS

1. Industrial Sector

The goal for industrial energy consumption requires a relatively modest increase in energy efficiency compared to other consuming sectors. Figure III-3 shows a gap between the "no action" projection and the goal of 2 quads in 1985 and 10 quads in 2000. The "no action" estimate assumes continued efficiency improvement in all fuel uses at the historical rate of 1.75% per year until 1985 (see Section II.B) and 1% thereafter, yielding 16% less energy consumption per unit of industrial output in 1985, (and 28% less in 2000) than was required in 1975.

The goals require that industrial sector energy consumption grow at 1% per year less than is projected. The average annual growth goal for the 25-year period is very close to the historical rate of 2.6%, even with substantially

FIGURE III-1
TOTAL US ENERGY CONSUMPTION BY FUEL TYPE
1950-1975 ACTUAL
1985-2000 PROJECTIONS AND GOALS

FIGURE III-2
TOTAL US ENERGY CONSUMPTION BY SECTOR
1950-1975 ACTUAL
1985-2000 PROJECTIONS AND GOALS

higher future economic growth. If all goals are achieved, industrial sector growth would be the highest of the three end-use sectors, rather than the lowest, as it has been since 1950. This trend is consistent with the NEP policy of attempting to minimize the negative impact of energy conservation on employment and production.

Figures III-3 and III-4 show the industrial sector consumption goals and projections by fuel type by total quads and percent of total consumption, respectively. The necessary transition in industrial sector energy use is one of fuel choice as well as efficiency. The NEP goals require much lower consumption of oil, gas, and electricity, but 5 quads greater coal consumption in 1985, and 10 quads greater in 2000. Energy sources such as hydropower, industrial waste and waste heat, etc., (labeled "Other" on the graphs) are not specifically treated by the NEP. The section labeled "Other" for 1985 on Figure III-3 is taken from the "no action" case.

2. Transportation Sector

The conservation goals for transportation sector energy consumption represent much slower growth from 1975 to 1985, and an actual decline from 1985 to 2000, as shown in Figure III-5. The President's goals, stated in the NEP, include a 10% reduction in gasoline consumption by 1985. As shown in the figures, the congressionally mandated improvements in automobile gasoline mileage are predicted to come close to achieving sector consumption goals in 1985.

After 1985, however, the opposite effects of the slowed improvements in fuel mileage and reduced service demand growth are expected to cancel; and fuel consumption is expected to grow at a uniform rate of 2.2% from 1975 to 2000. The achievement of conservation goals thus implies an improvement in overall sector fuel efficiency of over 50%, and a large-scale conversion from gasoline to lower grade liquid fuels (which could be produced from oil shale or even coal) and electricity, by the year 2000, as illustrated in Figures III-5 and III-6.

FIGURE III-3
CONSUMPTION BY FUEL TYPE
1950-1975 ACTUAL
1985-2000 PROJECTIONS AND GOALS

FIGURE III-4
PERCENTAGE OF INDUSTRIAL ENERGY CONSUMPTION BY FUEL TYPE
1950-1975 ACTUAL
1985-2000 PROJECTIONS AND GOALS

FIGURE III-5
TRANSPORTATION ENERGY CONSUMPTION BY FUEL TYPE
1950-1975 ACTUAL
1985-2000 PROJECTIONS AND GOALS

FIGURE III-6
PERCENTAGE OF TRANSPORTATION ENERGY CONSUMPTION BY FUEL TYPE
1950-1975 ACTUAL
1985-2000 PROJECTIONS AND GOALS

3. Residential/Commercial Sector

As illustrated in Figure III-7, the "no action" case projections and the NEP and MOPPS goals for residential/commercial sector energy consumption imply more modest growth than has been observed in the past. Projected growth, 3% until 1985 and 1.8% thereafter, is lower than the historical 3.5%, primarily because of predictions of slowed population growth. The conservation goals, however, require still lower annual increases in consumption, 1% until 1985 and only 0.3% from 1985 to 2000. The realization of those goals would require a 50% increase in sector energy efficiency by the turn of the century.

As shown in Figures III-7 and III-8, both goals and projections predict a shift in sector fuel mix. Electricity is seen to fulfill a growing share of fuel requirements, with the amounts of oil and gas declining proportionately. The reasons for this shift are discussed in Section II.D.

The goals for 2000 also include 1.1 quads of "other" energy sources, primarily from solar technology and integrated energy systems. An example of the latter are the district heating systems in some Western European countries, in which power plant waste heat is utilized to heat buildings.

4. Electric Utility Sector

The conservation goals from the industrial and residential/commercial sectors yield a much slower growth in demand for electricity than that projected in the "no action" case. If all goals are met in the two electricity-consuming sectors, the demand growth rate during the remainder of the century would be 3.2%, less than half of the historical 7%. The "no action" case, on the other hand, estimates average growth at just over 5%.

The fuel consumption necessary to support each level of demand is shown in Figures III-9 and III-10. (Figure III-9 is drawn like Figure II-27 in Section II.E. The length of the bar below the zero line represents electricity produc-

FIGURE III-7
RESIDENTIAL/COMMERCIAL ENERGY CONSUMPTION BY FUEL TYPE
1950-1975 ACTUAL
1985-2000 PROJECTIONS AND GOALS

FIGURE III-8
PERCENT RESIDENTIAL/COMMERCIAL ENERGY CONSUMPTION BY FUEL TYPE
1950-1975 ACTUAL
1985-2000 PROJECTIONS AND GOALS

FIGURE III-9
ELECTRIC UTILITY ENERGY CONSUMPTION BY FUEL TYPE
1950-1975 ACTUAL 1985-2000 PROJECTIONS (AND GOALS)

FIGURE III-10
PERCENTAGE OF ELECTRIC UTILITY ENERGY CONSUMPTION
BY FUEL TYPE
1950-1975 ACTUAL 1985-2000 PROJECTIONS (AND GOALS)

tion, the part above zero represents net fuel consumption, and the entire length of the bar is total fuel consumption). Average conversion efficiency is predicted by the NEP to remain the same as in 1975. As the graphs show, however, the fuel makeup of this consumption is substantially different in the two cases. While "no action" projections do include significant growth in nuclear power, and continued use of coal as the primary fuel source, the goals require the virtual elimination of oil and gas use from the utility sector. The percentage of fuel demand satisfied by coal would increase in the short term to 55%, then decline to less than its current level of 45% by the end of the century. The majority of power plant fuel requirements would then be filled by nuclear, hydro, and two quads of "other" sources, primarily solar and geothermal power. (Hydro is included in "other" sources in the graphs, but the same amount of hydroelectricity is assumed in both "no action" projections and conservation goals).

IV. SUMMARY

A. CONCLUSIONS

The comparison of consumption goals to "no action" case projections yields results consistent with assumptions behind the NEP. Industrial sector energy demand receives priority over residential/commercial and transportation sector consumption. Achievement of the NEP goals requires a modest efficiency improvement in industry, but a substantial shift from oil and gas to coal, so that the latter fuel satisfies 40% of sector demand, versus a projected 14%, by 2000. The transportation and residential/commercial sector goals require an increase in fuel efficiency of over 50% by the year 2000, but dependency on premium fuels (e.g., oil in transportation, natural gas and electricity in residential/commercial) is seen to continue.

In the nearer term, the transportation sector is required to make the largest efficiency improvement, but most of the requirement is assumed to be achieved by congressional mileage standards for new automobiles. The "no action" estimate of transportation sector consumption would increase by over 5 quads of gasoline in 1985 and 10 quads in 2000 without the legislated improvement in average new car mileage from around 14 mpg in 1975 to 27.5 mpg in 1985.

The "no action" case projections of oil and gas consumption are not intended to represent a probable, or even possible, future, as few supply constraints are considered. That the U.S. could be producing and importing over 100 quads of oil and gas annually by the end of this century is highly unlikely. Most supply studies show world production declining by that date, in some cases the decline is expected as early as the mid-1980's. By any estimate, the price of these fuels is expected to be so high that such levels of consumption could not be supported without serious economic consequences.

The "no action" case figures serve to illustrate the degree to which the U.S. has become dependent on inexpensive, clean, abundant fuel, and the magnitude of the transition that must take place if we are to have reliable supplies of energy in the future.

The increased consumption of coal and nuclear power is a key part of the NEP goals. Environmental and safety considerations, rather than supply constraints, are seen to be the limiting factors to reliance on these fuel sources during the rest of this century. Air quality standards have encouraged industrial and utility consumers to burn oil in their boilers, as the cost of currently available pollution-abatement devices adds substantially to the cost of coal-fired equipment.

One basic necessity to the realization of goals for 2000 is that these constraints will be removed, that acceptable safety measures and waste-disposal methods will permit the nuclear industry to expand, and that inexpensive, effective anti-pollution devices will be available to permit greatly expanded coal consumption without massive environmental degradation.

The goals also rely upon the substitution of 5 quads of "other" energy sources (i.e., solar, geothermal) for fossil fuel by 2000, and a large amount of the reduction in industrial fuel consumption depends on utilization of waste heat and burning of by-products for many uses which currently require purchased fuel.

This report undeniably sets forth some rather ambitious objectives--to reduce projected energy demand by 30%, and to cut by more than half a potential oil and gas demand of 100 quads per year in 2000, all without compromising economic growth or the quality of the environment.

The "no action" case assumes with few exceptions that the conditions governing energy consumption will be the same as during the historical period 1950-1975. One major determinant has been the falling price of fuel, a condition that has already been reversed. Preliminary figures for 1977 indicate that real GNP was 8% higher than in 1973, with only 3.5% greater fuel consumption, so the price increases faced by consumers are having an effect on historical energy usage trends. The conservation goals and usage projections (i.e., efficiency improvements and fuel switching) outlined in this report identify those areas where RD&D efforts are needed to continue this transition in the U.S. energy economy.

B. FUTURE EFFORTS

The energy consumption projections and goals contained in this report provide the basis for choosing between various program options open to the Division of Power Systems. The breakdown of the U.S. economy into the various consuming sectors and the identification of the many end-users in each sector will aid in the evaluation of any particular development project. The potential impact of a technological innovation will depend on market forces, as well as technical performance. The individual aspects of the market sector(s) addressed by any new technology must be understood before its potential for fuel savings can be assessed. These aspects will be explored in detail in the methodology development effort under Task 2.

Before Tasks 2 and 3 of this analysis can be carried out, some additional data must be collected. Detailed figures are needed on the number and size of fuel burning installations, normal equipment lifetimes, financial requirements, and expected additions to capacity in the major energy consuming industries. More detailed geographical breakdowns of industrial capacity and numbers of buildings will also aid in the analysis, as fuel costs vary in different parts of the country. With these additions to the data base, specific projects can be evaluated on their ability to satisfy the requirements developed in Task 1.

APPENDIX

REFERENCES

1. American Gas Association "Gas Facts", 1972.
2. American Public Transit Association, Transit Fact Book, Washington, DC, 1976.
3. Edison Electric Institute, Statistical Yearbook, 1975.
4. Electric Utility Systems and Practices, General Electric Company, Schenectady, New York, 1974.
5. Energy Demand by the Transportation Sector in 1985 and 2000: A Comparison of Five Studies, Doggett, Ralph M., International Research and Technology Corporation, for U.S. Energy Research and Development Administration, 1976.
6. The National Energy Plan, Executive Office of the President, Energy Policy and Planning, Washington, DC, 1977.
7. Options for U.S. Energy Policy, Institute for Contemporary Studies, San Francisco, CA, 1977.
8. Sourcebook for Energy Assessment, Brookhaven National Laboratory, for United States Energy Research and Development Administration, 1975.
9. A Time to Choose: America's Energy Future, Energy Policy Project of the Ford Foundation, Ballinger Publishing Co., Cambridge, MASS, 1974.
10. U.S. Department of the Interior, Bureau of Mines, Minerals Yearbook, Washington DC, (annual).
11. U.S. Department of Transportation, Energy Statistics, Washington, DC, 1975.
12. U.S. Department of Transportation, Federal Highway Administration, Highway Statistics, (annual)
13. U.S. Energy Research and Development Administration, Market Oriented Program Planning Study (MOPPS), Washington, DC, 1977.
14. U.S. Environmental Protection Agency, A Report on Fuel Economy, 1973.
15. U.S. Federal Energy Administration, "End-use Energy Consumption Data Base," Washington, DC, 1977.
16. U.S. Federal Energy Administration, Project Independence Blueprint, Final Task Force Report - Project Independence and Energy Conservation: Transportation Sector, Washington, DC, 1974.
17. U.S. Federal Energy Administration, Project Independence Evaluation System, Washington, DC, 1976.
18. U.S. Federal Power Commission, Electric Power Statistics, Washington, DC, 1976.

TABLE 1

TOTAL US ENERGY CONSUMPTION BY FUEL

QUADS/YEAR

FUEL \ YEAR	50	55	60	65	70	73	75
COAL	12.8	11.4	10.1	11.9	12.7	13.2	13.3
OIL	13.2	17.0	19.6	22.6	29.5	34.8	32.7
GAS	6.1	9.2	12.8	16.1	22.0	22.1	20.7
HYDRO	1.4	1.4	1.7	2.1	2.7	3.0	3.2
NUCLEAR	-	-	-	-	0.2	0.9	1.8
TOTAL	33.5	39.2	43.9	52.9	66.9	74.0	71.8

(TOTALS TAKEN FROM ORIGINAL, UNROUNDED DATA)

SOURCE: U.S. Bureau of Mines

TABLE 2

U.S. ENERGY CONSUMPTION BY THE INDUSTRIAL SECTOR

QUADS/YEAR

ENERGY SOURCE \ YEAR	50	55	60	65	70	73	75
COAL	6.0	5.7	4.7	5.4	5.0	4.3	4.3
NATURAL GAS -							
FUEL	3.3	4.5	5.9	7.4	9.5	9.5	8.8
NON-FUEL	0.4	0.4	0.4	0.3	0.7	0.6	0.5
	<u>3.7</u>	<u>4.9</u>	<u>6.3</u>	<u>7.7</u>	<u>10.2</u>	<u>10.1</u>	<u>9.3</u>
PETROLEUM -							
FUEL	2.3	2.8	2.7	2.8	3.3	4.0	4.0
NON-FUEL	0.4	0.6	1.0	1.3	2.0	2.2	1.8
	<u>2.7</u>	<u>3.4</u>	<u>3.7</u>	<u>4.1</u>	<u>5.3</u>	<u>6.2</u>	<u>5.8</u>
ELECTRICITY	0.6	1.0	1.3	1.6	2.2	2.6	2.7
TOTAL	12.9	15.1	15.9	18.8	22.6	23.3	22.1

SOURCE: U.S. Bureau of Mines

TABLE 3

INDUSTRIAL ENERGY EFFICIENCY INDEX
(INDUSTRIAL PRODUCTION ÷ ENERGY CONSUMED AS FUEL)

1967 = 100

YEAR	INDEX
1950	71.2
1951	69.4
1952	74.8
1953	76.2
1954	79.2
1955	78.5
1956	78.2
1957	79.6
1958	79.4
1959	86.4
1960	85.2
1961	86.0
1962	88.7
1963	89.6
1964	90.5
1965	95.0
1966	98.7
1967	100.0
1968	98.4
1969	101.8
1970	96.4
1971	97.0

SOURCES: U.S. Bureau of Mines
U.S. Federal Reserve Board

TABLE 4

U.S. ENERGY CONSUMPTION BY THE TRANSPORTATION SECTOR

QUADS/YEAR

FUEL \ YEAR	50	55	60	65	70	73	75
	(QUADRILLION BTU)						
GASOLINE	5.2	6.9	7.9	9.0	11.2	12.9	12.9
JET FUEL	-	0.3	0.7	1.2	2.0	2.1	2.0
DISTILLATE FUEL OIL	0.5	0.8	0.9	1.5	1.5	2.2	2.1
OTHER PETROLEUM	<u>1.1</u>	<u>1.1</u>	<u>0.9</u>	<u>0.9</u>	<u>0.9</u>	<u>0.9</u>	<u>0.7</u>
TOTAL PETROLEUM	6.8	9.1	10.4	12.2	15.6	18.2	17.9
NATURAL GAS	0.1	0.3	0.4	0.5	0.7	0.7	0.6
COAL	<u>1.7</u>	<u>0.5</u>	<u>0.1</u>	-	-	-	-
TOTAL	8.6	9.9	10.9	12.7	16.3	19.0	18.5

SOURCE: U.S. Bureau of Mines

TABLE 5
AVERAGE FUEL ECONOMY FOR THE AUTOMOBILE FLEET
(MILES PER GALLON)

YEAR	AVERAGE FLEET FUEL ECONOMY
1950	14.95
1955	14.53
1960	14.28
1965	14.07
1970	13.57
1975	13.00
1985	22.5
2000	27.5

SOURCE: U.S. Department of Transportation, Federal Highway Administration, Highway Statistics, annual; U.S. Environmental Protection Agency, A Report on Fuel Economy, October 1973

The 1985 and 2000 figures are projections, assuming that congressional standards for all new cars of 20 mpg in 1980 and 27.5 mpg in 1985 are met

TABLE 6
ENERGY CONSUMPTION BY THE RESIDENTIAL/COMMERCIAL SECTOR
QUADS/YEAR

FUEL \ YEAR							
	50	55	60	65	70	73	75
ELECTRICITY	0.5	0.9	1.3	1.9	3.0	3.7	3.9
PETROLEUM	3.0	4.0	4.9	5.6	6.5	6.7	5.8
NAT. GAS	1.6	2.8	4.3	5.5	7.1	7.6	7.6
COAL	2.9	1.7	1.0	0.7	0.4	0.3	0.2
TOTAL	8.1	9.5	11.4	13.8	17.0	18.3	17.6

SOURCES: U.S. Bureau of Mines
Edison Electric Institute Yr. Book 76
American Gas Association "Gas Facts"

TABLE 7
ENERGY CONSUMPTION BY THE ELECTRICAL SECTOR
QUADS/YEAR

FUEL \ YEAR	50	55	60	65	70	73	75
	(QUADRILLION BTU) 10^{15}						
COAL	2.2	3.5	4.3	5.8	7.3	8.6	8.8
PETROLEUM	0.7	0.5	0.6	0.7	2.1	3.7	3.2
NATURAL GAS	0.7	1.2	1.8	2.4	4.0	3.7	3.2
HYDROPOWER	1.4	1.4	1.7	2.1	2.7	3.0	3.2
NUCLEAR	<u>-</u>	<u>-</u>	<u>-</u>	<u>-</u>	<u>0.2</u>	<u>0.9</u>	<u>1.8</u>
TOTAL	5.0	6.6	8.3	11.1	16.2	19.8	20.2
ELECTRICITY PRO- DUCED	<u>1.2</u>	<u>1.9</u>	<u>2.6</u>	<u>3.6</u>	<u>5.2</u>	<u>6.3</u>	<u>6.5</u>
NET CONSUMPTION	3.8	4.7	5.7	7.5	11.0	13.5	13.7

SOURCE: Edison Electric Institute

TABLE 8

PROJECTED TRANSPORTATION OIL CONSUMPTION
BY PRODUCT AND END-USE

MODE	QUADS			
	GASOLINE	DIESEL	RESIDUAL PETROLEUM	JET FUEL
AUTOMOBILE				
1985	8.75*			
2000	10.07**			
TRUCK-NON FRT				
1985	1.8			
2000	2.8			
TRUCK-FRT.				
1985	3.38	2.0		
2000	5.27	3.12		
BUS				
1985	0.09	0.09		
2000	0.16	0.16		
RAIL				
1985		0.73		
2000		0.99		
SHIP-PRIVATE				
1985	0.14	0.14		
2000	0.23	0.23		
SHIP-FRT				
1985			0.73	
2000			0.98	
AIR				
1985				2.96
2000				6.15
TOTALS				
1975	12.8	2.0	0.6	2.0
1985	14.16	2.96	0.73	2.96
2000	18.73	4.50	0.98	6.15

*AVG. 22.5 MPG

**AVG. 27.5 MPG

TABLE 9
RESIDENTIAL/COMMERCIAL BUILDING STOCK BY FUEL TYPE
1975 ACTUAL
1985 AND 2000 PROJECTED

RESIDENTIAL FUEL	UNITS x 10 ⁶							
	1975			1985			2000	
GAS	44.11	+8.24	-2.23=	50.12	+10.6	-3.35=	56.93	UNITS
	62%	40%		57%	40%		53%	%
OIL	17.54	+2.06	-0.9 =	18.7	+ 2.54	-1.35=	19.89	UNITS
	25%	10%		21%	10%		18%	%
ELECTRICITY	9.18	+10.3	-4.7 =	19.01	+12.7	- .7=	31.01	UNITS
	13%	50%		22%	50%		29%	%
TOTALS	70.83	20.6	3.6	87.83	25.4	5.4	107.83	
COMMERCIAL FUEL	SQ. FT. x 10 ⁹							
	1975			1985			2000	
GAS	12.6	+5.53	-.89=	17.24	+9.6	-1.35=	25.65	UNITS
	52%	64%		55%	64%		58%	%
OIL	10.6	+2.44	-.74=	12.3	+4.27	-1.12=	15.45	UNITS
	43%	28%		39%	28%		35%	%
ELECTRICITY	1.21	+.69	-.09=	1.81	+1.22	-.13=	2.9	UNITS
	5%	8%		6%	8%		7%	%
TOTALS								
	EXIST'G 1975	BUILD	TEAR DOWN	PROJ. 1985	BUILD	TEAR DOWN	PROJ. 2000	

SOURCE: MOPPS

TABLE 10

CONSUMPTION PROJECTIONS

	BTU x 10 ¹⁵							
	OIL	GAS	COAL	NUCLEAR	ELEC	OTHER	TOTAL	
TRANSPORTATION	17.3	0.7					18.0	1975
	21.5	1.0					22.5	1985
	29.9	1.9					31.8	2000
RESIDENTIAL/ COMMERCIAL	4.7	7.6	0.2		4.0		16.6	1975
	5.2	9.3			7.7		22.2	1985
	5.8	11.7			11.3		28.8	2000
INDUSTRY	7.6	8.7	3.7		2.3	2.0	24.3	1975
	11.2	13.0	5.8		5.9	2.9	38.8	1985
	15.0	16.9	7.5		10.5	4.2	54.1	2000
ELECTRIC UTILITIES	3.2	3.2	8.8	1.8	(6.3)	3.2	13.9	1975
	6.6	6.6	19.8	7.5	(13.6)	3.4	30.3	1985
	10.6	10.6	31.6	15.0	(21.8)	3.5	48.5	2000
TOTAL	32.8	20.2	12.7	1.8		5.2	72.5	1975
	44.5	29.9	25.6	7.5		6.3	113.8	1985
	61.3	41.1	39.1	15.0		7.7	164.2	2000

TABLE 11
CONSUMPTION GOALS

	BTU x 10 ¹⁵							
	OIL	GAS	COAL	NUCLEAR	ELEC	OTHER	TOTAL	
TRANSPORTATION	17.3	0.7					18.0	1975
	20.3	0.7					21.0	1985
	18.0	0.5			1.0		19.5	2000
RESIDENTIAL/ COMMERCIAL	4.7	7.6	0.2		4.0		16.6	1975
	4.5	8.7			5.3		18.4	1985
	3.8	7.8			6.5	1.1	19.2	2000
INDUSTRY	7.6	8.7	3.7		2.3	2.0	24.3	1975
	8.5	9.5	10.6		4.5	2.9*	36.0	1985
	6.6	7.2	17.9		6.4	6.2	44.3	2000
ELECTRIC UTILITIES	3.2	3.2	8.8	1.8	(6.3)	3.2	13.9	1975
	2.8	1.1	17.6	8.0	(9.8)	3.4	23.1	1985
	1.0	0.0	20.0	20.3	(13.9)	5.4	32.8	2000
TOTAL	32.8	20.2	12.7	1.8		5.2	72.5	1975
	36.0	20.0	28.2	8.0		6.3	98.5	1985
	29.4	15.5	37.9	20.3		12.9	115.8	2000

*This figure was taken from the "no action" case,
as the NEP gives no specific amount

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