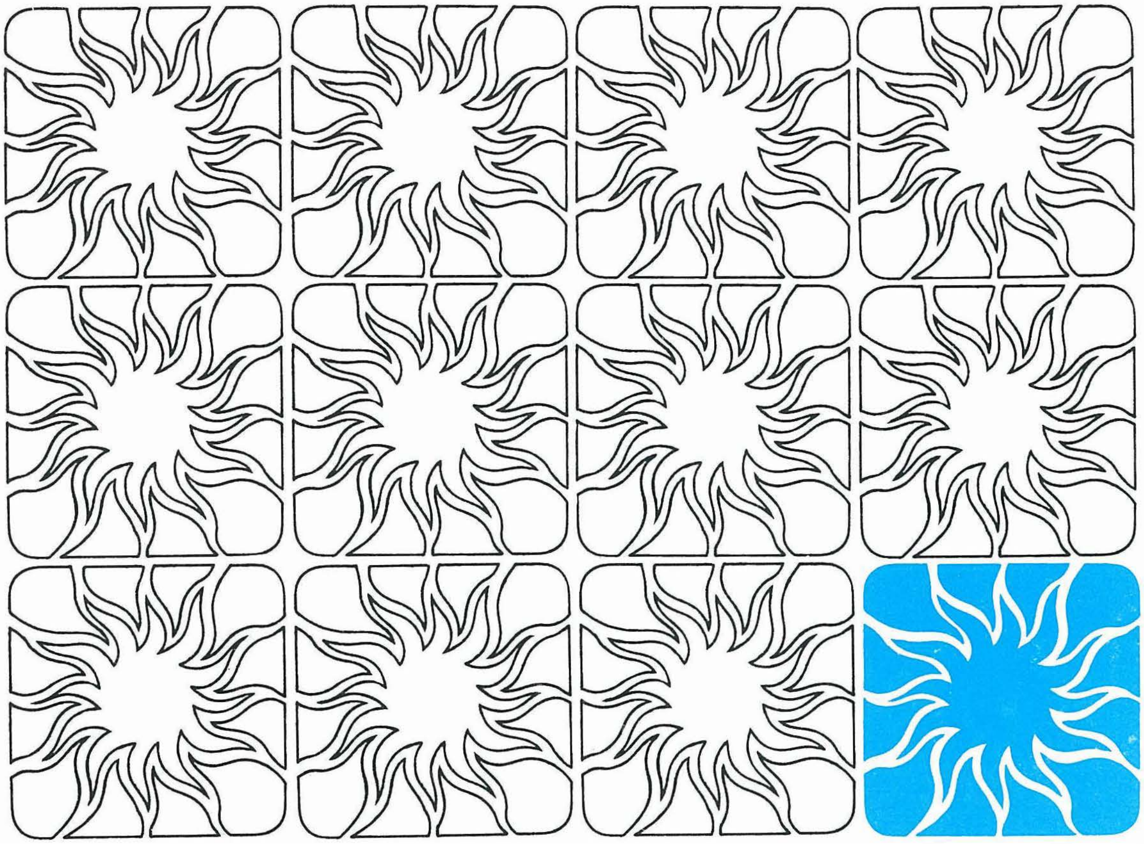

U.S. Energy Outlook

Energy Demand

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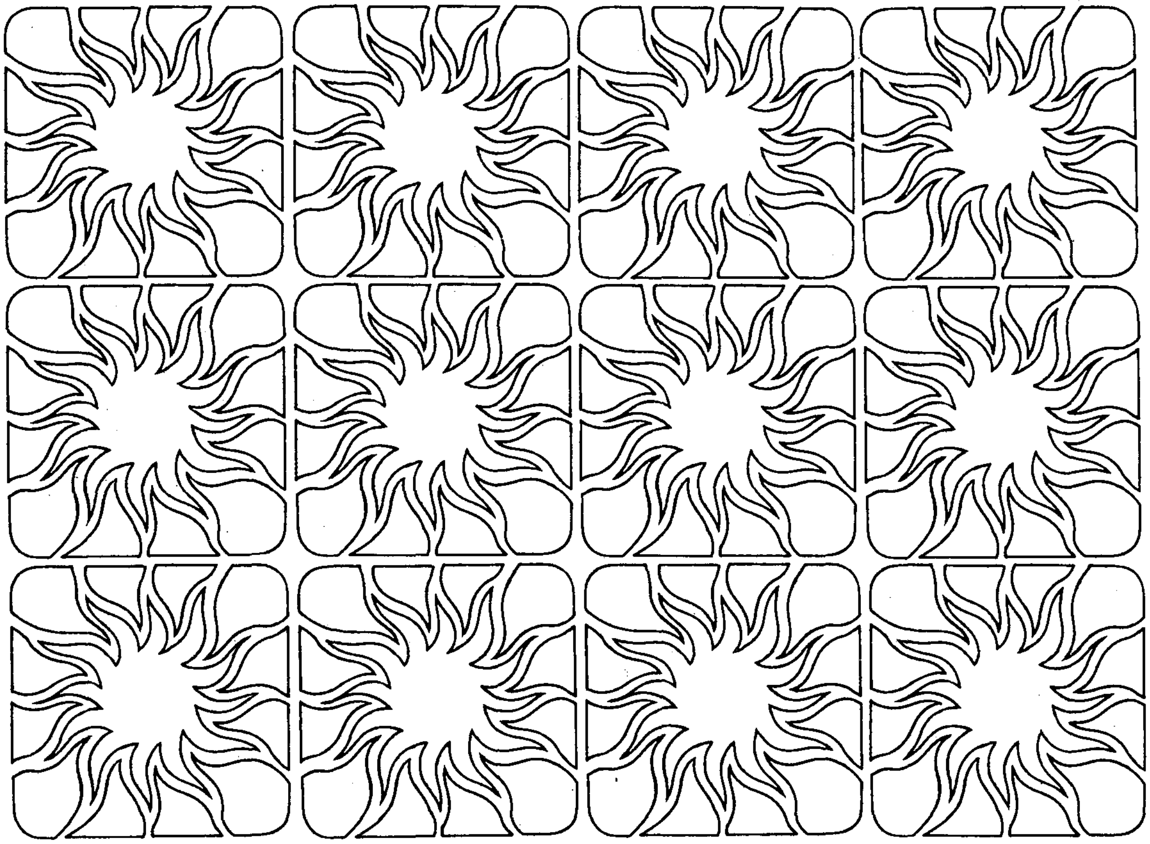

U.S. Energy Outlook

Energy Demand

A Report by the
Energy Demand Task Group
of the National Petroleum Council's
Committee on U.S. Energy Outlook

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PREFACE

On January 20, 1970, the National Petroleum Council, an officially established industry advisory board to the Secretary of the Interior, was asked to undertake a comprehensive study of the Nation's energy outlook. This request came from the Assistant Secretary-Mineral Resources, Department of the Interior, who asked the Council to project the energy outlook in the Western Hemisphere into the future as near to the end of the century as feasible, with particular reference to the evaluation of future trends and their implications for the United States.

In response to this request, the National Petroleum Council's Committee on U.S. Energy Outlook was established, with a coordinating subcommittee, four supporting subcommittees for oil, gas, other energy forms and government policy, and 14 task groups. An organization chart appears as Appendix B. In July 1971, the Council issued an interim report entitled *U.S. Energy Outlook: An Initial Appraisal 1971-1985* which, along with associated task group reports, provided the groundwork for subsequent investigation of the U.S. energy situation.

Continuing investigation by the Committee and component subcommittees and task groups resulted in the publication in December 1972 of the NPC's summary report, *U.S. Energy Outlook*, as well as an expanded full report of the Committee. Individual task group reports have been prepared to include methodology, data, illustrations and computer program descriptions for the particular area studied by the task group. This report is one of ten such detailed studies. Other fuel task group reports are available as listed on the order form included at the back of this volume.

The findings and recommendations of this report represent the best judgment of the experts from the energy industries. However, it should be noted that the political, economic, social and technological factors bearing upon the long-term U.S. energy outlook are subject to substantial change with the passage of time. Thus future developments will undoubtedly provide additional insights and amend the conclusions to some degree.

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INTRODUCTION

The full report of the National Petroleum Council's Committee on U.S. Energy Outlook* has looked beyond the narrow confines of the single case projections shown in the Committee's Initial Appraisal† to other possible cases that might develop between 1971 and 1985, and speculated on what might happen between 1985 and the end of the century. On the energy demand side, the study has attempted to come to grips with the difficult elasticity problems even though definitive answers in many cases could not be achieved. This study was developed during 1971-1972, prior to the Arab oil embargo and the subsequent sharp increases in energy prices. The effects of such large price increases on energy conservation, fuel substitution and business activity remain to be determined.

Alternative projections of demand based on different sets of assumptions with respect to economic, political and social conditions were developed. The main steps of the analysis were (1) selection of the more significant factors that were used in variant analysis, (2) estimation of the likely ranges of these factors, (3) measurement of the sensitivities of energy demand to the factors (e.g., price, economic growth, etc.) and (4) combination of the many alternatives into several "scenarios" of future energy demand. Wherever feasible, the estimates are expressed in quantitative terms.

The quantitative projections and conclusions deal with results that appeared to be practical and achievable when the analysis was made. Theoretically, if consumers were forced by government edict to radically alter their modes and standards of living, large decreases in energy consumption could be achieved. However, it seemed unlikely that the public would support such a course of action under non-emergency conditions. Therefore, the impacts of supply disruptions and mandatory regulations have been discussed primarily in qualitative terms, with the important exceptions of environmental controls and transportation options.

This report by the Energy Demand Task Group provides background details on the reasoning, methodology, data and degrees of confidence in the findings. It will be observed that many of the decisions came down to questions of judgment regarding market trends and consumer response. In this respect, the Task Group was well equipped to draw conclusions because the members were primarily energy analysts who have had long experience in marketing energy and in projecting supply/demand trends.

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* NPC, *U.S. Energy Outlook: A Report of the National Petroleum Council's Committee on U.S. Energy Outlook,* (December 1972)--hereafter referred to as the NPC Full Report.

† NPC, *U.S. Energy Outlook: An Initial Appraisal 1971-1985,* Vols. I and II (1971)--hereafter referred to as the Initial Appraisal or the intermediate case.

The major thrust of the study was directed toward estimating the sensitivity of energy demand to changes in various market forces. In the absence of published data, the Task Group developed theoretical and pragmatical procedures for determining the elasticities of total energy demand to significant factors in major consuming market sectors. It was also recognized that analysis of the cross-elasticities of demand for competing fuels such as oil, gas, coal and electricity would be desirable. However, under antitrust constraints the Task Group could not divide the total energy requirements among competitive individual fuels and hence did not attempt a study of cross-elasticities. Chapter One describes in more detail the analytical procedures for each of the consuming sectors, Chapter Two discusses demand projections out to the year 2000, and Appendices D-I include background papers prepared by individual members in support of the Task Group's consensus. The conclusions in the background papers do not necessarily represent the Task Group's final consensus, but they provided guidance in under-explored areas and interesting applications of relatively new research techniques.

The Summary and Conclusions are extracted from the final report of the NPC's Committee on U.S. Energy Outlook which was submitted to the Secretary of the Interior in December 1972. The discussion of energy demand in the Final Report is based on the detailed work of the Energy Demand Task Group contained in this volume.

SUMMARY AND CONCLUSIONS

The Initial Appraisal indicated that, under certain assumptions, U.S. energy consumption would grow at an average rate of 4.2 percent per year during the 1971-1985 period and that the United States probably would face increasingly tighter energy supplies. The final study adopted the 4.2-percent growth rate as a base case and analyzed the potential variations in future energy demand under sets of assumptions different than those used for the Initial Appraisal. The following variables were deemed to be the most significant long-range determinants of energy demand: (1) economic activity (real Gross National Product [GNP]), (2) cost of energy (including cost-induced efficiency improvements), (3) population, and (4) environmental controls.

In combination, the four selected parameters seem to explain most of the past changes in energy demand, as indicated by special background studies. The sensitivities of energy demand to each of these parameters were estimated for each market sector, and the parameters were varied systematically around the Initial Appraisal estimates. In this manner, a series of energy demand cases were developed for different sets of assumptions. Since the number of possible variations is extremely large, two projections were selected for each of the four variables so as to bracket most of the likely energy demand cases. They are called the "high" and "low" energy demand cases, while the Initial Appraisal projection of energy consumption, which falls between these two cases, is termed the "intermediate" demand case.

Simultaneous consideration of more than one parameter--for the United States and for each market sector--must be done on a judgmental basis because the parameters are not entirely independent of each other. For example, it is believed that conditions leading to very stringent environmental standards (which are characteristic of the the high demand case) would probably be associated with low economic growth and high energy costs, which are characteristic of the low case. Furthermore, it is unlikely that all factors would reach their "lows" and their "highs" simultaneously. Table 1 presents a likely summary for the U.S. energy demand which takes such relationships into account.

A probability analysis indicated that approximately 85 percent of the possible variations would fall within the high-low ranges shown in Table 1. A breakdown of these ranges by major consuming sector appears in Table 2. While these projections were considered to be the probable ranges of demand based on the economic variables deemed to be the most significant long-range determinants of energy demand, the many political possibilities were not factored into the equations.

The estimates shown in Tables 1 and 2 are based on the assumption that the Nation will continue to rely on private enterprise and free consumer choice; they do not contemplate reduced energy

TABLE 1

PROJECTIONS OF U.S. TOTAL ENERGY DEMAND UNDER THREE DIFFERENT SETS OF ASSUMPTIONS

Case	Growth Rate (Average Annual % Gain) 1970-1980	1980-1985	1970-1985	Volume (Quadrillion BTU's) 1980	1985
High	4.5	4.3	4.4	105.3	130.0
Intermediate (Initial Appraisal)	4.2	4.0	4.2	102.6	124.9
Low	3.5	3.3	3.4	95.7	112.5

TABLE 2

VARIANT PROJECTIONS OF U.S. ENERGY DEMAND* BY MAJOR CONSUMING SECTOR

	Demand Volume—Quadrillion BTU's						
	1970	1980			1985		
	Actual	Low†	Intermediate	High†	Low†	Intermediate	High†
Residential/Commercial	15.8	21.1	22.4	23.4	23.9	26.6	28.5
Industrial	20.0	24.7	26.8	27.2	27.1	30.9	31.9
Transportation	16.3	23.0	23.9	24.4	26.7	28.3	29.0
Electricity Conversion	11.6	20.7	22.8	23.5	26.7	30.2	31.4
Non-Energy	4.1	6.2	6.7	6.8	8.1	8.9	9.2
Total	**67.8**	**95.7**	**102.6**	**105.3**	**112.5**	**124.9**	**130.0**

	Growth Rates—Average Annual Percent Change						
	1960-1970	1970-1980			1980-1985		
	Historical	Low†	Intermediate	High†	Low†	Intermediate	High†
Residential/Commercial	4.0	3.0	3.6	4.0	2.5	3.5	4.0
Industrial	3.4	2.1	2.9	3.1	1.9	2.9	3.2
Transportation	4.2	3.5	3.9	4.1	3.0	3.4	3.5
Electricity Conversion	7.2	5.9	6.9	7.3	5.2	5.8	6.0
Non-Energy	3.4	4.3	5.1	5.3	5.5	5.9	6.2
Total	**4.3**	**3.5**	**4.2**	**4.5**	**3.3**	**4.0**	**4.3**

* Electricity is allocated to each consuming sector and is converted at 3,412 BTU's per KWH and included in the total energy demand for the appropriate sector; the energy used by utilities for generation is shown in the Electricity Conversion category. The following figures show a reconciliation of electricity demands in these sectors with the total electric utility energy inputs, for the intermediate case only:

Demand Volumes—Quadrillion BTU's	1970	1980	1985
Residential/Commercial	2.8	5.7	7.8
Industrial	2.3	4.4	6.3
Transportation	–	0.1	0.1
Electricity Conversion	11.6	22.8	30.2
Total Utility Inputs	**16.7**	**33.0**	**44.4**

† Based on the variables deemed to be the most significant long-range determinants of energy demand.

consumption because of supply limitations or political decisions. In such cases, growth rates for energy and economic activity would be much lower, and achievement of important social goals, such as full employment, higher standards of living and improvements in the environment, would be seriously impeded.

A substantial portion of the reduction in energy consumption shown in the low case is estimated to result from improved efficiency of energy use initiated by consumers in response to higher costs and improved technology. Additional forced reductions in energy consumption would lower economic growth and/or reduce consumer satisfaction. A few simple examples from the several consuming sectors, which serve to illustrate these distinctions, are shown in Table 3.

TABLE 3

METHODS OF REDUCING ENERGY CONSUMPTION

Result	More Efficient Use	Arbitrary Reduction in Use
Lower home fuel consumption	Better home insulation	Lower room temperature
Lower automotive fuel consumption	Increased engine fuel economy	Reduced automobile trips
Lower factory use of fuel	Installation of better machinery	Reduced factory output
Lower electric fuel requirement	Improved power plant heat rate: same light, same air conditioning	Reduced electricity consumption: less light, less air conditioning

ECONOMIC AND SOCIAL TRENDS

This section discusses some of the basic economic and social forces that will affect energy demand in the future. Although many of these background conditions can only be evaluated qualitatively, they will help to explain the likely variations of the specific parameters and their future relationships to energy demand.

General

The Nation's life-style is perhaps the most fundamental determinant of energy demand. While this factor changes slowly, the effects are cumulative, and the transformation in life-styles that might occur during the period under study would modify both the level of GNP and its relationship to energy consumption in the 1980-1985 period.

Future life-styles in the United States will influence and, to some degree, be conditioned by the following factors: (1) urban development (including transportation systems); (2) the rapidity of technological and social change; (3) communication systems; (4) demographic changes; and (5) the relationships among environment, population and industry. Although there could be an infinite variety of "mixes" of these factors, this report focuses on high and low variations in energy demand from the base or intermediate level established in the Initial Appraisal.

Extreme modifications of life-style are not very likely by the year 1985, although the beginnings of change are already evident. Despite a great deal of dissent from existing social, political and economic institutions, substantial changes in living habits during the period through 1985 are precluded by long-established social patterns and the complexities associated with social and economic change.

Urban Development

More than two-thirds of the U.S. population now lives in urban areas and this ratio is growing. Nevertheless, the urban development of the past few decades has apparently created a society and life-style that is unsatisfactory for large segments of the population--particularly those living in "central cities." Although practical programs for improving urban living are still in very rudimentary stages, several possible future trends are reflected in the three demand cases.

One possibility is that the "urban sprawl" could drift along as it has in the past, creating greater traffic congestion and central city decay. If present trends continue, increasingly serious bottlenecks are likely to appear after 1985 in the movement of goods, as well as people, within and between urban areas because there will be a precarious dependence on motor transportation. This development would help generate the high energy demand case.

At the other extreme, some progress could be made by 1985 toward the development of intermediate-size cities, separated by green belts but closely connected by high speed mass transit suitable for moving freight as well as passengers. Urban planning that would coordinate the various modes of transportation--e.g., highways, waterways, pipelines and underground mass transit--would be a component of this scenario. Achievement of such a system probably would be consistent with the low energy case up to 1985 and would be capable of supporting more economic growth and higher standards of living in the longer term.

Taking a middle ground, it might be expected that several new programs for a more rational type of urban development might get out of the "pilot plant" stage in a few years. These programs probably would include provision for more effective transportation systems for moving both passengers and freight. Programs for revival of rural communities also might be implemented. The latter development probably would tend to increase the per capita consumption of energy by dispersing the population outside the city core. Even after a viable urban program is under way, many years will pass before a significant change in life-style--and consequently, energy demand--takes place.

Accelerating Change in Technology

The rate of change in technology has been accelerating--a trend for which the historical evidence is well documented. Aside from social upheavals, this rapid technological change has had a variety of effects on energy requirements that are not easily distinguished. For a long period of time (until 1967) changes, on balance, were in the direction of more efficient energy use, or at least, less energy use per unit of GNP. Several of the many possible examples of higher efficiency are: (1) the trend toward lower heat rates in the production of electric power, (2) the substitution of much more efficient diesel locomotives for steam locomotives, (3) the introduction of high compression automobile engines and (4) the replacement of coal by oil and gas for space heating and industrial processing. Such improvements more than offset trends that increase energy use per unit of GNP, such as increased use of air conditioning and a growing reliance on electric power accompanied by losses in conversion and transmission.

The apparent reversal of trend began about 1967 when the use of energy increased more rapidly than did real GNP. While reasons for the reversal have not been completely identified, lack of new technological developments and increased energy use for environmental improvement activities (improvements included in GNP) have been cited as possible causes.

In the future, these factors will continue to operate in both directions. The ultimate trend of efficiency in energy use may well be determined by the pace of technological advance. It has been contended that most of the important scientific theories have already been formulated and that new discoveries in science and technology will come more slowly in the future. If this theory proves to be correct, a high energy case would be more probable. Social or political barriers against the introduction of new production techniques would also result in high energy per unit of GNP.

There is ample evidence to indicate that technological advances (in the energy industries as well as elsewhere) will continue even if there should be little progress in fundamental sciences. Many new projects are on the threshold of commercial application, requiring mainly engineering improvements or breakthroughs before they can be implemented. In the area of nuclear power and other electric power systems, there are notable examples of potential energy savings but many of these will not make significant impacts until the 1980's. In the intermediate case projections to 1985, the acceleration in technological development and energy conservation would be about sufficient to offset the factors working toward higher energy consumption per unit of GNP, including energy used for environmental improvement and a greater proportionate use of electric power.

Population

The trend toward a slower population growth rate and smaller family sizes definitely will have an impact on life-styles, although the results may not be as pictured in some of the environmental concepts. Some of these environmental theories associate lower population growth with low economic growth, a concept which may not necessarily prove to be correct. There are many other factors causing economic growth--e.g., labor productivity, capital formation and technological progress--which have greater impact on GNP growth rates than do population factors. In fact, population change has its greatest impact through its influence on the age distribution of the labor force. The current low birthrates will not significantly affect the labor force until after 1985. Up to 1985, the prognosis is for smaller, more affluent families and greater population mobility. This demographic outlook indicates a high economic growth, high energy consumption society.

Environment *Versus* Economic Growth

The desire on the part of society to control the adverse ecological effects of expanding industry and population has been slow to emerge, and it is generally acknowledged that there is a large backlog of corrections to be made. Such corrections, plus conformity to high environmental standards in the future, will require much larger amounts of energy than would adherence to the status quo. The energy volumes reflected in the intermediate case were judged to be sufficient to meet the environmental standards under consideration in mid-1971 when the case was developed. Since that time, however, considerably more rigorous limits on pollution have been proposed. The high demand case includes the energy requirements to meet those more stringent standards which society may adopt.

Proponents of the zero economic growth concept disregard the fact that the attainment of other social goals, such as adequate housing, jobs and education, would be sacrificed if economic growth were depressed. The successful functioning of the competitive enterprise/freedom-of-consumer-choice system, in effect, depends on profits and economic growth. These other important national policies, therefore, appear to rule out the possibility that the United States will choose to be regimented into a zero economic growth society and the life-style that would accompany it. Instead, some means must be found to make current systems reasonably compatible with the ecological objectives.

There are no automatic trade-offs between economic growth and anti-pollution in a free society. We could get "high pollution" with "low growth" because a poor economy with high unemployment is not likely to provide the capital expenditures that would be necessary to use energy more efficiently. Recycling solid wastes and purifying air and water are operations requiring technology, capital, and energy inputs that are more available in a growth economy.

The analysis in this report gives a very low probability to the projections that conclude there will be immutable finite limits to growth during the next 50 years. The major ecological abuses probably could be corrected by 1985 with the expenditure of 2 to 3 percent of the GNP and 8 to 9 percent of the energy consumption. The latter corresponds roughly to the energy volumes included in the high case for environmental factors shown in Table 11 (p. 27). However, these measures do not provide for correction of environmental deterioration in the broader sense which includes such problems as urban decay.

DEMAND VARIABILITY ANALYSIS

The following procedure was used for developing three cases for the U.S. energy demand outlook based on different economic and social conditions. The major factors in the long-term energy demand outlook were identified as economic growth, cost of energy (including cost-induced efficiency improvements), demographic changes and the use of energy for environmental control. These variables (or parameters) were analyzed with respect to their effects on energy demand within the following market sectors: (1) residential/commercial, (2) industrial, (3) transportation, (4) electricity, and (5) non-energy uses.

Specific values or guidelines were established for the parameters in order to determine the high, intermediate and low energy demand cases. The environmental control factor could not be assigned very precise quantitative ranges for each sector. However, since this factor is considered to be one of high significance, it is analyzed separately in a later section entitled "Energy for Environmental Improvement." Although the guidelines usually are specific as described in the following paragraphs, their impacts on energy demand in various markets frequently had to be evaluated on the basis of judgment and experience.

The Initial Appraisal, or the intermediate case, projected total energy demand at an average growth rate of almost 4.2 percent per year between 1970 and 1985, and the major background assumptions that were used for that case were as follows:

- Sustained economic growth--growth in real GNP at a rate of 4.2 percent
- Slower population growth--1.1 percent per year average growth during the 1970-1985 period (Census Series D)*
- Increased energy use for environmental development--increasing from about 2 percent in 1970 up to 4 to 5 percent of total energy consumption in 1980-1985
- Little change in "real" prices for energy

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* Bureau of the Census, U.S. Department of Commerce, *Bureau of Census Population Series,* P-25, No. 448 (August 1970)--hereafter referred to as Census Series C, D, or E, all published same date.

- Development of improved technology for fuel substitutions

- Growth in energy demand not restricted by capital limitations or other restrictions on total energy supplies.

Low and High Case Guidelines

Demand sensitivities are very difficult to project with confidence. Historical analogy provides relatively little guidance in estimating sensitivity to energy cost, for instance, because during the past two decades the overall trend of real energy costs has been declining, while energy costs are expected to rise in the future. Therefore, in projecting the response of energy demand to changes in economic conditions, it is necessary to use detailed information on the various markets in addition to rigorous analyses of past data.

As a rule, the immediate impacts on energy demand of changes in government policy, price, technology and other factors are minor because the full effects of obsolescence of equipment and modifications in consuming patterns require time--usually many years. For this reason, it seemed appropriate to measure demand sensitivities over relatively long periods, such as 1970-1980 and 1970-1985.

Economic Growth Assumptions

In the sensitivity analysis, changes in energy demand were related to variations in economic growth rates for real GNP, real personal income and industrial production. It was concluded that the future growth rate for real GNP, averaged for the 15-year period, would probably fall within the range of 3.2 to 4.4 percent per year. The former rate was used for the low energy demand case and the latter rate for the high demand case. Real personal income and industrial production were assumed to vary proportionately to variations in real GNP.

Cost of Energy, Including Cost-Induced Efficiency Improvements

A competitive price system provides the most efficient means of adjusting demand to supply without seriously retarding economic activity. In connection with essential energy uses, however, the effects of the price factor are gradual and very difficult to measure. Although a higher cost of energy probably causes some immediate reductions in consumption, the more important and long-term effects come about by inducing customers to purchase more efficient equipment and by using energy more efficiently. The energy saving can be accomplished in many ways, including the following: improved insulation for buildings, improved heating and cooling systems, more efficient industrial plants and equipment and smaller and/or more efficient vehicles. Conversely, a lower cost of energy may delay the introduction of fuel-saving equipment and lead to higher consumption.

The cost guidelines were established first for the primary markets (defined as oil and gas at the wellhead, coal at the mines, etc.) and were subsequently translated into guidelines for consumer markets. A given price change in primary markets (assuming no inflation) would result in much smaller percentage changes in the higher priced consumer markets, and the percentage changes generally will be smaller the farther the consumer is from the primary market. Thus, a $1-per-barrel or 30-percent increase in the 1972 price of crude oil at the wellhead would affect the industrial market by only half that percentage, and it would raise motor fuel cost by an even smaller percentage.

Table 4 summarizes the assumptions on cost ranges and translates the "primary" price changes into consumer price ranges which are more relevant to demand sensitivity analysis. The sensitivities of energy demand were estimated for the assumed percentage changes in energy cost in each major consuming sector. The high energy demand case is generated by a 10-percent decline in the primary market price, the intermediate demand case is associated with "no change" in price, and the low demand case is obtained with a 100-percent increase.

TABLE 4

ASSUMED PERCENTAGE CHANGES IN COST OF ENERGY—1970-1985
(Constant 1970 Dollars)

	Energy Demand Case		
Type of Market	High	Intermediate	Low
Primary Energy Cost	- 10%	No Change	+ 100%
Consumer Costs			
Residential/Commerical	- 2.5%	No Change	+ 25%
Industrial	- 5 %	No Change	+ 50%
Transportation	- 2.5%	No Change	+ 25%
Electric Utility	- 5 %	No Change	+ 50%
Non-Energy	- 5 %	No Change	+ 50%

Population

The term "population" is used as a proxy for all the demographic factors such as age distribution and immigration. The guidelines for the assumptions used in the high, intermediate and low demand cases were the Census Series D, C and E, which projected population growth at average annual rates of 1.3 percent (Series C), 1.1 percent (Series D) and 1.0 percent (Series E) for the 1970-1985 period.

Energy Requirements for Environmental Improvement

The demand projections in the intermediate case included large amounts of energy that were expected to be used for air and water purification and for treatment of solid wastes. As mentioned earlier, the sum of these requirements equaled about 2 percent of total energy demand in 1970 and were projected to be about 4 to 5 percent of the total demand in the 1980-1985 period.

A sensitivity range has been estimated for this factor which reflects (1) the high case with considerably more rigorous ecological standards and early imposition of such standards and (2) the low case with less strict standards (relative to the intermediate case) and more time to conform with the new regulations.

Environmental improvement also affects the cost of supplying energy. This effect is a part of the "cost of energy" parameter, but it is not segregated from other cost factors.

Conclusions for Total United States

Table 5 shows the results of the sensitivity analyses for each parameter for all consuming sectors combined. The next five sections will summarize the conclusions as they apply to each of the major individual energy markets--residential/commercial, industrial, transportation, electricity conversion and non-energy.

TABLE 5

SENSITIVITY ANALYSIS FOR TOTAL ENERGY DEMAND IN 1980 AND 1985—ALL MARKET SECTORS
(Quadrillion BTU's)

	1980			1985		
Parameter	Low	Intermediate	High	Low	Intermediate	High
Economic Growth Rate (Real GNP)						
Demand	94.8	102.6	104.3	111.0	124.9	128.1
% Change *vs.* Intermediate	(7.6)	—	1.7	(11.1)	—	2.6
Cost of Energy Including Cost-Induced Efficiencies						
Demand	98.5	102.6	102.6	116.4	124.9	125.4
% Change *vs.* Intermediate	(4.0)	—	—	(6.8)	—	0.4
Population Expansion Rate						
Demand	101.4	102.6	103.3	122.8	124.9	126.3
% Change *vs.* Intermediate	(1.2)	—	0.7	(1.7)	—	1.1
Energy for Environmental Improvement						
Demand	101.4	102.6	105.3	122.8	124.9	130.6
% Change *vs.* Intermediate	(1.2)	—	2.6	(1.7)	—	4.6

RESIDENTIAL/COMMERCIAL

Taking into account likely variations in the economy, population trends, energy cost and environmental considerations, it was estimated that growth in energy demand in the residential/commercial sector might range between a continuation of the 4.0-percent average annual rate of the 1960's, which would represent the high demand case, and a growth rate of only 2.5 percent per year for the low case. Compared with the Initial Appraisal, the higher growth rate would increase residential/commercial requirements 1.9 quadrillion BTU's in 1985 (7 percent), whereas the slower rate would reduce 1985 requirements 2.7 quadrillion BTU's (10 percent). The greatest impact of a slower growth in demand would come in the latter part of the 1970-1985 period. These overall estimates appear in Table 2, while the detailed analyses for each parameter are shown in Table 6.

TABLE 6

SENSITIVITY ANALYSIS FOR TOTAL ENERGY DEMAND IN 1980 AND 1985
RESIDENTIAL AND COMMERCIAL DEMAND (INCLUDING ELECTRICITY*)
(Quadrillion BTU's)

Parameter	1980 Low	1980 Intermediate	1980 High	1985 Low	1985 Intermediate	1985 High
Economic Growth Rate (Real GNP)						
Demand	21.5	22.4	22.9	24.8	26.6	27.4
% Change *vs.* Intermediate	4.0	—	2.2	(6.8)	—	3.0
Cost of Energy Including Cost-Induced Efficiencies						
Demand	21.6	22.4	22.4	24.8	26.6	26.6
% Change *vs.* Intermediate	(3.6)	—	—	(6.8)	—	—
Population Expansion Rate						
Demand	22.2	22.4	22.8	26.1	26.6	27.4
% Change *vs.* Intermediate	(0.9)	—	1.8	(1.9)	—	3.0
Energy for Environmental Improvement						
Demand	22.4	22.4	22.5	26.6	26.6	26.9
% Change *vs.* Intermediate	—	—	0.4	—	—	1.1

* Electricity is converted at 100-percent efficiency (or 3,412 BTU's per KWH), and the energy used by utilities for generation is shown in the electricity conversion sector in Table 9.

In the Initial Appraisal, it was concluded that many of the factors that caused the residential/commercial sector to grow at a rate of 4 percent per year over the past decade will be operating in the future. Large increases are expected in new household, labor force and family income, and a continuing shift of population to the suburbs or to satellite towns is anticipated. Shopping centers, service facilities and recreational activites are anticipated to expand rapidly, all of which will help to stimulate the growth in energy demand.

Several new conditions will tend to retard growth in the residential/commercial energy market: (1) the population mix is trending toward larger proportions of young adults, (2) there are fewer children per family and (3) real costs of land and construction have risen substantially. These factors suggest that the recent trend toward smaller dwelling units will continue throughout the 1970's. It is expected that new housing units will include a much larger proportion of apartments, in sharp contrast to conditions of the past 20 years when most new units were single-family dwellings. In the intermediate case, the net impact of these opposing forces results in a 3.6-percent rate of increase for residential/commercial energy consumption over the 15-year projection period.

In making sensitivity analyses of the impact of various factors on energy growth in the residential/commercial sector, the following specific parameters were investigated: (1) population trends, (2) economic activity, (3) energy costs (including cost-induced efficiencies and (4) energy associated with environmental standards. Each of these is discussed in the following paragraphs, with the exception of the environmental factor which is expected to have only a minor effect on residential/commercial energy use.

In general, changes that would tend to raise demand in this sector are expected to have less of an impact on energy consumption than changes that would reduce demand. The estimated possible reduction in demand in 1985 is 15 percent compared with a possible increase of 7 percent. The upward variability is small because the intermediate case contains a relatively high use of energy in this sector, and there are diminishing returns for the use of energy by households. The negative influences would have a greater impact except for the fact that a substantial proportion of residential/commercial energy consumption falls into the "necessity" classification in this country.

Variations in population projections are caused primarily by different assumptions regarding future birthrates. Changes in the birthrate would have a relatively small impact on residential/commercial energy demand in the next 15 years for several reasons. A main element in demand (numbers of households) is determined by the past, not the future, birthrate. A further reduction in the birthrate would probably emphasize the anticipated trend toward smaller housing units, but it would also point to more money available for non-essential consumption such as air conditioning, electric heat and other electric appliances. Conversely, larger families might mean larger, single-family houses (which are generally less efficient energy users in terms of consumption per dwelling unit) and more electricity for household appliances such as laundry equipment, but less discretionary income for luxury items requiring electricity to operate them. Compared with the Initial Appraisal, it is estimated that the lower birthrate assumption (Census Series E) would reduce residential/commercial demand by 0.5 quadrillion BTU's in 1985 (1.9 percent) whereas the higher birthrate (Census Series C) would raise requirements 0.8 quadrillion BTU's (3.0 percent) in 1985.

The intermediate case assumes a 4.2 percent average annual increase in real GNP over the next 15 years. Sensitivity analyses were made for (1) a higher rate of growth in GNP, i.e., 4.4 percent per year, and (2) a slowdown in GNP growth to 3.2 percent per year, the results of which are shown in Table 6.

Historically, the growth rates of residential/commercial energy consumption and GNP have been parallel. However, in the past, real energy costs were declining, and it is thought that this fact had some influence on the observed relationship between consumption and GNP.

Short-term variations in the economy would not have a substantial impact on residential/commercial energy consumption because in this country much of the energy used in this sector is classified as essential (e.g., heating, cooking, hot water and lighting). The main fluctuations would come in the use of electricity (e.g., air-conditioning) and in the commercial sector. In contrast, longer-term shifts in the level of disposable income are important determinants of energy consumption in this sector. A slowdown in GNP growth would have a greater impact on consumption than a higher rate of increase in GNP because there are diminishing returns on the application of energy for appliances in this sector.

In summary, it was estimated that the higher growth rate for GNP would raise 1985 residential/commercial energy requirements by 0.8 quadrillion BTU's (3.0 percent) and that the slower GNP growth would reduce requirements by 1.8 quadrillion BTU's (6.8 percent).

In the Initial Appraisal, it was assumed that real energy prices would remain fairly stable in the future in contrast to declining prices in the past. In the variance analysis, the price range guidelines used to estimate sensitivities were between (1) an increase of 25 percent in consumer prices in the low demand case, stemming from a 100-percent increase in primary energy costs and (2) a 2.5 percent decrease in real energy costs to the consumer in the high demand case, caused by a 10-percent decrease in primary energy costs. It is believed that there is a much greater probability of significant price increases rather than decreases over the period encompassed by this analysis. This accounts for the large upward price variation. It was concluded that the small decline in energy costs would have no measurable impact on demand in this sector but that a 25-percent increase in energy cost to the consumer by 1985 would reduce residential/commercial consumption by 1.8 quadrillion BTU's, or 6.8 percent.

The conclusion that residential/commercial energy demand is relatively insensitive to price changes is supported by econometric analyses of historical data as described in Appendices E and F. Both analyses indicate a price elasticity of about -0.4 which is reasonably close to the Task Group consensus described above. This means that a 10-percent increase in energy cost would result in a relatively small 4-percent drop in energy use, other things being equal.

Lower energy costs would provide some extra stimulus for purchasing and using electrical appliances, air conditioning and electric heat. However, rapid growth in the purchase of these items is expected with stable prices, so it is doubtful that very gradual declines in prices would add much to demand. The impact of higher costs would, however, be more noticeable. The greatest savings in energy would result from widespread use of insulation and improved heating/cooling systems, which would become more economically attractive with rising energy costs. Also, higher energy prices would probably lead to more efficient temperature controls, thus tending to restrain growth in energy used for air conditioning and heating. Appendix D attempts to put some quantitative ranges on these factors.

INDUSTRIAL

Historically, the net effect of the factors influencing industrial energy use has tended to favor greater efficiency, causing the demand for energy to grow more slowly than industrial output. While strong efficiency factors will continue to operate in the future, many have reached the point of diminishing returns, and gains in efficiency of energy use are expected to be more modest in future years. Some of the more important elements in the trend towards more efficient energy use were identified and discussed at length in the Energy Demand Task Group report for the Initial Appraisal.*

The most important influence on the future consumption of industrial energy is the rate of industrial production as measured by the Federal Reserve Board Index of Industrial Production (FRB). The industrial production rate in turn is closely linked to GNP growth. For example, the Initial Appraisal indicated that a 1.0-percent change in FRB or GNP trends would change the industrial energy consumption trend by about 0.8 percent. The many factors that have influenced this relationship between the FRB and energy in the past and those that might change it in the future were carefully analyzed and weighed in order to determine the possible variations in industrial energy demand.

Table 7 shows the impact of the range of alternative economic growth rates (considered in this study) upon industrial energy consumption. In the guidelines, it was assumed that the low GNP growth rate would be 1.0 percentage point below the 4.2-percent rate of the intermediate case while the high GNP rate would be only 0.2 percentage points above the intermediate case. The energy demand range reflects the same imbalance. In 1985, for example, the low case for economic growth would reduce energy demand by 3.6 quadrillion BTU's or 11.7 percent, while the high case would show energy consumption higher by 0.6 quadrillion BTU's, or 1.9 percent.

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* NPC, *U.S. Energy Outlook, An Initial Appraisal by the Energy Demand Task Group 1971-1985* (April 1972)--hereafter referred to as the Energy Demand Task Group Report (1972).

TABLE 7

SENSITIVITY ANALYSIS FOR TOTAL ENERGY DEMAND IN 1980 AND 1985
INDUSTRIAL (INCLUDING ELECTRICITY*)
(Quadrillion BTU's)

Parameter	1980 Low	1980 Intermediate	1980 High	1985 Low	1985 Intermediate	1985 High
Economic Growth Rate (Real GNP)						
Demand	24.5	26.8	27.1	27.3	30.9	31.5
% Change *vs.* Intermediate	(8.6)	–	1.1	(11.7)	–	1.9
Cost of Energy Including Cost-Induced Efficiencies						
Demand	25.4	26.8	26.8	28.4	30.9	31.1
% Change *vs.* Intermediate	(5.2)	–	–	(8.1)	–	0.6
Population Expansion Rate						
Demand	26.3	26.8	26.9	30.2	30.9	31.1
% Change *vs.* Intermediate	(1.9)	–	0.4	(2.3)	–	0.6
Energy for Environmental Improvement						
Demand	26.3	26.8	27.8	30.0	30.9	32.9
% Change *vs.* Intermediate	(1.9)	–	3.7	(2.9)	–	6.5

* Electricity is converted at 100-percent efficiency (or 3,412 BTU's per KWH), and the energy used by utilities for generation is shown in the electricity conversion sector in Table 9.

Another major determinant of industrial energy consumption is its cost. The effects of rising energy costs on energy consumption are particularly strong in the industrial market where energy, capital goods and labor compete over the long term as inputs in the industrial production process.

In order to determine the impact of the energy cost factor on future industrial energy consumption, it is necessary to estimate not only the price elasticity, but also future changes in prices and other inputs such as industrial labor and capital, so that the direction and degree of substitution can be determined. These estimates are important since competition in the future will undoubtedly be centered increasingly on cost reduction. Greater productivity is essential if the international competitive position of the United States is to be improved.

It is likely that the real cost of labor will rise more rapidly than the cost of capital. Trends toward a shorter work week and shorter working careers because of longer schooling and earlier retirement are factors that will contribute toward a higher price for labor. Rising employment in government and service industries combined with changing work attitudes may make productivity gains more difficult, while more liberal pension plans and higher payroll taxes will tend to increase unit labor costs.

The dramatic change, however, is expected to be in energy costs which may trend upward very rapidly, increasing industrial energy costs disproportionately. The industrial community will no longer be a beneficiary of regulated underpriced natural gas and low-priced coal and imported fuel oil, as all of these commodities are headed toward sharply increased prices. Moreover, industrial users of oil and coal will be required to invest in equipment to reduce atmospheric emissions, adding further to real energy costs. Increased reliance on electric power will provide no cost relief since rising power plant construction and operating costs (including fuel costs) will result in higher electricity prices. It is anticipated that these higher prices will be reflected in industrial power rates.

The combined effect of higher labor and energy costs on industrial energy demand would be twofold. First, greater incentives and opportunities to substitute capital for labor would indirectly tend to reduce energy requirements per unit of output. This is because new equipment is generally more efficient in terms of both labor and mechanical energy per unit of product than the equipment or process replaced. Second, rising energy costs would directly discourage energy use. There are, of course, practical limits to this type of substitution, and as mentioned earlier, many of the efficiency factors which have operated in the past may have reached the point of diminishing returns. However, an in-depth look at the industrial sector shows that, given the incentive of rapidly rising energy costs, numerous opportunities to conserve energy still exist. It seems likely that the use of energy in industry is not currently at equilibrium levels because of lags in equipment replacement. As energy costs rise, therefore, substantial reductions in industrial energy demand per unit of ouput could be expected. Earlier retirement of the existing inefficient stock of capital equipment and production facilities will be encouraged by the higher energy costs.

In an attempt to quantify the effects of price variations on industrial energy consumption, econometric models (described in Appendix G) were developed to try to determine these price elasticities. The results of testing these models tended to substantiate the hypothesis that increases in the costs of labor would result in capital substitution and decreased energy usage. For example, during a recent historical period, sharp increases in labor costs relative to other costs caused a shift to more capital-intensive production which was more efficient in terms of both energy and labor use. Conversely, if the cost of capital goods should rise, energy usage would be higher since there would be less incentive to introduce newer energy conserving machinery.

The econometric analysis indicated a point elasticity of demand for industrial energy with respect to energy cost of approximately -0.4. This response in energy consumption to energy prices appears to be a reasonable reflection of the relatively inelastic industrial energy demand *over the time period considered*. Other methods yielded somewhat higher price elasticities, particularly in the long run. On the other hand, the Task Group consensus of demand variability (shown in Table 7) is based on a slightly lower price elasticity for the specified range.

Possible impacts of changes in population growth rates on industrial energy requirements were considered. An alteration in the rate of population growth would directly affect the demand for consumer goods which, in turn, would modify consumption. The growth rate of the labor force, however, is more significant, and this is affected primarily by the birthrate only after a 15-year lag. It is estimated that a shift from Census Series D (assumed in the Initial Appraisal) to Series E would depress the annual rate of increase in industrial energy requirements by only a very small percentage in the 1970-1985 period. The potential increase in consumption as a result of faster population growth is even smaller.

TRANSPORTATION

In the Initial Appraisal, the consumption of energy for transportation was projected at a gradually declining rate averaging 3.7 percent per year for the 1970-1985 period. This decline, relative to the 4.2 percent per year growth rate of the 1960's, was attributed to lower birthrates, smaller families, a more "saturated" car market and larger proportions of economy cars. The final report deals with the possible deviations from that original projection and the reasons for such variations. The findings summarized here were developed by analyzing the components of energy consumption in transportation markets (cars, trucks, aviation, water transportation, railroads, etc.) and estimating the sensitivities of each component to the four major parameters that have been described in earlier sections.

Looking at the broad picture, the long-term changes in motor fuel consumption (which is by far the largest component) have correlated very closely with real GNP (and disposable personal income), even though there have been marked changes in demographic factors, driving habits, types of vehicles, fuel quality, highway conditions and alternative forms of transportation. The other categories of transportation energy show a variety of relationships to economic growth because of shifts in consumer and military demands and technological change. Aviation demand for fuel has increased sharply, while railroad and marine shipping requirements have been relatively stable. The estimated total transportation demand sensitivity to real GNP (and disposable personal income) is indicated by the ratio of 0.6-percent change in demand for each 1.0-percent change in GNP.

Assuming other conditions unchanged, the low case for economic growth would reduce the 1985 estimate for transportation energy demand by 2.1 quadrillion BTU's (or 7.4 percent) below the intermediate case level, and the high case would raise demand by 0.7 quadrillion BTU's (2.5 percent). The demand sensitivities for economic growth as well as for the other parameters are summarized in Table 8.

According to the overall guidelines, the primary energy costs (i.e., costs at the wellhead, mine mouth, etc.) in 1985 are assumed to reach 100 percent *above* the 1970 level for the low demand case and 10 percent *below* the 1970 level for the high case. Such primary

TABLE 8

SENSITIVITY ANALYSIS FOR TOTAL ENERGY DEMAND IN 1980 AND 1985
TRANSPORTATION (INCLUDING ELECTRICITY*)
(Quadrillion BTU's)

Parameter	1980 Low	1980 Intermediate	1980 High	1985 Low	1985 Intermediate	1985 High
Economic Growth Rate (Real GNP)						
Demand	22.7	23.9	24.3	26.2	28.3	29.0
% Change *vs.* Intermediate	(5.0)	–	1.7	(7.4)	–	2.5
Cost of Energy Including Cost-Induced Efficiencies						
Demand	23.2	23.9	23.9	26.8	28.3	28.3
% Change *vs.* Intermediate	(2.9)	–	–	(5.3)	–	–
Population Expansion Rate						
Demand	23.6	23.9	24.0	27.8	28.3	28.5
% Change *vs.* Intermediate	(1.3)	–	0.4	(1.8)	–	0.7
Energy for Environmental Improvement						
Demand	23.7	23.9	24.7	27.9	28.3	29.8
% Change *vs.* Intermediate	(0.8)	–	3.3	(1.4)	–	5.3

* Electricity is converted at 100-percent efficiency (or 3,412 BTU's per KWH), and the energy used by utilities for generation is shown in the electricity conversion sector in Table 9.

cost changes, of course, would result in smaller percentages in the prices that consumers pay for transportation energy.

Thus, the 1985 cost variation at the consumer level would range from +25.0 percent for the low case to -2.5 percent for the high case, relative to 1970. Most of the following discussion will be concerned with the low case because it was concluded that a decrease in price as small as 2.5 percent would have a negligible effect on demand.

There are several reasons why transportation fuel demand is not likely to be very sensitive to fuel price changes in the short run. They are:

- The consumer regards most automobile mileage to be fairly essential (although over the long term he may change his type of car).
- The cost of gasoline and oil has been only about one-fourth of the total cost of operating a private car.
- In the case of commercial transportation such as trucking, railroads and airlines, the fuel requirements are essential elements of the business.

For the long run, it has been estimated that there will be some transportation energy demand elasticity as a result of the following conditions:

- Although fuel cost is not the major item in the total cost of owning and operating a car, it is an out-of-pocket and highly visible cost. Therefore, it is likely to carry a disproportionate weight in consumer decisions.

- The higher cost of motor fuel is one of a package of economic inducements that would cause consumers to buy economy cars. Because of the difficulty of separating the components of this package, the sensitivity of energy demand to the use of economy cars has been included in this parameter.

- In commercial transportation, the cost of fuel is important enough to play a significant role in the operators' decisions relative to type of new equipment and timing of its purchase. In other words, it was thought that a 25-percent rise in the real price of fuel would provide a strong inducement to junk old, inefficient equipment and to emphasize fuel efficiency in new equipment.

The intermediate case assumed that there would be a mix of 90 million standard cars and 50 million economy cars in 1985--a ratio of 65:35, compared to 86:14 in 1970. For the low energy demand case, the Task Group estimated a 1985 mix of about 70 million standards to 70 million economy cars, or a 50:50 ratio. In the high demand case, the mix would differ very little from that of the intermediate case.

Such change in the mix of the car population is the largest factor in the cost-sensitivity calculation. In addition, there would be a small decrease in driving mileage and some efficiency improvement in commercial vehicle and aircraft efficiencies if fuel costs were considerably higher. Generally speaking, transportation energy demand is not highly sensitive to changes in the costs of fuel. Referring again to Table 8, the column for low demand in 1985 shows a reduction of 5.3 percent in energy consumption as a result of a 25-percent increase in the real cost of transportation energy and the increases in numbers of economy cars.

Potential differences in the rate of population growth between 1970 and 1985 would not be likely to affect the consumption of transportation energy significantly, because higher birthrates would not change the "driving age" groups during this period. As shown in Table 8, a shift in the assumptions to the faster population growth of Census Series C would increase the 1985 energy consumption to this sector by less than 1.0 percent. Likewise, a shift down to Census Series E would decrease 1985 energy consumption by only 1.8 percent.

ELECTRICITY CONVERSION

Electricity conversion refers to the energy loss that occurs in the utility plant when fuels are converted into electric power.* In the intermediate case, it was estimated that the heat loss in converting fuels into electricity would grow at a rate of 6.7 percent per year, or 0.5 percent more slowly than electricity consumption. The difference would be the result of improvement in the efficiency of processes for converting primary fuels into electricity. The variance in this sector, therefore, would be caused by the sensitivities of electricity demand and the heat rate to variations in the four major parameters.

Of the four parameters considered, the growth rate of real GNP is likely to have the greatest influence on the range of electricity consumption and on the electric utility demand for fuels. As indicated, electricity conversion losses would have to vary almost proportionately with the generating plant output because losses are equivalent to about two-thirds of the plant's energy input. This is a reason for expecting economic growth to be the main influence on the electricity conversion sector.

A *reduction* in the average annual growth of real GNP to 3.2 percent from the 4.2-percent rate of the intermediate case is estimated to reduce the 1985 utility requirements for conversion by 5.3 quadrillion BTU's (17.6 percent) below the 30.2 quadrillion BTU's of the intermediate case (see Table 9). The predominant impact of a lower rate of increase in real GNP would be on the industrial and commercial consumption of electricity in the 1970-1980 period, although, significant effects on residential consumption could also be expected by 1985. Part of the reduction in utility energy requirements up to 1980 (because of slowdown in demand for electricity) would be attributable to less utilization of older, thermally inefficient generating plants. This observation stems from the fact that plant expansion plans for electric utilities are now fairly firm up to and including 1980, and any reduction in overall electric energy requirements would permit the supply of a higher percentage of total kilowatt hours (KWH) required from the more efficient facilities. By 1980, utilities presumably would have adjusted their construction programs to the new lower growth rates, and thereafter the reduction in primary energy requirements would reflect essentially the lower demand for electricity by ultimate consumers.

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* Though commonly thought of as energy *suppliers*, electric utilities are actually also energy *users*, consuming coal, gas, oil, nuclear fission products, etc. Thus,utilities *convert* one form of energy to another. In technical parlance, electric utilities are users of *primary* energy sources and suppliers of *secondary* energy. For all states of their operation--production, transmission and distribution--approximately two-thirds of the BTU input goes into waste heat.

TABLE 9

SENSITIVITY ANALYSIS FOR TOTAL ENERGY DEMAND IN 1980 AND 1985
ELECTRICITY CONVERSION
(Quadrillion BTU's)

Parameter	1980 Low	1980 Intermediate	1980 High	1985 Low	1985 Intermediate	1985 High
Economic Growth Rate (Real GNP)						
Demand	20.0	22.8	23.2	24.9	30.2	31.1
% Change *vs.* Intermediate	(12.3)	–	1.8	(17.6)	–	3.0
Cost of Energy Including Cost-Induced Efficiencies						
Demand	21.8	22.8	22.8	27.9	30.2	30.5
% Change *vs.* Intermediate	(4.4)	–	–	(7.6)	–	1.0
Population Expansion Rate						
Demand	22.7	22.8	22.9	30.1	30.2	30.3
% Change *vs.* Intermediate	(0.4)	–	0.4	(0.3)	–	0.3
Energy for Environmental Improvement						
Demand	22.3	22.8	23.6	29.4	30.2	32.1
% Change *vs.* Intermediate	(2.2)	–	3.5	(2.7)	–	6.3

An increase in the annual growth of real GNP from 4.2 percent to 4.4 percent is estimated to raise the primary energy requirement for electricity conversion by 1.8 percent over the 1980 intermediate case and by 3.0 percent over the corresponding 1985 estimate. Also, as in the case of a reduced GNP growth, heat rate effects would account for some of the change in requirements up to 1980. This would result from the short-term need to use less efficient plants to meet a large part of the increase in electricity demand since construction lead times preclude a major change in expansion programs for the base-load plants. After 1980, however, heat rates could be expected to resume their "normal" levels, and the additional utility energy requirement would result mainly from greater electricity sales. In fact, more rapid gains in efficiency should be attainable as the addition of a large number of new efficient generating plants would increase the average efficiency level of the power generation industry.

An increase of 50 percent in the cost of fuel to electric utilities by 1985 could result in as much as 2.3 quadrillion BTU's (7.6 percent) below the intermediate case projection. These reductions would result from further improvements in the efficiency of power consumption in response to higher prices.

The potential for increasing efficiency would be extremely limited up to 1980 because of the constraints imposed on utilities by the characteristics of their existing plants (both those in service and those under construction). Some very marginal improvements might be achieved, however, through additional transmission interconnections between systems in order to make the fullest use of new low heat rate equipment, if the fuel savings involved could justify such steps. By 1985, however, a considerable improvement in efficiency may be achieved. Presumably, greater emphasis will be placed on more efficient, combined-cycle generating plants and supercritical (temperature) steam plants that have higher capital costs but are more efficient in the use of fuel.

Through 1985, the consumption of energy for electricity conversion is less sensitive to variations in the population growth parameter than to any of the other three parameters being considered. A population growth equivalent to the higher Census Series C projections could raise requirements by only 0.3 percent above the intermediate case level in 1985. This small increase presumably would be the result of marginal increases in electricity consumption in all consuming sectors. A reduction in the population growth rate to the Census Series E projection would have similar minor effects on the projections of energy for electricity conversion in 1985. In fact, significant effects could be expected only in the post-1990 period.

NON-ENERGY AND MISCELLANEOUS

Inclusion of a non-energy category in a projection of energy consumption requires a word of explanation. The primary output of coal, oil and gas is measured at the wellhead or mine where these minerals wind up in chemicals, lubricants, asphalts and similar products. These are not properly called energy uses, but they must be included if the consuming sectors are to add up to the primary energy supply.

Table 10 compares the intermediate case projection level with the levels that would result from changing the basic economic determinants--GNP, fuel costs (and cost-induced efficiencies), population and pollution controls. It is clear from Table 10 that the largest sensitivities result from changes in real GNP and energy costs. This is based partly on the judgment that it is realistic to assume that GNP and price could deviate substantially from intermediate case levels and partly on the relatively higher elasticity of the non-energy category with respect to GNP.

The assumed changes in population growth are estimated to have only minor impacts, and no effect at all is shown for the different assumptions on pollution controls.

In order to understand the sensitivities of the sector totals to these economic determinants, it is necessary to analyze the results in terms of (1) the sector's composition by fuel and by use and (2) the elasticities of the individual fuel-use elements. The sector totals are largely composed of three fuels--oil, gas and coal--while the largest and most dynamic uses are liquid and gas feedstocks for the chemical industry and major oil components such as lubricants and asphalts.

TABLE 10

SENSITIVITY ANALYSIS FOR TOTAL ENERGY DEMAND IN 1980 AND 1985
NON-ENERGY AND MISCELLANEOUS
(Quadrillion BTU's)

Parameter	1980 Low	1980 Intermediate	1980 High	1985 Low	1985 Intermediate	1985 High
Economic Growth Rate (Real GNP)						
Demand	6.1	6.7	6.8	7.8	8.9	9.1
% Change *vs.* Intermediate	(9.0)	—	1.5	(12.4)	—	2.2
Cost of Energy Including Cost-Induced Efficiencies						
Demand	6.5	6.7	6.7	8.5	8.9	8.9
% Change *vs.* Intermediate	(3.0)	—	—	(4.5)	—	—
Population Expansion Rate						
Demand	6.6	6.7	6.7+	8.6	8.9	9.0
% Change *vs.* Intermediate	(1.5)	—	0.5	(3.4)	—	1.1
Energy for Environmental Improvement						
Demand	6.7	6.7	6.7	8.9	8.9	8.9
% Change *vs.* Intermediate	—	—	—	—	—	—

Historically, the demand for petrochemical feedstocks has been noticeably responsive to changes in GNP, which is a direct reflection of the fact that feedstock demand is derived from the demand for chemical end-products that are used throughout the economy. The responsiveness with respect to price largely indicates the price competition between petrochemical end-products and substitute materials such as wood, glass and metals. The intensity of the response is heightened by the fact that feedstock costs represent a rising share of total chemical costs. A projection of rising feedstock prices is based on the following considerations:

- The current shortage of natural gas is likely to worsen, and the prospective increase in its price is likely to drive up the price of light feedstocks (ethane, propane and butane).

- The demand for ethylene/propylene is likely to remain strong though its growth rate probably will be less rapid than in the 1950's and 1960's.

- There are likely to be substantial cost increases for heavy feedstocks--e.g., naphthas and gas oils.

The gas component of the chemicals sector consists of gas feedstocks for the production of ammonia and a number of other chemicals, the most important of which are urea, methanol and acetylene. Ammonia, which accounts for 60 percent of methane-derived chemicals, is used very largely in the production of fertilizers.

The other important component in the non-energy projection is the demand for petroleum-based raw materials, almost 90 percent of which is accounted for by lubricating oil and asphalt/road oil. Analysis of past experience indicates that demand for lubes is highly dependent on industrial output, automotive vehicle use and exports, while demand for asphalt/road oil is dependent mainly on road construction and maintenance. These have a much higher elasticity with respect to the level of economic activity than with respect to price, although to a certain extent, asphalt/road oil has to compete on a price basis with cement.

ENERGY FOR ENVIRONMENT IMPROVEMENT

The harnessing of the earth's energy resources during the Industrial Revolution provided the opportunity for higher standards of living and an expanding population. By using increasing amounts of energy, the industrial nations have attained a mode of living characterized by relative comfort and convenience. However, unexpectedly in some areas, population and economic activity have increased to the point that the natural environment is less able to absorb the many kinds of pollution that were long accepted as necessary evils of a contemporary and progressive society. The problem has become an international issue, and some governments have been given mandates to develop the means for dealing with it effectively.

There has been much debate regarding the levels of permissible auto emissions. Although the specific technical capability of meeting the environmental goals is not yet available, the magnitude of the job and the penalties involved are reasonably well defined. In most other areas of private, commercial and industrial activity, the penalties and trade-offs associated with higher ecological goals and standards have not been completely defined. It has become quite apparent, however, that very large amounts of energy will be required to abate pollution and improve the quality of the environment.

Table 11 gives a breakdown by major categories of projected energy consumption required to meet anticipated environmental controls in 1980 and 1985. Two alternate cases are shown in this table: (1) energy consumption standards assumed in the intermediate case and (2) *additional* energy required to meet more severe standards such as those assumed in the high demand case. Individual environmental problems are discussed in the following paragraphs.

Automotive Emissions

The automobile emissions controls required by federal and state standards already have substantially reduced the number of miles per gallon obtained by newer model cars and have lowered their overall performance. It is expected that this trend will continue, thus increasing automotive fuel requirements by 20 to 30

TABLE 11

ENERGY CONSUMPTION TO MEET ENVIRONMENTAL STANDARDS
(BTU x 10^{12})

Activity	1980 (1)*	1980 (2)†	1985 (1)*	1985 (2)†
Auto Emissions Controls	914	–	400	–
Electric Utility Industry				
For Control of Waste Heat	–	247	–	1,331
For Control of NO_x (Coal)	–	252	–	471
For Control of NO_x(Residual Fuel Oil)	–	45	–	76
For Fuel Desulfurization (Residual)	120	119	202	202
For Stack Gas Scrubbing (Coal)	63	63	117	118
Subtotal—Electric Utility Industry	**183**	**726**	**319**	**2,198**
Sewage, Water and Solid Waste Treatment	2,000	2,542	2,432	2,580
Industrial Sector				
Residual Oil Desulfurization (to 0.3% S)	–	167	–	304
Coal Gas Scrubbing (Equivalent to 0.3% S)				
Coking	–	50	–	71
Industrial ‡	–	35	–	43
Other Environmental Control by Industry	976	244	1,298	972
Subtotal—Industrial Sector	**976**	**496**	**1,298**	**1,390**
Consumption for All Environmental Controls	4,073	3,764	4,449	6,168
Total Energy Consumption—Initial Appraisal	102,581	–	124,942	–
Environmental as % of a Total Energy Consumption	4.0	3.7	3.6	4.9

* Approximate quantities included in Initial Appraisal.

† Additional energy requirements because of higher environmental standards subsequent to the Initial Appraisal.

‡ Including a relatively small amount for residential/commercial.

percent during the 1970-1985 period. The estimates shown in Table 11 assume that the octane pool level will remain no higher than 91-93 and that technological improvements will be made in motor fuel, automobile engine design and vehicle weight that will eventually overcome many of the penalties that are apparent in current year models.

Table 8 shows estimates of all transportation energy demand variability with changes in the environmental controls. Although automotive consumption is the major item, it is expected that there will be significant modifications in other types of vehicles, aircraft, etc., so that the new air quality standards will be met. As a rule, such changes will lower engine efficiency for at least another decade. Since it would be difficult to separate the efficiency improvement trends from the efficiency reductions resulting from anti-pollution devices, these effects are all combined under the environmental control parameter. The estimated variability in Table 8 indicates a strong possibility that transportation energy use will be increased as a result of air quality standards.

Observing the current "state-of-the-art" in automobile anti-pollution devices and assuming that no-lead gasoline with an octane number of 91-93 will be required for 1976 models, the average efficiency of new cars of that vintage will probably be substantially below current levels. It will be many years, however, before the older cars are scrapped and the entire car population reflects the new standards. In the meantime, a variety of changes in the engine and system design are likely to increase efficiency. Many of these trends have been incorporated into the intermediate case. The high demand variant case is based on the possibilities that (1) strict standards for nitrogen oxide (NO_X) control will be enforced as early as 1975-1976 and (2) anti-pollution standards will be applied to all cars on the road.

Waste Heat Control

The waste heat control category includes the energy requirement to convert condenser cooling of electric power plants (presently cooled by rivers and streams) to wet and/or dry cooling towers. The estimates of added energy requirements in column (2) of Table 11 are based on the assumption that one-fourth of all power generated will be utilizing wet and dry cooling facilities for waste heat (rather than rivers and streams) by 1980. The 1985 estimate assumes that the equivalent of one-half of all electric power generated will require cooling towers.

Control of Nitrogen Oxide Emissions

The estimates for the high case in the NO_X categories are based on the assumption that an 85-percent reduction in emissions of NO_X from power plants would be required by 1985. This, in turn, would reduce boiler efficiency. Thus, the consumption increments reflect the additional energy that would be required if two-thirds of all coal and residual oil-fired power plants were to have this standard (85-percent reduction) imposed before 1980 and if all plants were required to meet the standards by 1985.

Desulfurization

Sulfur emission levels now are imposed on *new* power plants in certain areas. For oil, there is an extra energy requirement to process the fuel before burning. This requirement is shown in Table 11 in the electric utility category, although it could be classified as either industrial or electric utility. The estimate reflects the assumption that desulfurized fuel oil will be required for two-thirds of the residual oil demand projected for power generation by 1980 and for all of the demand by 1985. For coal, it is assumed that stack gas scrubbing will become technically and economically feasible so that the process can be employed widely by 1980. It is also assumed that stack gas scrubbing will be required for one-third of the demand projected by 1980 and one-half of the 1985 demand.

Also, in Table 9, the sensitivity of energy demand to variations in environmental standards is estimated for electricity conversion consumption. These calculations take into account the major factors discussed above except for the portion of fuel desulfurization that is carried on outside of the electric utility plant.

Assuming that environmental protection regulations would be stricter than those used for the intermediate projection, energy requirements of electric utilities could be higher by 3.5 percent in 1980 and 6.3 percent in 1985. These increases would result primarily from additional requirements for the control of waste heat disposal through the operation of cooling towers and for moving water in and out of cooling ponds. Losses in boiler efficiency due to NO_x control would be the second most important factor contributing to the increase in requirements. Stack gas desulfurization scrubbers for eliminating sulfur dioxide (SO_2) emissions would account for most of the remainder of the increase.

A relaxation of regulations below those implied in the intermediate case could reduce demand by as much as 2.2 percent in 1980 and 2.7 percent in 1985. The reduction in energy requirements would most probably result from less severe limitations on cooling water disposal, particularly for nuclear plants.

Sewage and Water Treatment

Treatment of sewage, water and solid waste have been familiar problems to the general public because the expansion of cities and suburbs across the Nation have required improved sewage treatment, better garbage disposal and increased water supply. Unfortunately, nationwide data describing the magnitude of the current effort are not readily available, so estimates were prepared from county and municipal data. These data were ultimately expanded for the entire country using the Census Series D population forecast. The additional energy needs are mainly requirements for pumping and filtering and were derived from EPA sources. It is assumed that high standards of sewage treatment will be in effect across the Nation by 1985; thus, energy requirements for both sewage and water treatment will become significant parts of total energy consumption.

Other Solid Waste Disposal

Little is known yet about the nationwide energy requirements and cost of solid waste disposal (wastes such as muncipal trash, garbage and other refuse) except that great efforts are being made to minimize costs. Some facilities in Europe have converted waste products to useful energy, and it is expected that future research will demonstrate many more opportunities for utilizing waste products to generate energy. Therefore, it is assumed that in the long run the energy derived from such efforts will about equal the energy required for the gathering and preparation of wastes. However, it is doubtful that these conservation systems can be in general use before 1980.

Industrial Sector

In the second part of Table 11, residual oil desulfurization and coal gas scrubbing items reflect the estimates of energy consumed in the manufacture of low-sulfur (0.3 percent) fuel oil and desulfurization of coal gases (through stack gas scrubbing, chemical treatment or other means) for the volume of fuels consumed in the industrial sector. Small amounts of energy used for processing fuels for the residential/commercial sector have been added to this industrial category. The increased energy usage was calculated by assuming that about two-thirds of these sectors' fuel consumption would be required to meet the low-sulfur standards by 1980 and that all must meet such standards by 1985.

Consumption by Large Industrial Users

A broad survey of electric utility customers by the Edison Electric Institute developed some estimates of energy requirements for pollution abatement.* The responses from the survey indicated that about 8.4 percent of the electricity consumed by large industrial customers was used for pollution abatement in 1971 and that the proportion would rise to 12.9 percent by about 1972-1973. It is believed that this is a conservative projection for this category of electric energy users.

The sensitivites of industrial energy to more or less stringent emissions standards, as estimated by the entire Task Group, are shown in Table 7. The high demand case indicates the additional energy that would be required to meet the much tighter controls under consideration in 1972 for possible adoption in 1975 or thereafter (i.e., about 2.0 quadrillion BTU's, or a 6.5-percent increase). Although the low case shows the sensitivity to the imposition of lower standards than those envisioned in the intermediate case, the potential variation on the low side is much less, and it has a low probability.

A greater measure of uncertainty surrounds the impact of environmental improvement standards on industrial energy consumption relative to the other sectors. There is no doubt that large amounts of energy will be required to clean up industrial wastes, but the stringency of the regulations, the degree of enforcement and the level of voluntary compliance to the regulations will have marked effects on the amount of energy that ultimately will be required.

Overall Costs

Estimates of the annual total cost of pollution abatement and environmental restoration may vary from $25 to $50 billion, projected

* Results of 1971 survey summarized in Table 23.

over a rather indefinite time frame. The real dollar cost must necessarily reflect the rate of imposition and enforcement of pollution standards and the technological capability (including manufacturing facilities and adequately trained operating manpower) to perform a task that is not yet too well understood. The Environmental Protection Agency (EPA) has estimated that in 1970 total expenditures for all kinds of air, water and waste treatments amounted to $9.3 billion.

About 4 percent of energy requirements projected to 1980 (or 4.1 quadrillion BTU's) was included in the intermediate case as energy consumption for environmental improvements. It now seems that new standards might require a commitment of an additional 3.8 quadrillion BTU's in 1980. For 1985, the comparable figures are 4.4 and 6.2 quadrillion BTU's respectively. Thus, the 1985 high level of energy consumption of 10.6 quadrillion BTU's for environmental controls is equivalent to 8.5 percent of the total U.S. consumption estimated for the intermediate case, or a doubling of the share of energy used for those controls.

EFFECTS OF REDUCED ENERGY CONSUMPTION

The total value of energy at the consumer level contributes almost 10 percent to the GNP, while primary fossil fuels amount to about 5 percent. In one form or another, energy is an absolutely vital link in the production process. Since lower energy consumption could be very costly in terms of lost production and human welfare, the full implications of proposals to reduce energy growth require careful examination.

Voluntary improvements in efficiency of energy use by individuals and industry are effective and compatible with other national goals. This type of conservation has been and will continue to be developed fairly rapidly through technological advances and the price system. The extent to which this current trend might be accelerated in the future is one of the subjects of the parametric analyses described later in this section.

In contrast, arbitrary restrictions on energy use would have predictably undesirable effects on the economy and on individual freedom and welfare. Such restrictions are likely to be discriminatory, especially against low income groups. It is this arbitrary type of reduction in consumption that is evaluated in the following paragraphs.

Effects on Economic Growth

Arbitrary reductions in energy consumption would have significant impacts on U.S. economic growth as indicated by the following examples. If 1985 energy demand were so reduced by 10 percent, real

GNP would be lowered an estimated 7 to 18 percent.* The range in effect on GNP is the result of the different paths the reduction might take. The lower effect would apply if energy-intensive uses (metals, machinery, chemical industries, etc.) were restricted first; the upper end of the range would apply if all uses were restricted on a proportionate basis. An even more severe effect on the economy would occur if it were assumed that less energy-intensive uses were restricted first. In a more extreme example in which the 1985 energy consumption level would be lowered by 30 percent (equivalent to consumption growth of only 1.7 *versus* 4.2 percent in the intermediate case), the resulting reduction in real GNP would range between 20 and 50 percent.

Employment Effect

Other things being equal, a lower GNP will be accompanied by higher unemployment. A 7-percent decrease in real GNP in 1985 could possibly increase unemployment by about 2 million persons. (The unemployment rate increase used here is based on the Okun formula which relates the unemployment rate to various levels of GNP.†) A 50-percent reduction in GNP, as mentioned in the preceding paragraph, is outside the range of data experienced in the past. However, as a point of comparison, the reduction in real GNP experienced during the Depression period (1929-1933) was 31 percent, and the civilian unemployment rate reached 25 percent (or an increase of 22 percent). At that time, 12.8 million persons were unemployed. A much larger number of unemployed could be expected in the future with a similar percentage reduction in GNP. These calculated unemployment impacts could be partially offset by changes in the economic structure and life-style, but such changes would be slow and difficult to achieve.

Other Effects

The impact of slower energy growth on poverty levels has also been estimated. For example, if the GNP growth rate between 1970 and 1985 were reduced from the 4.2-percent rate of the intermediate case to 3.2 percent per year, total personal income would be much lower, and the number of people within the poverty categories (in 1985) would be increased by 2 to 3 million.

If energy consumption were reduced because of limited supply, a significant increase in market price would be one of the condi-

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* The proportions are based upon the relationship between energy consumption and GNP established by input/output analyses of the U.S. Department of Commerce for the year 1963 and NPC projections of trends through 1985.

† President Johnson's Council of Economic Advisors study based on 1953-1963 data.

tions because of the relatively low elasticity of energy demand to price. Higher energy costs presumably would be reflected very soon in the prices of virtually all goods and services. In other words, higher prices would be one of the social costs that the Nation would bear if energy were in short supply. Other economic redistributions would also occur. Energy-intensive industries, for example, would sustain higher operating costs and would have greater difficulty in competing against industries with lower energy requirements per dollar of output.

If energy use were lower because of limits placed on specific energy uses for environmental or other reasons while energy prices were controlled, an appearance of price stability could exist. This could impose a partially obscured and very costly set of economic penalties upon society. If, for example, motor gasoline use were curtailed, fewer and/or smaller cars would be purchased, thus requiring less output of steel, rubber, plastic, etc. Aside from lower standards of vehicular transportation and more unemployment in the automotive and related industries, the impact of reduced energy usage would be very unevenly distributed throughout society. In effect, the well-being of automobile owners, passengers of all forms of transportation, heads of households, small businessmen, and indeed, most individuals would be reduced. The largest relative impact would fall on the lower income groups. The industrial sector would be able to adjust eventually to a lower energy consumption through marginal substitutions of capital and labor for energy, passing on the additional costs in the form of higher prices for goods and services.

Chapter One

DEMAND VARIABILITY ANALYSIS FOR THE 1971-1985 PERIOD

The purpose of this part of the energy demand study may be summarized as follows: Given the conditions of energy financing, production, transportation and consumption, as assumed in the intermediate case, to what extent can flexibility in energy demand help to achieve a final balance of supply and demand? The first step in answering this question was to identify the factors (parameters) whose variations would cause significant changes in energy demand and then to provide quantitative estimates of the effects of changes in each parameter on the demand for total energy. As mentioned in the Introduction, these parametric ranges were established long before the Arab oil embargo and large price increases of 1973. Consequently, the findings of the study do not reflect these recent political events.

SELECTION OF PARAMETERS

As discussed in the Summary the following economic factors were identified by the Task Group as significant parameters that might be analyzed quantitatively: (1) economic activity (GNP), (2) price of energy (including cost-induced efficiency improvements), (3) population and (4) environmental controls.

Economic Growth

Overall economic growth appears to be best represented by real gross national product. In some markets (as in the residential, for instance), the best manifestation of economic growth may be found in the personal income trend which is, nevertheless, closely related to GNP. Likewise, industrial activity shows a closer year-to-year correlation with the Federal Reserve Board Index of Industrial Production (FRB) rather than with GNP. For purposes of long-term analysis, however, it has been assumed that all of these parallel economic series would vary in proportion to assumed variations in real GNP--relative to the intermediate case.

Cost of Energy, Including Cost-Induced Efficiency Improvements

The price of energy, or the "cost of energy to the consumer" as it is called in this study, was selected as a parameter not because energy demand elasticity has been very evident in the past (when there was a slow decline in the "real" price of energy) but because price trends could be much different in the future and because price is one of the factors common to both the supply and demand functions. In the judgment of the Task Group, significant changes in demand might be associated with very large increases in energy costs. At any rate, it was a subject that needed to be investigated even though the Task Group was not optimistic that precise quantitative values could be determined. A few price elasticity studies have been published but most of them dealt with particular fuels in special markets and thus were of little help in developing estimates of total energy demand elasticity.

In looking at the "efficiency of energy use" factor, the Task Group became convinced that it would be impractical to try to separate the effects of efficiency change from the direct impact of energy cost because cost frequently is the motivating force for efficiency improvement, and the consumer will not fully react to fuel price changes until he has had time to change his equipment. This is true for the homeowner who is considering additional storm windows as well as for the manufacturer who is evaluating the pros and cons of new machinery. Therefore, the second parameter was defined as "cost of energy, including cost-induced efficiency improvements." For the transportation sector, this efficiency factor includes variant cases for the number of economy cars-on-the-road because no satisfactory way was found to separate consumer responses to changes in motor fuel cost from responses to changes in the whole package of automobile operating costs.

Technological breakthroughs do not figure significantly in the variant analysis because breakthroughs generally require long time periods for testing and retooling, but *evolutionary* technological developments and their effects on efficiency in energy consumption are integral components of several of the parameters, including energy cost and environmental improvement. Unforeseen revolutionary technological innovations might have large impacts on energy demand but the estimated probabilities of such innovations being completed in the period 1971-1985 are not high enough to figure in the range of variance shown herein.

Population

The "population" factor was selected because it is widely regarded as having an important and direct correlation with energy demand growth.* On the basis of experience and logic, the Task Group decided that it would be desirable to treat separately the economic growth and population factors because the relationships between them are complex and not necessarily direct. The complexities may be observed in the changing GNP/population relationships from state to state in the United States and from country to country.

Energy Requirements for Environment Improvement

Environmental control was the fourth factor selected for the parametric study because its impact on energy is expected to have

* In this context, "population" means all the demographic changes that are encompassed by the various projections of the U.S. Bureau of Census. The Initial Appraisal used the August 1970 Census Series D, which projected total U.S. population at 240.9 million persons in 1985, indicating an average growth rate of 1.1 percent per year.

a much larger weight in the future than it has had in the past; moreover, the possible effects could have wide variances. It was difficult to express this parameter in quantitative terms because there has been no previous summation of the total amounts of energy required to purify air and water and to dispose of solid wastes, even though much has been said about total financial costs. "Environmental improvement" in the context of this parametric study generally refers to the ecology and not to the economic and social milieu of urban life which may present equally serious problems.

There are several other kinds of developments which, though important in molding energy consumption patterns, do not lend themselves to quantitative expression. Governmental policies and life-style of the people are two examples which have been discussed qualitatively in the NPC Full Report.

Since this study deals with long-term trends, it does not show reductions in consumption that probably would take place as a result of supply cutoffs or other short-term emergencies. Nevertheless, these are ever-present dangers that could affect long-term demands if emergencies happen to occur at frequent intervals.

METHODOLOGY

Many of the variables affecting future energy demand (although generally recognized as existing problems) had not been previously explored. Therefore, special studies were undertaken by individual Task Group members and several of the background papers are presented in Appendices D-I of this report. These deal with the following energy topics: (1) econometric models for estimating demand elasticities in the residential/commercial and industrial sectors, (2) efficiency improvement through insulation of buildings, etc., (3) variability of electricity demand and (4) technical possibilities for improving efficiency of consumption.

To provide a framework for the study, the Task Group agreed upon some general guidelines as to the factors that affect the rate of change in energy demand. One such factor is the change in the machinery and equipment that is in general use. This equipment represents large capital investments; therefore, fuel savings would have to be substantial to justify its replacement by new and more efficient equipment. Until machinery is scrapped, modified or duplicated, the change in demand is not likely to be dramatic. Replacement and modification will probably be made gradually so that the time factor is of great importance in measuring the response of energy demand to different assumptions. For purposes of simplification, the demand function is defined in three different ways:

- In the short-term, consumers can operate their equipment more or less intensively.

- In the intermediate period, submarginal equipment will be improved or replaced.

- In the long-term (say 10 to 15 years), equipment could be substantially modified, and the substitutability of fuels would be high.

In addition, energy demand trends exhibit a good deal of inertia because selected parameters are likely to change by relatively small increments. For example:

- Economic growth has been a slow moving item, by definition.

- Population growth rates are low and relatively steady.

- It was judged from past experience that the real cost of total energy would change gradually. Since it is impossible to predict the timing of sudden price swings that might result from emergencies, the Task Group assumed that price changes would occur in equal annual increments over the 1971-1985 study period.

- The exact occurrence of significant efficiency changes and environmental improvements are also unpredictable and are, therefore, assumed to be gradual.

For such reasons, the parametric variances are expressed as growth rate changes over 10- and 15-year periods, and the effects on energy demand are estimated as changes in the growth rate. No attempt was made to estimate variant cases for 1975 because the parametric changes would not have time to take full effect and cyclical swings are likely to obscure the long-term trends for that year.

The "panel of experts" method was used for developing alternative energy demand cases. Each panel member, working within definite guidelines and assumptions, estimated the sensitivities of total energy demand (in each market) to changes in each of the four parameters. As a rule, a consensus was determined by a panel of six members.

It was decided that three points should be estimated for each parameter except "cost of energy," for which consumer response was expected to increase markedly in the high cost ranges. The three selected points would help to determine "high," "intermediate" and "low" cases. The Task Group tried to set specifications for these cases so that they would span the range of the more probable variations of total energy demand trend during the 1970-1985 period, as described in the following paragraphs.

For the "economic growth" parameter, the Task Group agreed to use real GNP with a growth rate ranging between 3.2 percent and 4.4 percent per year, including the intermediate case (Initial Appraisal) rate of 4.2 percent. These are 15-year averages; the upward trend is expected to be faster in early years and slower toward the end of the period but part of the change in rate is a result of using a depressed year (1970) as the base year. The dispersion of the Task Group's estimates was somewhat broader than this 1.2-percent point spread but most of the estimates were near the average. The range limits also reflect the Task Group's feeling that there is greater probability and the actual trend would fall below, rather than above the intermediate case.

In the intermediate case, the energy demand projections were prepared independently of the energy supply analysis. However, in this final analysis, the selections of high and low projections for "cost of energy to consumer" were influenced by the findings of the NPC Full Report regarding future supply trends. As a basis for the high case, it was assumed that the "real" cost of "primary" energy would double by 1985, increasing on a straight-line trend.* For the low case, it was assumed that the primary energy cost (in real terms) would gradually decline by 10 percent over the 15-year period. The intermediate case, of course, predicated no significant change in the real cost of energy. Such assumptions on primary price changes would result in much smaller percentage changes in the cost of energy to the consumer, as shown in Table 4 (p.11).

The U.S. Bureau of the Census has developed satisfactory estimates of population trends under different sets of assumptions; the difficulty lies in selecting the more probable alternatives. At the beginning of the study, the Task Group chose Census Series D, published in August 1970, as the population assumption for the intermediate case. Subsequently, Series C and Series E (from the same publication) were selected for the high and low energy demand cases respectively. Although it is still too early to be certain, the current decline in the fertility rate suggests that the U.S. population is more likely to fall below (rather than above) Series D levels but, even if the total fertility rate should drop to as low as 1,500 per thousand in 1980 (*versus* the long-term replacement rate of 2,110), the Nation still would have a population increase of some 23 million by 1985.

The population numbers shown in Table 12 differ slightly from the Census revisions (Series D, C and E) published in December 1972.

Starting with an average age of 27.7 in 1970, the Census Series C, D and E project average age for the total population in 1985 at 28.8, 29.8 and 30.3, respectively.

It was not feasible to set specific guidelines for the "environment control" factor; however, a special study of possibilities in this area was undertaken to provide background information and a cross-check on the panel's estimated high energy demand case. A summary of the results of this study was shown in Table 11. The amounts of energy to be consumed for environmental improvement in the intermediate case projections are estimated to equal almost 4 percent of total energy consumption in 1985 *versus* 2 to 3 percent used for that purpose in 1970.

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* The "real" cost of primary energy results from an average of fuel prices at the wellhead, mine, etc., assuming no inflation in the projection period.

TABLE 12

U.S. TOTAL POPULATION PROJECTIONS

	Census Series C		Census Series D		Census Series E	
	Million Persons	Average Annual Percent Change	Million Persons	Average Annual Percent Change	Million Persons	Average Annual Percent Change
1970	204.9		204.9		204.9	
		1.3		1.0		1.0
1980	232.4		227.5		225.5	
		1.4		1.2		1.0
1985	249.2		240.9		236.9	

Source: Bureau of Census, Department of Commerce, *Census Series P-25, No. 448* (August 1970).

Table 13 summarizes the salient guidelines, described in the preceding paragraphs, which were applied to the parametric ranges. These same average annual growth rates were used by all task group members in order to obtain consistency in their sensitivity analyses.

TABLE 13

GUIDELINES FOR THREE ENERGY DEMAND CASES
AVERAGE ANNUAL GROWTH RATES – 1970-1985

	High Demand	Intermediate	Low Demand
Real GNP Growth	4.4%	4.2%	3.2%
Real Cost of Primary Energy*	-0.6%	No Change	4.7%
Population	1.3%	1.1%	1.0%
Environmental Controls	Very Strict Standards	Strict Standards	More Lenient Standards

* For the consumer, cost changes assumed at about one-third of these rates.

It was agreed that reasonably good approximations of demand sensitivitites could be derived by careful examination of the many individual markets and uses for energy. With such breakdowns, the applications of econometric models were facilitated and the Task Group could draw on the expertise of marketers and technicians who were familiar with particular markets. When all the energy uses were combined, some of the errors in the components probably were offsetting so that the Task Group had a fairly high degree of confidence in the total energy variances.

The decision to include "electricity usage" with total energy consumption in each consuming sector requires a word of explanation. Electricity will compete more and more with certain fossil fuels in many sectors and to treat it separately would necessitate the calculation of cross-elasticities of demand for fuels and electricity which, as explained previously, could not be done by the Task Group because of antitrust implications. Even without this restriction, it appears that the possible gains in accuracy resulting from such conceptual rigor would not have been significant enough to justify the greater analytical complexities that it would entail.

SECTOR ANALYSIS

Residential and Commercial

An approximate breakdown of total 1970 residential/commercial energy consumption, by component use, is shown in Table 14. This category also includes consumption in public buildings.

TABLE 14

1970 RESIDENTIAL AND COMMERCIAL ENERGY CONSUMPTION

Usage	Quadrillion BTU's	Total (Percent)
Space Heating and Cooling	10.65	67
Water Heating	2.05	13
Refrigeration	1.15	7
Lighting	0.70	5
Cooking	0.68	4
Other Residential Use*	0.35	2
Other Commercial and Public Use †	0.22	2
Total	**15.80**	**100**

* Television, all other appliances and equipment.

† Elevators, appliances and other equipment.

Since the data listed above are not regularly published for all the categories, the statistical analysis presented here has been applied to the total residential/commercial energy consumption series.

The findings were adjusted on a judgmental basis to allow for expected changes in the relative weights of the component uses. For instance, the demand for air conditioning is expected to become proportionately larger, and this is one of the more elastic components of residential/commercial demand.

Almost all of the demand sensitivity in this sector must occur in the first four items of Table 14 and, in fact, heating and air-conditioning are likely to provide most of the demand flexibility.

One parameter--economic growth--could affect all of the use components because it determines the level of income, the numbers of homes, commercial and public structures and the number of energy-consuming appliances.

Correlations of historical data for residential/commercial energy demand with either real GNP or real personal disposable income showed very close relationships ($R = 0.99$). Regression coefficients for economic growth indicated that energy consumption would vary by approximately the same percentage and in the same direction as income (or GNP) variations. These coefficients changed very little when the price of energy, temperature (degree days) and population were added to the equation as independent variables in multiple correlation analyses. Although these historical relationships provided some guidance for projections, it was the Task Group's belief that high income effects masked the independent impacts of price and population, which usually were operating in the same direction. In this historical period, population was increasing comparatively rapidly and the trend of real energy price was downward; therefore, the income factor's historic coefficient of unity was reduced in order to eliminate the effects of these other factors on the income/GNP component. The degree of reduction is a question of judgment. According to the Task Group consensus, an increase of 1 percent in the GNP growth rate would increase residential/commercial energy growth rate by 0.6 percent, and a decrease of 1 percent would decrease the energy growth rate by 0.5 percent.

An examination of the processes by which energy price motivations are likely to modify consumption led to the following conclusions regarding the impact and timing of the parameter "cost of energy to the consumer:"

- Higher energy costs, *if sudden*, might stimulate homeowners to lower the thermostat in winter, use the air conditioner less in summer, turn off lights, keep doors and windows closed and economize in other small ways. The same reactions would be expected in the commercial and public sectors. This direct influence of price was not given a large weight because the cost change was not assumed to be large enough or sudden enough to induce consumers to modify their habits significantly. It will be recalled that the range of variability for cost of energy to the consumer assumes only a 2-1/2 percent cost decrease over 15 years for the high demand case and a 25 percent cost increase for the low demand case.

- A trend toward higher real costs of energy (probably accentuated by inflationary pressures) could operate to significantly improve the efficiency of use in this sector. This trend would be reinforced by higher Federal Housing Administration (FHA) standards and other governmental incentives and admonitions. In order to estimate the magnitude of this cost-induced efficiency improvement, a special review of the effects of insulation and other opportunities for fuel savings was undertaken by the Task Group. This is summarized in Appendix D. The intermediate case assumes a continuation of past trends toward better insulated buildings and improved heating plants. For the low energy demand case, the panel consensus indicates that there would be a growth rate reduction of 0.6 percent as a result of an energy price rise of 1.5 percent per year (i.e., -0.4 elasticity) which is a somewhat lesser response than the theoretical reduction shown in Appendix D.

- Several panel members experimented with econometric models fitted to historical data with the objective of calculating energy demand-price elasticity for the residential/commercial sector. Although there were few instances of real price increases in the historical period, there have been large declines and it may be argued that these declines could determine the shape of a demand curve which would be valid for price increases as well as decreases. The most promising method seems to be the two-stage least squares technique which was used on consumption data--both including and excluding electricity. The findings of the models indicate demand-price elasticity of -0.4 to -0.5 which is very close to the findings of other types of analyses as well as to the Task Group consensus. There are many limitations to such models, some of which are discussed in Appendices E and F where it is suggested that models should give more emphasis to recent experience, that electricity and fossil fuels should be handled separately and that the demand functions probably should include more variables. The significance of this study lies in the guidance developed for further modeling.

- In the judgment of the Task Group, the demand-price elasticity would be greater in the higher price ranges and attempt was made to quantify this difference within the assumed price range. The conclusions are not shown separately but are reflected in the energy growth rate for the high cost case.

With regard to the population parameter, it was concluded that variations among the Census Series C, D and E would have only minor effects on energy consumption in the residential/commercial sector. The differences in assumptions regarding birthrates are relatively small and these differences should have negligible effects on the labor force and on household formations prior to 1985. It is thought that the multiplier effect from a higher population growth would have its impact on consumption primarily after it caused increases in labor force and household formation. The Task Group consensus shows impacts on the energy demand growth rate of +0.2 percent for Census Series C and -0.1 percent for Series E, which are exactly the differences in population growth rates among Series C and E and the intermediate case, Series D

It was concluded that various pollution control cases would have relatively small direct effects on this sector.

Table 15 shows the assumed parametric ranges and the variability in energy demand growth rates that would result from the "independent" variation of each parameter in the residential/commercial sector. The plus or minus variations are measured from the growth rates estimated for the intermediate case. The elasticities can be readily determined from this table. Table 6 translates the sensitivity analysis into energy consumption ranges for the terminal years 1980 and 1985.

TABLE 15

RESIDENTIAL/COMMERCIAL DEMAND SENSITIVITY (PERCENT) TO PARAMETRIC VARIATION

	Change in Energy Growth Rates From Initial Appraisal (Rate of 3.6 percent)	
Parametric Range	**1970-1980**	**1970-1985**
Economic Growth Rate (Real GNP)		
(Initial Appraisal = + 4.2%/Yr.)		
+ 4.4%	+0.12	+0.12
+ 3.2%	-0.5	-0.5
Cost of Energy Changes — %/Yr.		
(Initial Appraisal — No Change)		
- 0.2%/Yr.	0	0
+ 1.5%/Yr.	-0.4	-0.6
Population		
(Initial Appraisal = + 1.1%/Yr.)		
+ 1.3%	+0.2	+0.2
+ 1.0%	-0.1	-0.1
Environmental Controls		
Higher Standards	0	+0.1
Lower Standards	0	0

Industrial Energy Demand

In the 1972 report of the Energy Demand Task Group the relationship between economic activity and industrial energy consumption was described in detail. It was pointed out that there are many developments, both technological and economic, that will continue to modify this relationship. During the post World War II period, industrial energy consumption grew at only 60 percent of the expansion rate of industrial production, even though energy prices were declining in terms of constant dollars. The indicated improvement in efficiency of energy use is believed to have been primarily a result of technological change and a shift from coal to oil and gas. The technological and economic trends were studied for each individual industry in order to determine the extent to which the efficiency of energy use will change in future years and how industrial consumption of energy is likely to correlate with economic growth.

Although each Task Group member submitted his own estimates of future demand sensitivity, background information was provided by a series of special studies of the industrial sector which included development of the econometric model described in the following pages and in Appendix G.

In attempting to quantify the effect of energy cost on energy consumption in the industrial sector, computer modeling techniques were used to try to determine elasticities. In experimentation with different models, thousands of candidates were investigated using a search routine which examined combinations of variables to find "best" fits. These searches produced about 50 promising candidate models, and these in turn were reduced to four. Each offered some special insight or advantage, and each was based on the premise that energy, capital goods and labor all compete for the productive funds of industry.

To remove the domination of industrial production from total Industrial Energy demand, a number of regressions were run with "energy per unit of the FRB production index" as the dependent variable. Model A (see Table 16 and Appendix G for model descriptions) represents the simplest model, based only on relative prices of three aggregate factors of production--energy, capital goods and labor. In the experimentation, however, the level of production still seemed important, apparently due to an economy of scale consideration, which led to the development of Model B. Model D, which uses only the price of labor as an explanatory variable, represents an attempt to reduce the process to as simple a device as possible while retaining reasonable accuracy over the historical period. Finally, after working with combinations of lagged variables, Model C emerged as the most descriptive model of the system interactions in the historical period. Most important, the form of Model C seemed stable in that coefficients of the variables stayed close to those found in Model C as other variables were added.

For purposes of projection, however, Models A, B and D were used since an equilibrium model seems less subject to statistical bias than a dynamic one. Model C would require anticipating not only relative prices, but also predicting a distributed lag over the projection period. Modeling for projections into the future, of course, also involves a combination of experience and judgment not apparent in other regression models. Table 16 shows energy projections through 1990, using three alternative models and a judgmentally adjusted projection. This table also shows the projections

TABLE 16

TIME SERIES PROJECTIONS
(1957-1959 = 1.00)

	FRB Index of Industrial Production	Price of Industrial Energy	Price of Capital	Price of Industrial Labor	Implicit GNP Price Deflator
1975	2.009	1.457	1.539	1.998	1.623
1980	2.457	1.859	1.851	2.549	1.881
1985	2.919	2.262	2.188	3.176	2.128
1990	3.418	2.669	2.549	3.957	2.408

Projections of Industrial Energy Demand (Quadrillion BTU's)

	Model A	Model B	Model D	Adjusted Projection
1975	20.99	20.85	21.83	23.10
1980	22.44	22.39	24.32	26.30
1985	23.61	23.60	26.49	29.07
1990	24.99	24.66	28.38	31.88

as well as time series estimates used in developing the energy figures. The data on energy demand were derived from U.S. Bureau of Mines figures. The implicit GNP price deflator was used as an overall price index, while the price of capital was approximated by the implicit price deflator for fixed non-residential investment. The energy price was developed from the annual Bureau of Census Survey of Manufactures, and the labor price was approximated by the average hourly gross earnings for all manufacturing per production worker.

The fact that all of the variables in the models reflect historical trends toward more efficient utilization of energy results in the models' forecasts of industrial energy demand being somewhat lower than the adjusted projection. When all of the evolving trends which argue for higher rates of industrial energy use in future years were considered, the adjusted case appeared more reasonable.

Examination of the signs of the models' coefficients reveals that demand for energy per unit of FRB would increase with an increase in the price of capital goods since there would be less pressure to substitute capital for energy. Conversely, price increases in energy and labor would result in capital substitution and decreased energy usage. Sharp increases in labor rates relative to other prices during the historical period caused a shift into production utilizing more capital equipment which is more efficient in terms of energy and labor use. This trend in the historical data has placed a downward bias on the model's energy projections and accounts for a major part of the difference between the energy projections generated by the models and the judgmentally adjusted projection (see Table 16).

The main conclusion from the analysis of the yearly time series data was an apparent point elasticity of approximately -0.4. This response in energy consumption to energy prices probably is a fairly accurate reflection of the relatively inelastic industrial energy demand over the short run.

Next, a cross-section study based on the 1963 Census of Manufactures was attempted to examine price elasticity on a state level. Since energy prices vary much more widely across states than when aggregated for the country, it was hoped that the cross-section study would yield something approaching a long-term price elasticity. Using a model similar to Model A, a regression was run which yielded an energy point elasticity of -1.1 with a standard error in the coefficient of 0.1. A one-tailed test on the coefficient would conclude that energy demand is relatively elastic at roughly an 84-percent level of confidence under conditions approximating long-run stability. In contrast, a similar test on the time series data used in Model A, B or C would indicate a relatively inelastic demand at the 99-percent level of each model. On a cautionary note, it should be pointed out that the cross-sectional analysis probably overstates elasticity measurements. A number of non-price factors affect industrial energy consumption in various states (e.g., proximity of a skilled labor force, tax structures, etc.) and it would be impossible to isolate their exact impacts. It does raise the possibility, however, that the demand for industrial energy may be elastic in the long run.

Many of the efficiency factors observed in the past have reached "maturity" and may be somewhat less important during the projection period. Examples are (a) decreasing opportunities to achieve additional economies of scale and (b) shifting towards purchased electricity from self-generation. There are also saturation levels beyond which the substitutions among energy, capital and labor are not tenable. When these limitations are combined with newly evolving trends towards less efficient application of energy--e.g., the use of energy for pollution control and the rapid growth of energy intensive industries--the net effect is a considerable moderation in the trend towards more efficient employment of industrial energy.

As a final consideration, it is necessary to assess the possible impact of energy costs on the demand for industrial products. Substantially higher energy costs would encourage the consumption of products of relatively low energy content. For example, wood products would gain relatively to plastics or aluminum. Since industrial commodities on balance have larger energy contents than most services, higher energy costs would also encourage the consumption of services relative to the purchase of goods. Both of these shifts in market preference would tend to decrease net energy requirements.

In summary, it is estimated that part of the historical trend toward more efficient consumption of industrial energy will continue in the future. Additional incentive for efficiency would be provided if the relative cost of energy were to rise significantly. The econometric model has indicated that industrial energy demand will be affected by several factors, especially by the prices of industrial labor and capital goods, in addition to the four major factors that were selected for sensitivity analysis. Other factors have been taken into account by the intermediate case even though they have not been given variant assumptions for high and low cases. One qualification should be noted regarding the reliability of econometric modeling as a device for measuring demand elasticity, based on past data. When end-use and price are regulated by government, a calculated price elasticity would not be reliable. Natural gas, in particular, has been under allocation to some degree for several years. This is one reason for working with total energy demand.

Table 7 in the Summary and Table 17 in this chapter show the Task Group's estimates of the *independent* effects of each of four parameters on industrial energy demand, assuming that the other parameters remain constant. The differences in demand *growth rates* between high and low cases are shown in Table 17, for the assumed ranges of each parameter, and the same variations are translated into quadrillion BTU's in Table 7. The consensus estimate of demand/price elasticity and other elasticities can be readily calculated from Table 17.

TABLE 17

INDUSTRIAL DEMAND SENSITIVITY (PERCENT) TO PARAMETRIC VARIATION

	Change in Energy Growth Rates From the Intermediate Case (Rate of 2.9 percent)	
Parametric Range	**1970-1980**	**1970-1985**
Economic Growth Rate (Real GNP) (Initial Appraisal = + 4.2%)		
+4.4%	+0.16	+0.16
+3.2%	-0.7	-0.7
Cost of Energy Trend — %/Yr. (Initial Appraisal — No Change)		
-0.3%/Yr.	0	+0.1
+2.7%/Yr.	-0.5	-0.6
Population Growth (Initial Appraisal = +1.1%/Yr.)		
+1.3%	+0.1	+0.1
+1.0%	-0.1	-0.1
Environmental Controls		
Higher Standards	+0.4	+0.5
Lower Standards	-0.2	-0.2

Transportation Energy Demand

The transportation sector has been a favorite target for schemes aimed at conserving energy. Most consumers are especially lavish in using energy for private transportation because they have large investments in their vehicles; therefore, the incremental cost per mile is small for automobile travel relative to mass transit. Furthermore, the private car generally is much more convenient. It is easy to point to fuel savings opportunities: "doubling-up" (two or three in a car rather than just the driver), walking, bicycling, using smaller cars, using mass transit and so forth. But it is more difficult to evaluate the corresponding losses to the economy and to consumer satisfaction.

Because of the fact that oil supplies approximately 95 percent of the energy used in the transportation sector, a special study of the many possibilities for economizing on fuel for transportation was made by the Oil Demand Task Group at the request of the Energy Demand Task Group.

The following were considered to be some of the more important possibilities for demand reduction:

- Shift passengers from private cars to buses
- Construct and rehabilitate rail mass transit facilities
- Increase automobile occupancy
- Increase fuel costs
- Tax private car production by weight or horsepower
- Partial ban on automobile traffic in central cities
- Higher tolls on bridges, tunnels and highways in central cities
- Improve automobile efficiency
- Improve freight distribution systems
- Raise load factors for air travel
- Introduce air flight scheduling efficiencies
- Modernize older airports.

The estimated range of reductions in transportation sector demand (as compared with the Initial Appraisal) developed by the Oil Demand Task Group are shown in Table 18.

The Energy Demand Task Group also considered all of these possibilities but felt that many of them would not be totally effective,

TABLE 18

POTENTIAL REDUCTIONS IN TRANSPORTATION SECTOR ENERGY DEMAND VERSUS INITIAL APPRAISAL PROJECTIONS

	Ranges*		
	1975	1980	1985
Increased Car Pooling			240/970
Smaller Cars	225/425	350/700	450/900
Fewer Cars per Capita			1,000/2,100
Less Driving			600/1,500
Increased Mass Transit	325/1,290	380/1,520	430/1,710
Improved Airline Schedules		85/175	120/240
Representative Range of Overall Reduction Achievable			**2,600/4,000**

* Thousand barrels per day equivalent.

practical or politically realistic, except under emergency conditions.

The only good empirical evidence on which to base opinions regarding fuel savings possibilities was the Nation's experience with gasoline rationing during World War II. This was an extreme emergency; nevertheless, the gasoline savings were not remarkable and they were partly the results of shortages of cars and tires and fuel distribution problems. In the low energy demand projection, however, the fuel savings that might result from larger proportions of small, economy cars on the road were taken into account in the efficiency improvement factor as well as small reductions in driving mileage.

For the peace-time conditions assumed by this energy study, the same four parameters were used for variance analysis of each component of the transportation sector.

In the first parametric analysis, fuel consumption (during an historical period) was correlated with appropriate economic growth series for each end-use market. The statistical relationships are shown in Table 19.

The regression coefficients in Table 19 were used for guidance in projecting demand sensitivities into the future but they were modified where there was evidence of bias or change in conditions. Perhaps the most significant adjustment was a reduction of the average highway coefficient from 0.75 to 0.50 in order to eliminate those influences that were believed to have biased the historical

TABLE 19

CORRELATIONS OF TRANSPORTATION ENERGY DEMAND WITH ECONOMIC GROWTH

End-Use	Economic Growth Series	Regression Coefficient*
Highway (Weight = 73%)		
Passenger Car Gasoline (51%)	Personal Disposable Income	0.85
Commercial Gasoline (13%)	FRB Index	0.29
Highway Diesel, etc. (9%)	Real GNP	0.85
Average Highway Use		**0.75**
Aviation Fuels (Weight = 18%)		
Aviation Gasoline (1%)	Personal Disposable Income	0.85
Naphtha Jet (1%)	No significant measure	0
Kerosine (16%) (Commercial Jet)	Personal Disposable Income	0.85
Average Aviation Use		**0.80**
Railroad Distillate (Weight = 3%)	Real GNP	0.40
Vessel Bunkers (Weight = 3%)	FRB Index	0.65
Pipeline Fuel (Weight = 3%)	Real GNP	0.30
Average Transportation (Weighted)		**0.7**

* Percentage change in demand associated with 1 percent change in economic growth.

relationship--influences such as the exceptionally large movement of population to the suburbs and the increased gasoline demand resulting from pollution control devices on cars. With such adjustments the total transportation demand/income elasticity was modified to about 0.5 percent for each 1 percent change in real income or real GNP.

The effects of fuel costs on transportation demand could not be measured statistically because fuel is a relatively small portion of total travel cost and there are many other weighty influences at work, such as location of home and job, vacation plans, type of car, etc. Gasoline and oil account for only about one-fourth of the total cost of owning and operating a car but this is an out-of-pocket and highly visible cost, so it probably contributes to an individual's decision regarding size and kind of car to be purchased even though it may not greatly affect mileage driven.

The parametric variation estimates of the cost (or price) effect, therefore, had to be based primarily on experience and judgment. It was felt that the accuracy was improved by studying the many components of the transportation market individually. In this way, the analyst could call on the expertise of marketers in each field.

The changing proportions of economy cars in the total car population is a factor of such importance that it could not be ignored. Since it is an efficiency factor, it was included in the "cost of energy-efficiency" parameter even though economy car sales are responsive to *total* driving costs as well as to fuel cost. Each Task Group member developed his own estimates of the numbers of economy cars on the road. Although concepts of "economy" or "small" cars differ considerably, the differences in numbers are generally offset by variances in unit consumption. The Oil Demand Task Group, for example, divided the 1970 car population into 13 million small cars and 77 million standard cars. In the Initial Appraisal, the 1985 car population would be made up of 50 million small cars and 90 million standards. The low demand case would have 70 million small cars and 70 million standards.

The use of "economy" and "standard" categories is merely a convenient way of dealing with a car population that, in fact, ranges continuously from the smallest compact to the heaviest luxury car. A similar result was obtained by using a broader definition for "economy" cars and a higher gallons-per-mile consumption for that category. According to this definition, there were 25 million economy cars and 65 million standards in 1970, consuming 500 and 770 gallons of gasoline per car per year respectively. For the intermediate case, these numbers increased to 60 million economy cars and 76 million standards in 1985. Under low demand case conditions, with sharply higher fuel and oil costs, expensive anti-pollution equipment and many other increases in driving costs, the number of economy cars on-the-road were estimated to rise to 80 million. This case would reduce the passenger car consumption growth rate by almost 0.5 percent per year, which is about the same as would be obtained using the other classification of cars.

Referring again to Table 19, it is apparent that a -0.5 percent point change in the growth rate for passenger car consumption is equivalent to a -0.25 percent change for total transportation energy. Improvements in automobile, aircraft and commercial vehicle efficiencies (as a result of higher costs) and minor reductions in mileage would increase these energy savings somewhat.

The independent effects of a change in the population growth assumption from Census Series D to C or E were not considered to be very large because children born during the 1970-1985 period would not reach driving age during the period. In several respects, this factor could have an impact. A higher birthrate, for example, tends to promote faster migration to the suburbs because of the need for more living space and suburban living is associated with more driving mileage.

It was felt that there was little possibility that anti-pollution regulations for transportation industries would become more lenient and reduce energy consumption significantly. (The term "more lenient" means relative to the Initial Appraisal projection.) In contrast, a wide variation is likely in the direction of more severe anti-pollution standards, since these standards have already been legislated. There was a considerable difference of opinion within the Task Group regarding the impact of more severe environmental controls on passenger car consumption of fuel. A study by one member, the findings of which are summarized in Table 11, concluded that the potential increase in automotive fuel consumption resulting from severe emission control standards would be offset by technological improvements in engine design. The other members were not so optimistic, as indicated by the Task Group consensus shown on Table 20 and Table 8 (page 20). Note that severe environmental standards (i.e., the high demand case) would increase transportation energy demand by 5.3 percent above the intermediate case in 1985, according to the consensus.

TABLE 20

TRANSPORTATION DEMAND SENSITIVITY (PERCENT) TO PARAMETRIC VARIATION

Parametric Range	Change in Energy Growth Rates From the Intermediate Case (Rate of 3.7 percent) 1970-1980	1970-1985
Economic Growth Rate (Real GNP)		
(Initial Appraisal = + 4.2%)		
+ 4.4%	+0.12	+0.1
+ 3.2%	-0.4	-0.4
Cost of Energy Trend – %/Yr.		
(Initial Appraisal – No Change)		
- 0.2%/Yr.	0	0
+ 1.5%/Yr.	-0.3	-0.4
Population Growth		
(Initial Appraisal = + 1.1%/Yr.)		
+ 1.3%	+0.1	+0.1
+ 1.0%	-0.1	-0.1
Environmental Controls		
Higher Standards	+0.3	+0.4
Lower Standards	-0.1	-0.1

Electric Utility Demand for Energy

The electric utility use of fuels and conversion losses will vary with the demand for electricity by the other sectors and with the utility heat rate. The Energy Demand Task Group Report (1972) discussed the outlook for these items under intermediate case assumptions, summarizing the projections as shown in Table 21.

The Task Group consensus on energy demand sensitivity in this (conversion and transmission loss) sector is shown on Table 22 and

TABLE 21

ELECTRIC UTILITIES' ENERGY INPUT AND KWH SALES
(In Trillion BTU Equivalents)

	(1) Electric Utility Input*	(2) Conversion and Other Losses†	(3) Electric Utility Sales‡	Sales by Sector: Residential and Commercial	Sales by Sector: Transportation	Sales by Sector: Industry and Other
1970	16,695	11,639	5,056	2,767	31	2,258
1975	23,525	16,234	7,291	4,094	43	3,154
1980	32,996	22,776	10,220	5,720	67	4,433
1985	44,363	30,162	14,201	7,830	117	6,254

* BTU content of fossil-fuel inputs plus hydro and nuclear power in fossil-fuel equivalents.

† Includes *all* line losses and utility use. In the Initial Appraisal (Volume II), the footnote to Table 1 erroneously stated that "conversion, transmission and distribution losses are shown under the electricity conversion category." In fact, the distribution losses are in the consumption figures for the individual consuming sectors. The transmission loss part of column (2) above varies from 3 percent to 5 percent. The somewhat erratic estimates of transmission losses resulted from the method used to assemble the figures. The projections by consuming sector are not on the same basis as the Bureau of Mines' historical data because the Bureau pro-rates both transmission and distribution losses to the consuming sectors. However, the Energy Demand Task Group Report of 1972 (Appendix C, Table 23) incorrectly interpreted the Bureau of Mines' historical data *by sector* to exclude transmission losses.

‡ The KWH sales converted at 100 percent efficiency, i.e., @ 3,412 BTU's per KWH.

TABLE 22

SENSITIVITY OF ENERGY USE FOR ELECTRICITY CONVERSION AND TRANSMISSION (PERCENT) TO PARAMETRIC VARIATION

Parametric Range	Change in Energy Growth Rates From the Intermediate Case (Rate of 6.6 percent): 1970-1980	1970-1985
Economic Growth Rate (Real GNP)		
(Initial Appraisal = + 4.2%/Yr.)		
+ 4.4%	+0.2	+0.2
+ 3.2%	-1.2	-1.2
Cost of Energy Trend — %/Yr.		
(Initial Appraisal — No Change)		
- 0.3%/Yr.	+0.1	+0.1
+ 2.7%/Yr.	-0.4	-0.7
Population Growth		
(Initial Appraisal = + 1.1%/Yr.)		
+ 1.3%	+0.1	+0.1
+ 1.0%	0	0
Environmental Controls		
Higher Standards	+0.4	+0.5
Lower Standards	-0.2	-0.2

Table 9 (page 23). This sector is estimated to be the most sensitive to the economic growth parameter--showing an elasticity slightly above unity. Since utility fuel requirements have expanded at a much faster rate than real GNP, despite a long-term declining trend in the heat rate, it is concluded that the difference is a result of the declining cost of electricity plus consumer propensity to use more power because of its convenience and the availability of many new appliances.

The elasticity of fuel consumption to cost of fuel is quite small up to 1980 but, for the longer term, the response to cost is estimated to become larger. The change would reflect the potential installation of new systems that would reduce the heat rate and transmission losses. Higher fuel costs are expected to accelerate such improvements.

Environmental controls are expected to add significantly to the energy requirements for electricity generating losses. Part of the additions would arise from desulfurizing fuels or cleaning stack emissions or controlling waste heat, and part would be a result of greater sales to customers. The latter type of increase is illustrated by Table 23 which shows the findings of an Edison Electric Institute 1971 survey to determine additional power requirements by utilities' industrial customers resulting from pollution control measures. The additional power requirements would fall in the industrial sector, but the generating losses would be in the electric conversion sector. These processes have been shown in greater detail in Table 11.

Non-Energy and Miscellaneous Markets

A projection of fuel consumption in this sector is shown in Table 24, in order to illustrate the relative importance of the various components.

In Table 24, the largest elements are the oil and gas components of the chemical sector and the oil component of the raw material total. These will be analyzed in some detail below. Other components are of less significance. Coal used in the chemical industry consists of by-products in the carbonization of coal at high temperatures in slot-type coke ovens. These by-products yield a number of chemicals or chemical mixtures, the most important being aromatics. Because of their by-product nature, the coal feedstock volume is unlikely to be responsive to price changes. It is projected to grow, like coal consumption, at less than the rate for energy as a whole. The natural gas component of the raw materials sector consists of gas used in manufacturing carbon black. This is projected to decline substantially due to declining gas availability and rising gas prices. Oil is a likely substitute. The unallocated oil component, in the absence of specification of end uses, is predicted to grow approximately with GNP, except for minor elements which are expected to continue at constant levels.

TABLE 23

FIRST RESULTS OF EDISON ELECTRIC INSTITUTE (EEI) SURVEY OF MEMBER COMPANIES ON ELECTRICAL REQUIREMENTS OF LARGE-USE CUSTOMERS FOR POLLUTION CONTROL AND ENVIRONMENTAL ENHANCEMENT

		Electricity Used for Environmental Improvement						
		1970		1972				
	Customers' 1970 Annual Use (000 KWH)	KW	(000) KWH	KW	(000) KWH	Major Environments Involved		Processes or Products Involved
	1839055	8800	21840	10300	23840	Air-Water		Paper
	2145740	13000	76700	49750E	205700E	Air-Water		
	137001	2015	7250	1880E	6650E	Air-Water		Chemical
	197720	3950	8400	6750	18000	Air-Water	Solid Waste	Primary Metals
	190192	20895	67952	21418E	70268E	Air-Water		
	3091351	37300	301800	55000	441800	Air-Water		Petroleum & Coal
	891340	NR	354920	NR	354920E	Air-Water	Landscape	
	113079	815	3022	862E	3062E	Air-Water		Stone, Clay & Glass
	4434451	100593	407392	141621E	710938E	Air-Water		
	1370232	12275	6000	65500	33000	Air-Water		Sewage Treatment
	1961300	27900	176850	51550	282800	Air-Water	Noise	
	219619	1795	7338	2320E	9403E	Air-Water		Fabricated Metals
	162260*	NR	NR	NR	NR	Air-Water		
	5273	NR	1265	NR	1265E	Air-Water		Food & Kindred
	NR*	NR	20000	NR	20000E	Air		Transportation
	1007307	6494	31090	19101	110196	Air-Water-Noise Visual		Electric Machinery
Total	**17603660**	**235832**	**1471819**	**426052**	**2271842**			Waste Recycle
			8.4%		12.9%			
								Ordnance
								Rubber Products
								Furniture & Fixtures
								Machinery Except Electric

* Not included in Total

Source: Responses to survey from 16 EEI Member Companies.

Note: In a sampling of EEI member companies, 85 different manufacturers which purchase electricity from 16 electric utility companies were fround to be using annually 1,471,819,000 KWH exclusively for pollution control or environmental enhancement. These KWH represent 8.4 percent of the total annual electrical requirements of these 85 customers. In the future, these customers expect to be using 2,271,842,000 KWH/year strictly for environmental considerations which would be 12.9 percent of their present annual electrical requirements.

TABLE 24

TOTAL U.S. CONSUMPTION
OF NON-ENERGY AND MISCELLANEOUS
(Trillion BTU's)

	1970	1975	1980	1985
Chemicals				
Oil	1,369	1,952	2,624	3,452
Natural Gas	880	1,240	1,576	1,945
Coal	157	174	192	212
Total	**2,406**	**3,366**	**4,392**	**5,609**
Raw Materials				
Oil	1,556	1,835	2,161	2,539
Natural Gas	89	72	52	26
Total	**1,645**	**1,907**	**2,213**	**2,565**
Unallocated				
Oil	567	723	799	852
Total Non-Energy and Miscellaneous	**4,618**	**5,996**	**7,404**	**9,026**

Petrochemical feedstocks, in accordance with current classification procedure, are defined to include feedstocks originating in gas processing plants (Natural gas liquids [NGL]) as well as in the petroleum industry proper. The type and quantity of product used for petrochemical feedstocks historically has been somewhat responsive to short-run changes in feedstock prices, with chemical companies shifting into and out of the ethane-propane market as costs have dictated. There is reason to expect that such responsiveness will continue. For example:

- Raw materials are a rising percentage of chemicals manufacturing costs due to (1) rapidly rising cost of light hydrocarbons (C_2-C_4), (2) greater economies of scale in processing and (3) the promise of improved technology (catalysts, etc.) which should reduce the capital costs of chemical manufacture.

- Since domestic chemicals are in price competition with imports, higher feedstock costs would tend to decrease chemical exports and increase imports. This in turn would directionally reduce domestic feedstock requirements.

- Petrochemical end-use products are, to a substantial extent, substitutes for materials like wood, glass, metal, etc.

- Higher feedstock costs might promote the recycling of chemicals, thus tending to lower feedstock requirements.

The supply/demand outlook implies a relative shift from light toward heavy feedstocks in the 1970-1985 period and a less rapid overall growth rate in feedstock demand as higher costs of feedstocks are reflected in higher prices and slower growth for end-use products, such as polyethylene and polypropylene.

The gas component of the chemicals sector consists of gas feedstocks for the production of ammonia (60 percent of the methane-derived chemicals) and a number of other chemicals, the most important of which are urea, methanol and acetylene. Since ammonia is used very largely in the production of fertilizers, increases in the price of gas feedstocks might be expected to hamper the growth in demand for fertilizers. Because of lack of suitable substitutes, however, price elasticity is likely to be low.

The last important component in the projection is the oil used for "raw materials." Almost 88 percent of this component is accounted for by lubricating oil and asphalt/road oil, the other significant items being wax (2 percent) and petroleum coke (10 percent) used primarily by the aluminum industry for electrodes.

Lubricating oils are produced from crude oil through complex refining sequences. Demand for lubes in the United States has been growing at about 2 percent per year. It appears to be relatively insensitive to price changes because of the lack of suitable substitutes. Synthetic lubes are used only in applications that require specific properties not available in crude based lubes and supply about 1 percent of the total lube demand. Raw material cost (crude oil) represents a relatively small part of the total cost of producing lubes. The major portion of the costs can be attributed to processing, additives, packaging and handling. As an example, only about 2 percent of the price a consumer pays to have a quart of motor oil put into his automobile can be attributed to the cost of crude to the refiner.

Review of past lube demand performance indicates that demand has been highly dependent on industrial output and automobile use. During one period (1951-1962), wholesale lube prices fluctuated plus and minus 25 percent about the average, while lube demand continued its gradual increase.

The conclusions reached here are that (1) demand for lubes is relatively inelastic when related to crude prices, (2) there is little substitutability for petroleum lubes due to their unique properties, and (3) there is a high correlation between lube demand and economic growth.

Asphalt demand has been growing at about 4 percent per year. In 1970, 79 percent of the asphalt used in the United States was used for road paving, 12 percent for roofing products and 9 percent for specialty products.

Based on 1972 prices, asphalt for road paving had little potential competition. Portland cement is the only other widely used road paving material, but cost comparison of asphalt and

Portland cement paving on a laid down basis in 1972 for a comparable road shows that asphalt would have to cost the road builder about two and a half times the 1972 cost before the paving costs would be equal. However, Portland cement is required by some highway construction codes. For certain applications, such as patching and resurfacing, paving asphalt has been used almost exclusively.

About 12 percent of the total cost of paving, resurfacing, and patching roads (excluding right-of-way, design and engineering, land clearing, and structure costs) could be attributed to the asphalt itself. Labor, equipment, sand, gravel, etc., comprise the remaining parts of the total cost. Most road paving is paid for by tax supported government agencies and, if it were assumed that these agencies are on fixed budgets, sharply higher costs for paving could result in less paving, e.g., a 100-percent increase in asphalt cost could lead to a 12-percent increase in paving costs and potentially an 11 percent lower demand for asphalt road paving.

Wood, slate, tile, aluminum, etc., in addition to asphalt, are used as roofing materials but are much more costly on an installed basis than asphalt roofing. Asphalt represents 30 to 50 percent of the cost of making asphalt roofing. However, when included in the total cost of building construction, the cost of the asphalt used in the roof is not large. Demand for roofing asphalt is closely tied to building construciton trends and probably will not vary significantly with changes in price.

The preceding conclusions on elasticities in the non-energy sector are fairly consistent with the Task Group consensus shown in Table 25. (The volume effects appeared in Table 10, page 25.) This composite illustrates that income (or GNP) elasticity is relatively high--i.e., almost unity--while demand-price elasticity is low. Little variability in this sector is expected to result from population changes during the next 15 years, and practically no impact is anticipated from environmental controls.

Effects of Changing Environmental Standards

Analyses of new programs designed to purify the Nation's air and water and dispose of solid wastes have indicated that such programs almost invariably require additional energy, at least in the early stages of development. Although there are estimates of dollar costs for improving the environment, there are no generally accepted estimates of the total impact on energy demand. Therefore, a first approximation of these energy requirements were developed under two different cases as shown in Table 11 on page 27. Note that the energy requirements in column (2) must be added to column (1) in order to obtain the case for more strict environmental standards.

It was noted previously that different trends in technology and consumer preference could modify several of the categories in this table, especially automobile emission controls, but the total picture is regarded as the best available.

TABLE 25

NON-ENERGY DEMAND SENSITIVITY (PERCENT) TO PARAMETRIC VARIATION

Parametric Range	Change in Energy Growth Rates From Initial Appraisal (Rate of 5.4 percent) 1970-1980	1970-1985
Economic Growth Rate (Real GNP)		
(Initial Appraisal = + 4.2%)		
+ 4.4%	+0.16	+0.16
+ 3.2%	-0.7	-0.7
Cost of Energy Trends — %/Yr.		
(Initial Appraisal — No Change)		
- 0.3%/Yr.	0	0
+ 2.7%/Yr.	-0.3	-0.3
Population Growth Rate		
(Initial Appraisal = + 1.1%/Yr.)		
+ 1.3%	+0.1	+0.1
+ 1.0%	-0.1	-0.1
Environmental Controls		
Higher Standards	0	0
Lower Standards	0	0

The energy requirements for sewage and solid waste treatment were particularly difficult to estimate. These were based on the waste disposal experience of several representative communities and cities, expanded to cover the estimated total population in the years 1980 and 1985. Consideration was given to EPA standards and possible improvements in waste disposal technology. In addition to the local experience, useful data were obtained from EPA hearings. The following references also were helpful:

- *Solid Waste Management*, U.S. Office of Science and Technology.
- *Technical-Economic Study of Solid Waste Disposal Needs and Practices*, U.S. Department of Health, Education and Welfare.
- *The Economics of Urban Sewage Disposal*, Paul B. Downing. This book includes a case study of the Madison, Wisconsin sewage system.

Chapter Two

DEMAND PROJECTIONS FROM 1985 to 2000

Although projections of energy demand 30 years in advance must be extremely speculative, they may provide a framework for policy determination based on broad assumptions relative to certain economic, political and technological events. Within this framework, the energy demand projection will appear as a range of possibilities, each differing in accordance with basic assumptions and implications. In order to provide a manageable set of conditions, the following broad assumptions were established for the period between 1972 and the year 2000: (1) there will be no major wars, worldwide depressions or other catastrophes; and (2) there will be no substantial interruptions in trade among nations, particularly with respect to the international flow of fuels.*

The following are areas of especially great uncertainty: new discoveries of oil and gas, uranium and other resources; technological breakthroughs, such as possible development of fast breeder reactors; economic growth; and political attitudes on environmental controls.

The Task Group continued to use the consensus of a "panel of experts" as the basic method for extending energy demand projections beyond 1985 to the year 2000. For this more distant timeframe, however, the influences of the causal factors are stated in qualitative terms, rather than quantitatively, because of the very speculative nature of the problem. The spread between high and low demand cases in the year 2000 was determined approximately by the range of the Task Group members' estimates. This method, of course, tends to narrow the range from high to low, relative to the method used for the 1970-1985 period. For this reason, the growth rates for the high and low projections were calculated for the entire 30-year period.

Prior to submitting projections, the panel members discussed the likely economic, social and political trends of the future and reached agreement on many background assumptions for the 1985-2000 period. Having assumed that there will be no catastrophes of the type that would be likely to raise the birthrate, the Task Group selected the U.S. Bureau of the Census' Series X as representative of demographic conditions between 1985 and 2000.† The assumptions

---

* The Arab oil embargo of 1973/1974, which occurred since completion of this study, may significantly affect the projections based on those assumptions; however, the long-term impact is still uncertain.

† Bureau of the Census, U.S. Department of Commerce, *Bureau of Census Population Series*, P-25, No. 480 (April 1972)--hereafter referred to as Census Series X.

behind this series are: (1) the future average number of children per 1,000 women at the end of their childbearing age will gradually decline to 2,110, which is the "replacement level;" and (2) net immigration will amount to 400,000 per year. The population forecast for the year 2000, based on these assumptions, is shown in Table 26.

TABLE 26

POPULATION PROJECTION TO THE YEAR 2000

	Population In Thousands	Average Annual Percent Change	
		Period	Percent
1960	180.7		
1965	194.2	1960-1965	1.4
1970	204.8	1965-1970	1.1
Projections			
1985 (Initial Appraisal)	240.2	1970-1985	1.1
2000	271.1	1985-2000	0.7

The population trend has special significance for energy demand projections to the year 2000 and beyond. In the intermediate case mentioned above, the average age of the population will be increasing relatively fast--it will increase from an average age of 27.9 in 1970 to 30.0 in 1985 and to 33.1 in the year 2000--and the age distribution of the population will change considerably, i.e., in 2000 there will be fewer people in the 0-24 age groups and many more people in the 30-59 age groups (relative to the 1970 pattern), as illustrated by Figure 1. It is significant that the age groups that are expanding rapidly are those that typically have higher incomes, higher skills (relative to the average) and usually are in the "head of household" category. Thus, the population of the year 2000 will have the characteristics of higher average age, higher levels of education and greater productivity. The estimated smaller size of family suggests that the Nation will spend relatively less on elementary education and more on higher education.

The average of the panel's estimates for economic growth (real GNP) is 3.7 percent per year for the entire 1970-2000 period, consisting of 4.2 percent for 1970-1985 and 3.2 percent on the average for 1985-2000. These represent the intermediate case. The individual estimates for the 30-year period ranged from 3.8 percent down to 3.5 percent.

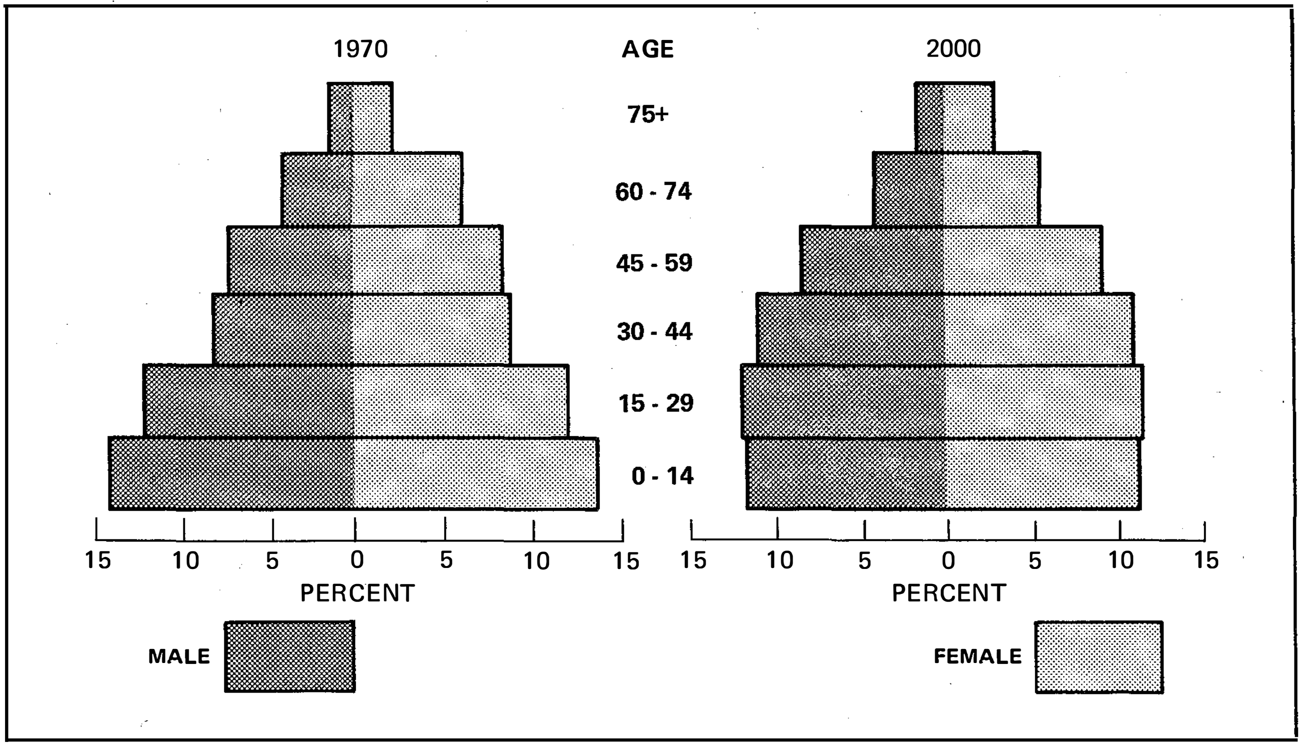

Figure 1. Percentage Distribution of the Population by Age and Sex.

The methods used by the individual panel members for projecting GNP were rather similar. Starting with the same demographic projection (i.e., Census Series X, with 400,000 per year imigration), the labor force participation rate was estimated. The latter, of course, is the result of conflicting trends such as growing participation by women, longer periods of education, earlier retirements, partial retirements, etc. During the 1985-2000 period, the labor force will probably increase somewhat faster than population. It was assumed that the unemployment ratio will be below the 1970 level, but this would make little difference over such a long time span.

Perhaps the factor with the greatest uncertainty in this calculation is the rate of productivity improvement. It is generally agreed that productivity in service industries is lower than in all industry and that services will grow more rapidly than other industries. There is considerable debate, however, regarding the outlook for productivity improvement in services. The estimates used here generally take a middle ground in this controversy.

The findings of the NPC Supply Task Groups show that the U.S. energy availability could range from almost complete domestic self-sufficiency to a very much greater dependence on Middle East oil. But their conclusions also clearly indicate that industry efforts to satisfy demand will become increasingly more difficult and costly. Therefore, the Energy Demand Task Group factored these cost considerations into its selection of high, low and intermediate cases.

Based on assumptions such as those described above, the total demand for energy was estimated to be 200 quadrillion BTU's in the year 2000, compared with 68 quadrillion in 1970. The round number for demand in 2000 is indicative of the degree of confidence; however, the variance is specified to range from a high of 215 quadrillion BTU's down to 170 in that year, as shown in Table 27 and Figure 2. The initial projections of the panel members were a

TABLE 27

PROJECTIONS OF TOTAL U.S. ENERGY CONSUMPTION

	Energy Consumption (Quadrillion BTU's) Actual 1970	2000	Growth Rate (Percent) 1970-2000
High Case		215	3.9
Intermediate Case	67.8	200	3.7
Low Case		170	3.1

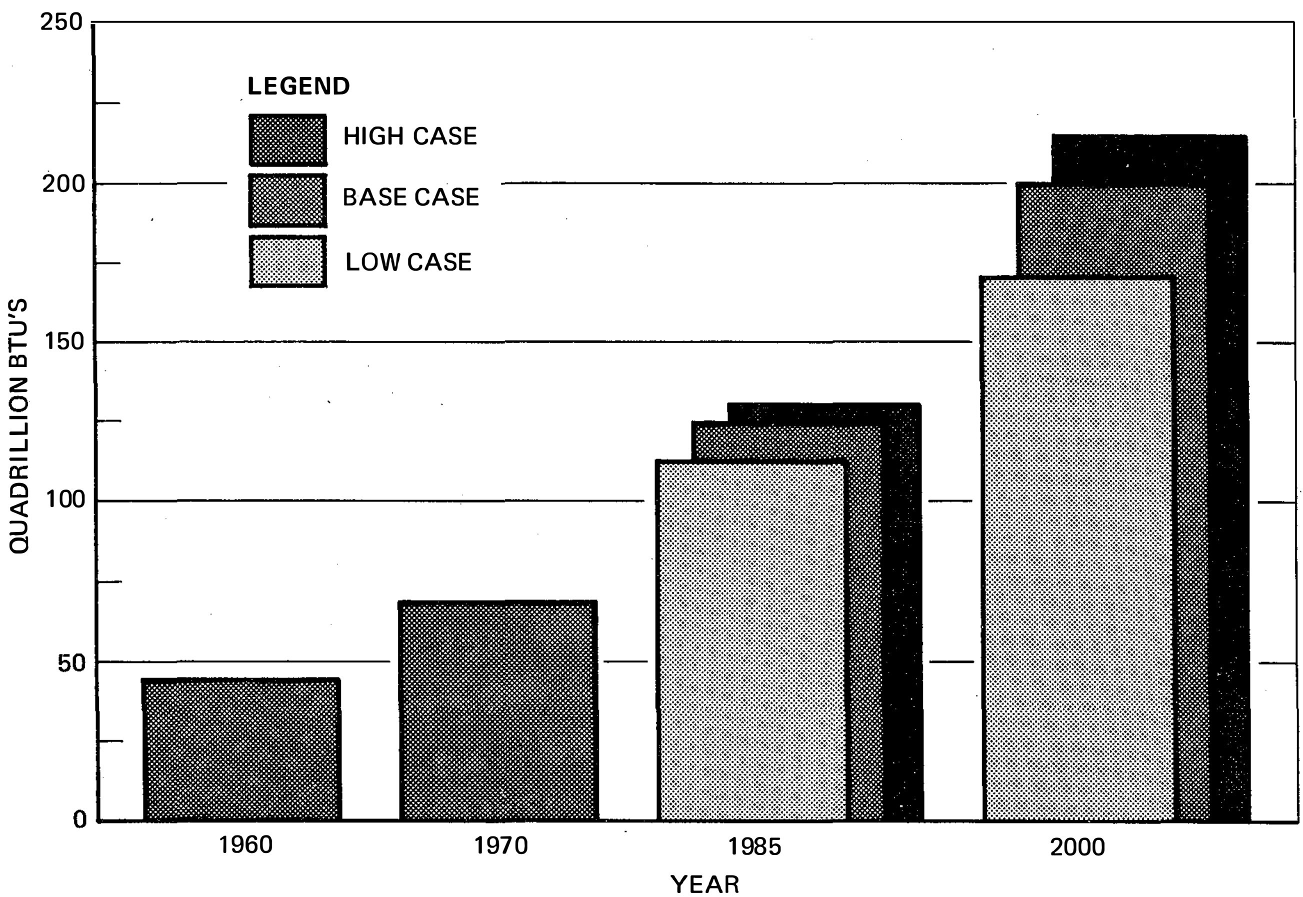

Figure 2. Total U.S. Energy Consumption Projection--Variations on the Base Case.

little higher than the final consensus figures but they became more pessimistic as the outlook for energy supply deteriorated. In this sense, the projections of consumption are supply-limited. As a consequence, a substantial improvement in efficiency of energy utilization is expected.

The breakdowns of the intermediate case projection by consuming sector appear in Table 28.

In describing the profile of the 1985-2000 period, several characteristics have already been discussed--e.g., the lower rate of population growth and smaller families, the slower economic growth, the more service-oriented economy, the higher cost of energy and improvement in efficiency of use. Increasing percentage of apartment dwellings and/or townhouses, smaller cars and greater use of mass transit are predicted.

TABLE 28

U.S. ENERGY CONSUMPTION ESTIMATES BY CONSUMING SECTOR — INTERMEDIATE CASE
(Quadrillion BTU's)

	Initial Appraisal		
Sector	**1970**	**1985**	**2000**
Residential/Commercial	15.8	26.6	36
Industrial	20.1	30.9	46
Transportation	16.3	28.3	38
Non-Energy & Miscellaneous	4.1	8.9	15
Electricity Conversion*	11.6	30.2	65
Total	**67.8**	**124.9**	**200**

Average Annual Percent Change in Total Energy Consumption

Sector	**1970-1985**	**1985-2000**	**1970-2000**
Residential/Commercial	3.6	2.0	2.8
Industrial	2.9	2.7	2.8
Transportation	3.7	2.0	2.9
Non-Energy & Miscellaneous	5.4	3.5	4.4
Electricity Conversion	6.6	5.2	5.9
Total	4.2	3.2	3.7

* This category is total generating and transmission losses. The actual consumption of electricity is included in the appropriate consuming sector, assuming 3,412 BTU's per kilowatt hour.

Another very significant development will be the emergence of electricity as the dominant form of energy. By the year 2000, energy requirements for electricity will account for almost half the primary fuels consumed *versus* one-third in 1985 and one-quarter in 1970. During the 1985-2000 period, the growth rate for electric utility fuel requirements is expected to average more than 5 percent per year, while other energy consumption will grow at less than 2 percent per year. This high rate of growth for electricity will be stimulated by economic factors (i.e., the costs of electricity generated in nuclear power stations are expected to increase at a slower rate than fossil-fuel costs) and by changing life-styles. Relatively more apartments and townhouses and greater population concentrations in the milder-climate areas will bolster electrical heating and air conditioning. A high degree of uncertainty is associated with the projections of electricity and fuels purchased by industry. One of the reasons for this is the possibility that nuclear power plants may develop the capability of supplying process heat economically.

The panel's average projections of electricity consumption in each major sector are shown in Table 29. The transportation outlook, of course, depends in part on the assumptions made regarding the number of electric cars in use.

TABLE 29

ELECTRICITY CONSUMPTION, BY MARKET SECTOR

	Trillion Kilowatt Hours		
	1985	**2000**	**Average Annual Percent Growth**
Residential/Commercial	2.30	5.23	5.7
Industrial	1.83	4.05	5.4
Transportation	0.04	0.16	9.7
Total	**4.17**	**9.44**	**5.8**

Appendices

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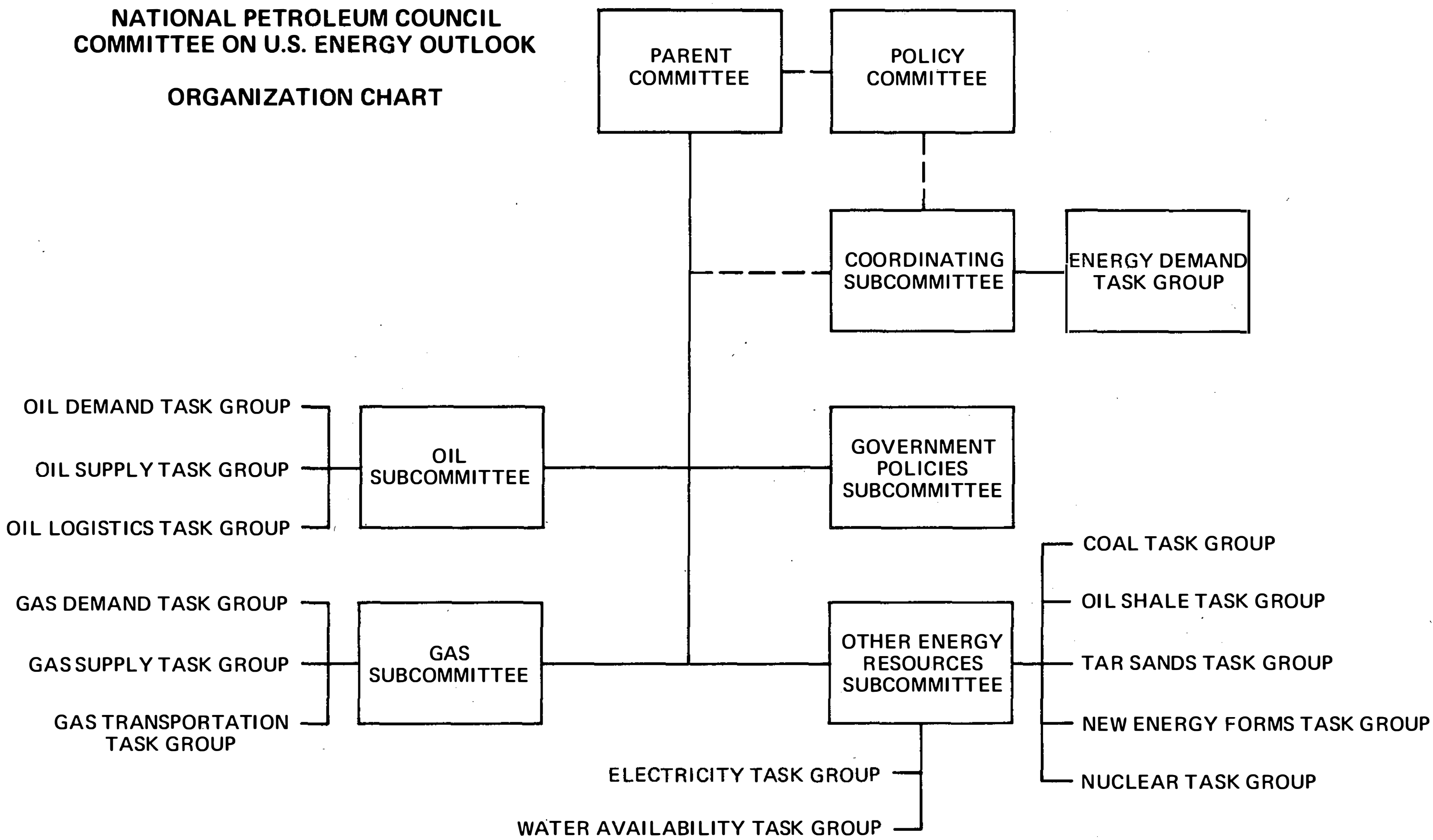

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PROBABLE ENERGY SAVINGS RESULTING FROM IMPROVED INSULATION AND HEATING PLANTS

The U.S. energy consumption trend, as projected in the National Petroleum Council's Initial Appraisal, assumed a gradual improvement in insulation of buildings and efficiency of heating plants. It did not anticipate a rapid upgrading of building standards, higher energy costs and other incentives to use energy more efficiently. The proposed improvements would contribute to the public health and comfort and would reduce energy consumption, relative to the intermediate case, without detracting from the Nation's commitments to economic growth, full employment and clean environment.

Very few reliable data are available relative to the overall conditions of existing structures, so conclusions must be drawn from a variety of estimates and theoretical calculations adjusted in accordance with expectations of public reaction to government policy and higher fuel costs.* Fairly precise calculations can be made regarding new buildings and dwelling units, but at any given time these new units represent only about 3 percent of the total in existence. Therefore, the impact of new building standards on energy consumption will show up mostly in long-term benefits.

Theoretically, a 50-percent savings of heating fuel could be obtained by full insulation of walls, ceilings, pipes and ducts, by weather stripping and double glazing--relative to the fuel consumption in a private home without these features. Additional savings could be made through better adjustments of burners and thermal controls. Although potential savings in apartments and commercial structures are less, they are still very significant. The existing buildings in this country, on the average, have added many of the abovementioned features but they have achieved far less than the full potential efficiency.

The maximum fuel savings are not likely to be achieved because most of the motivation will be financial, and it is estimated that maximum insulation would not be a rational choice for the average consumer, under the stated price assumptions. Even when capital expenditures to save fuel are worthwhile, consumers tend to delay because of inertia or lack of information. Furthermore, new buildings frequently are constructed for speculation and, in such

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* The following are useful sources for data on existing and new buildings: "Thermal Insulation for Buildings," a report prepared by Fredrick Olson for the Organization for Economic Cooperation and Development (*circa* 1970); studies by the Small Homes Council, University of Illinois (1965-1972); U.S. Census Studies of Housing (1960-1970).

cases, the builders are less likely to add expensive equipment in order to improve operating efficiency. Such roadblocks to achievement of the full efficiency potential are important in commercial and industrial construction, as well as in home building.

In addition to the fuel savings and greater comfort obtainable by insulation, significant efficiency improvements are possible through changes in building design, better heating/cooling systems and even by frequent adjustment of existing burners and controls. The architectural design of suburban schools, to mention one of the many examples of fuel waste, seems to place a low priority on thermal efficiency. Furthermore, operating efficiency could be greatly improved; for example, a case study of one school concluded that there was a possible fuel savings of 17 percent just through better thermostatic controls. The quantitative expression of these statements is summarized in Table 31 at the end of this Appendix.

HOUSING

The latest Census reports indicate that the total number of dwelling units in the United States increased during the last decade from 58 million to almost 68 million dwelling units, or a gain of 16 percent. From the standpoint of energy consumption, however, the breakdowns of these totals into types of dwelling units are especially significant. The breakdowns shown in Table 30

TABLE 30

U.S. HOUSING PATTERNS 1960-1970

Suburbs	**1960**	**1970**	**Change (Percent)**
Multi-Unit Dwellings	2,674,162	5,244,350	96.1
Single-Unit Dwellings	15,179,739	17,793,206	17.2
Mobile Homes	334,031	673,196	101.5
Central Cities			
Multi-Unit Dwellings	9,335,193	10,919,260	17.0
Single-Unit Dwellings	11,002,478	11,471,239	4.3
Mobile Homes	95,784	175,396	83.1
U.S. Total			
Multi-Unit Dwellings	13,789,663	18,859,968	36.8
Single-Unit Dwellings	43,758,556	46,900,548	7.2
Mobile Homes	766,565	1,847,326	141.0
Total	**58,314,784**	**67,607,842**	**15.9**

indicate that the largest gains in absolute numbers have been (1) in apartment dwellings and (2) in the suburbs. The percentage gains for mobile homes were very large but they are not so important in terms of numbers.

The trends during the next decade are expected to be rather similar. From the point of view of potential savings by insulation, Table 30 indicates several offsetting conditions. As a rule, single-unit dwellings have more potential for heat savings (relative to multi-unit) but in this case, the big growth in multi-unit dwellings has been in the suburbs where the garden apartment is the typical structure. Garden apartments tend to have heat losses approaching those of single-unit dwellings. Incidentally, mobile homes usually have extremely high heat losses and require much greater air-conditioning relative to size, so there are opportunities for energy savings in this category. The potential volume, however, is relatively small.

Although Table 30 does not indicate size and location--both of which have important effects on heat loss--it is known that there has been a shift of population toward the South where unit energy consumption is not quite as high. In the 1960-1970 period, the dwelling units became somewhat larger. Currently, however, there are clear indications that new dwelling units are becoming smaller on the average, adapting to the smaller size of families. In the Initial Appraisal, it was assumed that the latter trend would continue under the conditions of the Census Series D population projections. Furthermore, it was expected that about 50 percent of the new dwellings would be in multi-dwelling structures.

QUANTITATIVE ESTIMATES

It is impossible to accurately measure the average improvement in heating/cooling efficiency that has taken place in the Nation's stock of buildings, but reasonable "order of magnitude" calculations can be made. Our best estimate indicates that the fuel consumption growth rate in this sector probably was reduced by about 0.5 percent per year during the past two decades as a result of insulation and other efficiency improvements, and a similar trend was included in the energy demand projection for the Initial Appraisal in the residential/commercial sector. The following paragraphs attempt to evaluate the magnitude of additional energy savings that could be achieved in a lower demand case.

For the existing structures during the 1970-1985 period, it is estimated that there would be additional potential savings of about 10 percent of heating/cooling energy, or about 0.7 percent per year on the average, by using more insulation, storm windows and doors, weather stripping, etc., in homes and commercial and public buildings, on the assumption that real energy costs to consumers would increase.

It was further concluded that *new* buildings could be designed to consume 20 percent less energy than was assumed for the Initial Appraisal--premised on higher costs for energy. These estimates are very similar of the potential savings that the OECD study calculated for Europe. The greater efficiency of new buildings would be slow to show an impact on the energy market because the number of new units added each year equal only about 3 percent of the total number in existence. Thus, the annual effect of improving new structures would be a reduction of heating/cooling energy growth rate by 0.6 percent per year. The estimated potential energy reduction at the end of 15 years as a result of improving both existing and new structures would be nearly 20 percent of the heating/cooling demand, or about 1.3 percent annually. (Incidentally, the long-term demand elasticity for this factor might operate over a period of 30 or 35 years in order to replace all existing structures.) However, it is doubtful that a substantial improvement in the efficiency of new buildings has begun (in 1972) or will begin for several more years.

In addition to the measures discussed in the preceding paragraphs, there are large potential savings by means of improvements in current heating and cooling systems as well as more efficient heating/cooling systems in new buildings through improved technology, given adequate incentives. Such savings by improved equipment and systems are estimated at 0.5 percent per year.

TABLE 31

ENERGY CONSERVATION RESULTING FROM GRADUAL INCREASES IN ENERGY COSTS IN THE RESIDENTIAL/COMMERCIAL SECTOR (PERCENT)

	Estimated Potential Reduction	Low-Case Consensus
Demand Growth Rate Reduction Versus Intermediate Case for Heating/Cooling Only		
Insulation Etc.		
Old Buildings	0.7	
New Buildings	0.6	
Improved Systems	0.5	
Total Heating/Cooling Reductions	**1.8**	
Effect on Total Residential/Commercial Growth Rate of 3.6 percent		
(i.e., 1.8 multiplied by 67 percent)	1.2	0.6
Intermediate Case Energy Savings		
Annual Percent Residential/Commercial	0.5	0.5
Total Annual Savings — Residential/Commercial	**1.7**	**1.1**

Since heating/cooling usage is approximately 67 percent of the total residential/commercial energy consumption, the maximum response to gradual cost increases in this sector would be a reduction in the energy/demand growth rate of 0.67 times 1.3 percent + 0.5 percent, or 1.2 percent per year, including minor effects in water heating, lighting, etc. The Task Group consensus expected a lesser response for various reasons. According to the consensus, an increase in the cost of energy to residential/commercial consumers over the next 15 years totalling 25 percent, or 1.5 percent per year, would stimulate efficiency improvements that would reduce demand by 0.6 percent per year, relative to the intermediate case. This elasticity relationship was used for the low energy demand case (see Table 31) which summarizes the findings discussed above.

The demand variance (in this sector) associated with the high case is estimated to be much smaller or non-existent. Not only is the assumed price deviation considerably smaller, but also the elasticity to price reductions probably is less. After a long history of improving standards for insulation and other building specifications, the public is not likely to become more wasteful of energy especially while the Federal Government is upgrading its standards.

APPENDIX E

AN ECONOMETRIC MODEL OF RESIDENTIAL DEMAND

In compiling its parametric studies of demand, the Energy Demand Task Group has attempted to analyze the effects of price on energy demand, especially since the effect of price is of considerable importance in an era of impending energy shortages. This analysis looks specifically at residential energy demand with the view of estimating price elasticity of all energy forms used in the household.

Some exception may be taken to the fact that demand for electrical energy for other than home heating purposes is lumped into total demand for all household uses, the other major component being home heating. It could be argued, and probably correctly so, that consumer preferences for home appliance electricity are likely to have entirely different characteristics from preferences for home heating.

Given the scope of the Task Group's effort, which included separate analyses of the four major energy demand sectors--residential/commercial, industrial, transportation, and utilities--and the relatively small amount of time allocated for each, econometric modeling had to be suitably tailored to the broader, more immediate needs of the Task Group's effort.

This model of residential energy demand does not attempt to discriminate between households' relative preferences among energy uses, nor among their possible preferences for energy forms (with the exception of coal). Rather than beginning with a more general specification of a consumption function and budget constraint, quantity demanded is simply deemed to be a linear function of several independent variables which would be logical candidates for inclusion in a more rigorously developed household preference function.

This Appendix is organized in the following manner: Section I reviews the results of the demand model and some of the implications of these results, Section II provides a more detailed explanation of the model itself, while Section III concludes with suggestions for further research.

SECTION I--A BRIEF SUMMARY OF THE DEMAND MODEL AND A SUMMARY OF RESULTS

The primary aim of this study is to provide some basis for estimating price elasticity. The model is relatively effective in achieving this purpose. The demand for energy in the residential sector on a per household basis was found to be inelastic at current prices, but for prices 50 percent higher, the demand curve approaches unitary elasticity.

The demand equation was estimated using the two-stage least squares technique. In its final form, quantity demanded (in terms of hundreds of BTU's per household) was hypothesized to be a linear function of price, the ratio of fuel burners to coal stokers, degree days, and two dummy variables: one for the war years, the other for years of rapid inflation. The homogeneous product includes contributions of oil, natural gas and electricity, but excluded coal. The period of the study covers 36 years--1935 to 1970.

The hypotheses relating to each variable are briefly indicated here.

Price: The inverse relationship between quantity demanded and price is, of course, the demand function. It is expected that as prices fall, quantity demanded will increase, other things being equal, and vice versa.

As is often the case, the most readily (if not the only) available data is in terms of average prices, although it is marginal prices which would represent the proper behavioral variable. That marginal and average prices are not the same in this market is quite clear from the prevalence of the block rate pricing structure, where the supply price falls by discrete steps over larger and larger quantities. The question of suitability of average price is basically a behavioral one, relating to the information easily available (and used) by the consumer.

In general, it is probably fair to say that consumers' attitudes are much more likely to be affected by information appearing on their fuel and electricity bills, and this information is most readily translated into average prices.

The calculation of energy price consisted of converting fossil fuels and electricity into BTU's and dividing this total annual figure into total revenues of gas and electric utilities plus revenues from sales of fuel oil and distillate for each year of the period covered in the study. This information is readily available in the American Gas Association's *Gas Facts*, the Edison Electric Institute's *Statistical Yearbook* and the Interior Department's *Mineral Yearbook*. Real prices were then found by deflating the series by the consumer price index.

The price series which resulted indicates the strong down-trend of energy prices relative to the general consumer price index. Over the period encompassed in the study, real prices paid by households dropped by roughly 75 percent. Where the general inflationary trend was low, as in the decade of the 1950's, the real price of energy was relatively stable, dropping by 8 percent. In the 1960's, however, with the high inflationary rate experienced during the latter half, energy prices dropped by 28 percent.

Real Disposable Income per Household: The expected relationship here is positive: as real income increases, households would be likely to increase their consumption of energy. Particularly, with the great increase in consumer durables over the period of the study one would expect these intensive energy users to strongly influence consumption via the income link.

Ratio of Fuel Burners to Coal Stokers: This variable consists of a ratio by the average stock of oil and gas burners to coal stokers in use during a given year. The systems under consideration are for domestic use and for automatic central heating. The relationship between quantity demanded and this variable is likely to have two effects. First, to the extent that oil and gas systems were more efficient than coal stoking systems, an increase in the ratio should result in decreased quantity demanded. Second, however, the historical increase could reflect consumers' preferences for oil and gas systems over the coal stokers which were more difficult and laborious to operate and certainly less clean. In addition, the shift to non-coal-fired heating systems should reflect a changing price ratio between coal and other alternative energy forms.

The purpose, in fact, for including this variable was, primarily, to account for shifts in the non-coal energy demand curve due to the movement away from coal usage to alternative energy forms in the residential market. Normally, one would consider using a price relative directly; i.e., the ratio of non-coal energy price to coal price to account for product substitution effects, rather than accounting for it indirectly by the burner ratio. Such a price relative was computed and tested, but its inner correlation with energy price was so high that little could be concluded about its independent explanatory power. Use of the burners to coal stoker ratio reduced this inner correlation, yet reflected the effects of changing relative prices. Since coal prices rose relative to non-coal energy prices, the effects of the shift in tastes and the increasing price relative together constituted a positive influence on quantity consumed and was considered likely to override the inverse efficiency effects.

Degree Days: This variable accounts for yearly fluctations in weather. The measurement of weather is asymmetrical since it measures intensities of coldness rather than warmth. Given the period of the study and the nature of the product being analyzed, this asymmetry does not constitute a problem. Degree day variables constituted a weighted average where the populations of six major cities provided the weights. The expected relationship to energy consumption is positive.

First Dummy Variable--the War Years: The period from which data is gathered for this study extends through the war years of 1941 to 1945. During these abnormal years the prices for many products, including energy products, did not adequately reflect relative scarcities. This was due to wartime controls which dictated or at least constrained resource usage to assure that priorities were met. Since it would be unrealistic to treat the wartime relationship between prices and the other independent variables and quantity consumed on a par with the observed relationship during more normal times, the econometric technique of using a dummy variable is employed.

It would be expected that wartime priorities for energy would tend to decrease consumption in the residential sector. That is, for a given level of income, prices, degree days and distribution of types of heating units, quantity consumed would be less than in normal times. Thus, the sign of the estimated coefficient should be negative, reflecting this inverse relationship.

Second Dummy Variable--Inflationary Periods: During the 1958-1970 period, the price of energy in current terms rose about 15 percent. In that same period, however, the real price declined by 14 percent. Energy to the residential sector, supplied in large part by regulated utilities with monopoly positions in the markets they serve, tends to have widely publicized prices. It may well be the case that consumers react not so much to the real price of energy, but to its more publicized current price. This implies a sort of money illusion (commonly associated with wages) in the energy market, which we call the "current price effect."

To be more specific, suppose there were a sharp upward change in the consumer price index; that is, the price of goods in general rises, while the current price of energy remains relatively constant. The result would be a decrease in the real price of energy. Our hypothesis states that consumers are slow to react to the change in relative prices and thus maintain approximately the same level of energy consumption as in the previous period.

The result of this behavior with respect to the demand curve, for example, is a set of price-quantity points lying below and to the left of the demand curve reflecting real prices. The slope of the curve connecting these points is negative (the sign on the coefficient of this dummy variable should thus be negative) and hypothesized to be the same value as the slope of the demand curve reflecting real prices.

To capture the current price effect, those years in which the consumer price index rose by 5 points or more were singled out and given a value of one. Other years were given a zero value. It was felt that the current price effect on energy consumption would most likely be present in years of sharp upward changes in the general consumer price level.

This completes a brief enumeration of the variables used on the demand side and the hypotheses associated with their incorporation in the model. The second stage of the two-stage least squares process was estimated in the following form:

$$Q_D = B_0 + B_1 P + B_2 Y + B_3 H + B_4 D + B_5 W + B_6 I,$$

where P = price estimated in the first stage

Y = real disposable income per household

H = non-coal to coal-fired heating systems

D = degree days as a population-based weighted average

W = dummy variable for the war years

I = dummy variable for the current price effect

Q_D = quantity demanded in hundred of BTU's per household.

The values of the estimated coefficients, B_i i = 0, . . . 6, and their associated t- statistics are:

	Coefficient	t - Statistic
B_0	1026100.0	----
B_1	-6445450.0	-19.6
B_2	-21.8	- 2.1
B_3	5978.8	17.5
B_4	193.7	4.3
B_5	- 197375.0	- 5.1
B_6	- 258991.0	- 8.8

The regression coefficient (R^2) was .98, the F-test 367.6, while the Durbin-Watson test statistic was 1.34. In summary, the model appears highly reliable with the exception of the clouds cast by the Durbin-Watson, and these may be significant clouds.

All but one of the signs conforms to expectations, but the exception is a puzzler, since the unexpected sign comes on B_2, the estimated coefficient of the income variable. The relationship between quantity demanded and income is indicated as inverse. Further, the coefficient is significant at the 5-percent level, although it is statistically less significant than any of the other estimated coefficients. Beta coefficients, which give indications of relative explanatory power of the variables, were derived and it was found that income ranked lowest among the variables tested. (The ranking of the other variables from highest explanatory power on down were: (1) price, (2) ratio of coal to non-coal heating units, (3) current price effect, (4) war years and (5) degree days.)

In Section II a plausible explanation for the income relationship is offered. The explanation itself leads to concrete suggestions for further study and the structuring of alternative models.

The principal purpose for this study was the derivation of price elasticity estimates. At 1970 levels of the exogeneous demand variables (the last and most current year of the data period), price elasticity in terms of 1970 real prices was -.46, while at a price 20 percent higher, elasticity was -.62. At a price approximately 50 percent higher than current real prices elasticity was -.91. These results show that while the demand curve is inelastic in the range of current real prices, it is perhaps not as inelastic as was expected. In the price range 50 percent higher than current real prices the demand curve is nearing unitary elasticity. Such a level of price increase is probably not outside a "tolerable" range--the quotation marks indicating extra-economic connotations.

It should be noted that the figure of -.46 is corroborated by a similar study, described in Appendix F, which covered a period from 1950 to 1970.

SECTION II: CONSTRUCTION OF THE DEMAND MODEL

As previously stated, the demand model was estimated in the second state of the two-stage least squares technique. The technique is required because, in effect, both the supply and demand equations must be estimated. Historical price and output data denote intersections of supply and demand schedules. By estimating both supply and demand, we can account for the simultaneous solution of price and quantity, which historical data reflects, caused by shifts of both the supply and demand curves.

The procedure involves regressing one of the endogenous variables (price) on all exogenous variables in order to obtain an estimated price. It was found that the exogenous variables explained approximately 90 percent of observed price movements. In the second stage, quantity demanded and supplied is regressed on the appropriate exogenous variables plus the estimated price obtained from the first stage.

Variables included on the demand side have already been discussed. Those on the supply side include:

G = change in average gasoline price

I_t = current end of period inventories of distillate and residual oil

I_{t-1} = previous period's end of year inventories of distillate and residual oil

C = electrical utility generating capacity

L = natural gas pipelines

S_{t-1} = natural gas reserves in the previous period

T = pounds of coal per kilowatt hour, an indicator of technological change

X = dummy variable indicating sharp increases in Texas shut-down days

Y = dummy variable indicating years of sharp decreases in Texas shut-down days

P = estimated price.

Analysis of the supply side of the model is only in the first stages. The very high R^2 and F-test scores (.99 and 1247.6, respectively) are viewed with some skepticism and further tests for autocorrelation are in order. At this time it will be sufficient to indicate which variables appear to play a significant role in determining supply.

Variables significant at the 5-percent level include change in gasoline prices, electrical generating capacity, natural gas pipelines, and pounds of coal per kilowatt hour, the indicator of technological improvement. The price variable was not significant at the 5-percent level, but was at the 20-percent level. The signs of the coefficients on the supply side were perplexing in several cases. Since the purpose of this study is chiefly concerned with the demand side, little will be gained by a lengthy analysis of the supply side. What is important for our purposes is that exogenous variables on the supply side contributed significantly to the derivation of estimated price.

These statements should not be interpreted as attempting to bypass some of the thorny problems raised by supply factors. This area is highly complex and in dealing with the aggregate energy market the possibility of generating definitively testable hypotheses is probably quite remote. This issue, in part, gives rise to the suggestion in the final section that further study be conducted in the context of more limited product areas. At the very least, electricity and fossil fuels should be handled separately.

Returning to the demand side, suggestive explanations are in order to account for the negative coefficient on the income variable. In hypothesizing the determinants of energy demand in the residential sector several possibilities come to mind. Such variables as family size, demographic movement of all kinds, preferences for types of housing, as well as income and the other variables tested were all potential candidates for inclusion in the model. It was felt that the first three candidates mentioned above were probably, in one way or another, highly correlated with income and, since income was an easy statistic to obtain, we decided to use this encompassing variable to the exclusion of the others.

Such an approach is particularly justifiable when our particular interest lies in some other variable--in this case, price. On the other hand, it is a less advantageous procedure if it is expected that forecasts will rely heavily on the excluded variables.

The negative sign of the income coefficient is hard to believe, particularly in light of the great increase in electricity-using appliances afforded by growing family income. This is less of a consideration when one observes the relative contribution of electrical BTU's to total BTU's in the residential sector. Electrical BTU's were, in each year of the period covered, much smaller than the BTU constributions from fossil fuel sources. The relationship between income and BTU's, therefore, is going to reflect the relationship of fossil-fuel sources far more strongly than the electricity element.

Although it seems quite likely that a positive relationship exists between income and electrical BTU consumption, what are some possible overriding relationships between income and fossil-fuel consumption which are implicit in the time series data?

The period covered by the data is extensive and encompasses a time of considerable social and economic change. Large redistributions of the population took place through migrations to warmer climates. In addition, the quality of residential housing in general improved, incorporating better insulation and other energy saving characteristics. There was also a strong movement, particularly during the 1960's, into apartment houses. Apartments, on the whole, are considered to be more efficient users of energy per energy customer.

These trends, strongly correlated with income in some cases and all likely to affect residential consumption inversely, could easily be reflected in the negative coefficient of income. This analysis indicates, therefore, that such variables should be investigated independently in the demand equation. Our purpose, however, was to draw some conclusions on price elasticity which we believe can be done on the basis of the model tested.

CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The model was constructed for the purpose of determining the elasticity of total energy demand in the residential sector on a per household basis. Whereas this objective was essentially accomplished, the model's usefulness as a forecasting tool is extremely limited. The reason for this is that one of the most significant variables--the ratio of coal stokers to total burners--is not going to be very relevant in the future.

In addition to this, the demand curve for energy in the future is going to reflect changing usage of electricity. Over the period covered, electricity was used primarily for lighting and the operation of appliances. In the future, electricity is likely to become a competitor in the space heat market. Generally, this sort of competition was minimal during the period of the study. The future demand curve for space heat may be affected by the incursion of electricity into this market. On an input basis, electricity in the home is much more costly per BTU than fossil fuels. It has been argued, however, that this cost does not reflect the true differential between these alternative energy sources. Electrical heat operates on a resistance basis at nearly 100-percent efficiency. Fossil fuels, on the other hand, are subject to considerable BTU loss as the generated heat passes through ducts to the areas to be heated and through the stacks. Thus, the real cost of these fuels is greater by the amount of this sort of wastage.

Even considering the efficiency factor, however, electrical heating will be more expensive; therefore, any major increase of it would reflect a definite relative preference on the part of consumers and space heat demand on the whole would thus be less price elastic.

By and large, the significance of this study lies in the various guides developed for further modeling. In the future the data should cover shorter and more recent periods and should be sufficiently cross-sectional to allow adequate degrees of freedom. Separate models should be constructed for fossil fuels and electricity. Demand functions should include variables indicating demographic and life-style changes. Models constructed on this more disaggregated basis will be more effective than the encompassing model presented here; they may be difficult to specify, but interpretation of results will be far more concrete.

APPENDIX F

ESTIMATING ELASTICITY IN THE RESIDENTIAL ENERGY MARKET: AN ECONOMETRIC APPROACH

The purpose of this Appendix is to provide an estimate of the elasticity of demand for fossil fuels in the overall market for residential/commercial energy. The conclusion may be stated briefly: The price elasticity of demand in 1970 produced a coefficient of -0.49--i.e., approximately one-half of one percent demand response to a 1-percent change in real price.

PROCEDURE

In attempting to measure the elasticity of demand, a linear system of equations was formulated to describe the market response of both supply and demand to price. A properly specified simultaneous system avoids the problems of identification, as from a single equation model, which may produce a function that is neither supply nor demand.

The method of estimation was two-stage least squares, which generates consistent estimates of both price and quantity. This procedure allows one to operate under the classical assumption of the dual causality of the price-quantity relationship. It is usually assumed that the determinants of quantity in the market are the same determinants of price. This is accomplished by estimating price in the first stage against the exogenous variables in the system, and replacing it as an instrumental variable in the structural form of the model. Not only is the system then consistent, but the reduced form equation allows some insight into the specification of price at equilibrium. This is a general characteristic of reduced form equations with respect to endogenous variables.

THE MODEL

Specification of the demand model is made in terms of the following variables:

Price: An average price (rather than marginal) was derived by weighting average prices of coal, fuel oil and gas by their respective consumption each year. This series is then deflated by the Consumer Price Index, and stated as price per 10^8 BTU's. One would expect an inverse relationship between prices and quantity in the demand function.

Income per Household: Income in hundreds of 1958 dollars, adjusted by the number of household units. The expected relationship is positive.

Heating Degree Days: A measure of the variation from normal temperatures during the heating season. Positive variation is interpreted as colder than normal, and the expected sign here is positive.

Consumption of BTU's per Heating Unit: A ratio of residential/commercial fossil-fuel consumption (in BTU's) to heating equipment in existence. Over time, efficiency gains (for numerous reasons) have lowered the BTU consumption per unit, and consequently the physical requirement for space heat. This is interpreted as a declining operating cost per unit of heating equipment. Increases in efficiency of a given stock of equipment might be expected to lower the demand for fuel in the short run, but in the longer run it may lead to lower costs which would stimulate demand.

Dummy Variable: Occasional shifts in demand are best explained by above-normal shifts into electricity. A dummy variable of 1.0 is inserted for those years, 0.0 for all others. The expected effect of this shift on fossil fuel demand is negative.

The results of the demand equation in general form were as follows:

$$\underset{}{Qd} = 126.1 - \underset{(-4.07)}{.789\ P} + \underset{(5.65)}{1.099\ Yh} + \underset{(5.20)}{.133\ DD} - \underset{(-3.17)}{.488\ C} - \underset{(2.99)}{2.522\ Du}$$

$R^2 = .99$ F-test = 402.45
Durbin-Watson Statistic = 2.02

Where:

Qd = quantity demanded 10^{14}, BTU's in fossil fuels
P = price estimate
Yh = income per household
DD = heating degree days
C = consumption of BTU's per heating unit
Du = dummy variable for inter-fuel shifts

The numbers appearing in parentheses are the student - t tests, the significance of the variation of a particular variable in explaining the variation in the dependent variable. The R^2 of .99 and the F - test which is the ratio of explained to unexplained variance, all indicate a reliable model for the demand side. The Durbin-Watson statistic is in the range which allows one to reject the hypothesis of positive autocorrelation. It seems the specification as computed for demand performs exceedingly well.

The signs of the variables in the demand equation all conformed to expectations. In terms of demand sensitivity, the following order was observed (from highest to lowest): (1) income per household, (2) price, (3) efficiency of heating units, (4) dummy variable and (5) variations in weather.

The model for the demand side generated an elasticity of demand at constant dollar 1970 prices of -0.49, and a like coefficient of -0.78 at prices fifty percent higher. Elasticity considerations beyond this exceed the relevant range of the price data, and are, therefore, extremely hazardous.

The time series covers annual data from 1951 to 1970 inclusive. While a few more data points might have been included, it is felt that more recent observations are more valid, given the structural shifts in the immediate post-World War II economy.

While it is not the purpose of this Appendix to discuss supply, the procedure and test results will be covered briefly.

The variables on the supply side included:

Price: estimated average price per 10^8 BTU's

Refinery Capacity Utilization: operating capacity of U.S. refineries as a percent of total capacity

Reserves of Gas: in millions of cubic feet, at the end of the previous year

Nelson Index of Refining Operating Costs: average for U.S. refineries

Dummy Variable: for inter-fuel shifts.

Using the above specification, all variables proved to be significant at the 5 percent level. The R^2 was .98 while the F - test was 198.4. The Durbin-Watson statistic was 1.86, again allowing one to reject positive autocorrelation. While the supply function does not adequately account for competing fuels, it does provide an approximation which identifies the position of the demand curve--the basic concern here.

The signs appear to be correct, including the negative sign on price. This was expected, given the regulation of gas prices at the wellhead. Regulated prices have not kept pace with prices in general, and gas consumption has played an increasingly important role in determining weighted average prices in this market. Consequently, increasing quantities of fossil fuel at lower real prices were not surprising, particularly while gas was plentiful.

Some concern has been expressed over the use of both the Nelson Index of refinery operating costs and refinery capacity utilization in the same equation. Though one might hypothesize collinearity between these variables, statistical tests do not bear out this relationship. Rather, a high partial correlation coefficient exists between total refinery capacity (not just utilization) and the Nelson Index. In fact, the coefficient for the Nelson Index and refinery capacity utilization was only -0.49, while total capacity and the Nelson Index were correlated by 0.84. Variations in operating cost would appear to be dictated more by the total amount of capacity rather than the amount utilized at a particular point.

CONCLUSION

The purpose of this Appendix has been to provide an initial estimate of price elasticity using readily accessible data, such as that available through the API's *Petroleum Facts and Figures*, the *Oil and Gas Journal* and statistics published by the Bureau of Mines, the Department of Commerce and the U.S. Weather Bureau. While further testing and analysis should provide closer, more inclusive specification of the residential/commercial market for fossil fuels, the above model does provide some initial insight into the shape of the demand curve facing the industry.

APPENDIX G

INDUSTRIAL ENERGY DEMAND MODELS

ANALYSIS OF THE INDUSTRIAL MARKET

Econometric analysis indicates that industrial energy consumption is correlated with the cost of labor, capital and energy. Further, it seems likely that future competitive pressures will focus increasingly on cost reduction in manufacturing industries.

Significant increases in the costs of primary energy are possible and, if this should happen, the effect on industrial energy costs would be disproportionately large because industry has been a prime beneficiary of cheap gas, coal and imported fuel oil. The combined effect of higher energy cost on industrial energy demand would be twofold. First, greater incentives and opportunities to substitute capital for labor would tend to reduce energy requirements per unit of output, because new equipment is generally more efficient in terms of both labor and energy per unit of product than the equipment of process replaced. Second, rising energy costs would discourage energy use and would encourage the substitution of labor for energy.

These types of substitution are limited by existing and prospective opportunities to conserve industrial energy, so an in-depth look at such opportunities is necessary to determine the possible impact on energy consumption.

First of all, the viewpoint of industrial management must be considered. Industrial users are long-term investors who intend to own facilities throughout their project life in contrast to homeowners who move frequently. Thus, they are considerably more likely to react quickly and rationally to rising fuel costs than are homeowners because they must consider payout of equipment or construction investment in terms of annual fuel savings. Industrial users are willing and able to invest substantial funds in research and development of architectural designs to minimize fuel costs. This is, at least partly, a result of the fact that relatively fewer industrial concerns rent their properties, so there is no separation of owner from tenant economics--i.e., apartment builders may seek minimum construction costs with little regard for utility charges if paid by renters. Industrial market competition will require that firms respond promptly and efficiently to changes in energy costs. The successful competitors will be those who make appropriate substitutions of capital and labor for energy in response to rising energy costs.

Even a casual survey indicates that industrial energy use is not currently optimized. Higher energy costs, however, will focus attention on existing technologies which permit important energy cost savings. A good example is widespread computer control of process utilities. One Gulf Coast refinery has installed a computer to monitor steam, electricity, air, gas and water supplies, and the application has been very successful in optimizing energy usage while maintaining system stability, resulting in the lowest possible cost for process operation.

As energy costs rise in proportion to total manufacturing costs, the response of industry to changes in energy costs will increase more than proportionately. In other words, the elasticity of demand will rise. Earlier retirement of the existing stock of capital equipment and production facilities will be encouraged by higher energy costs. Much of this equipment converts energy to useful work in a highly inefficient manner, and its replacement with equipment of newer design not only will use energy more efficiently, but also will attain higher output rates, thus substantially reducing energy consumption per unit of product. A number of specific opportunities for reducing industrial energy consumption in this manner are discussed in the paragraphs below.

Space Heat and Air Conditioning

A significant fraction of industrial fuel is used simply for space heating and cooling. Numerous opportunities exist for improvements in design and insulation of industrial structures to reduce fuel requirements.

Process Heat

In many instances, industrial equipment purchasers are able to make trade-off decisions between more costly, but thermally more efficient, processes or equipment. Higher fuel charges will shift economics more in favor of the more efficient equipment available. The improved thermal efficiency of such industrial operations will also reduce overall thermal emissions, thus marginally contributing to improved air quality. Opportunities for improved employment of industrial process heat include the following options:

- More carefully controlled combustion
- Improved transfer of heat to area of application
- Improved insulation of furnaces and ovens
- Greater application of heat exchangers when heating and cooling operations are jointly employed
- More efficient scheduling of operations to economize on the use of heat by minimizing the number of heat-ups and the duration of heat consumption per application.

Process Steam

Generally, industrial boilers can be engineered to increasingly high levels of efficiency at greater costs. Again, higher fuel costs make thermally efficient designs economically attractive. A considerable amount of industrial steam production is for the on-site generation of electrical power. Sharp increases in fuel costs are likely to shift economics in favor of electricity purchased from utilities as opposed to self-generation. This should result in some overall fuel savings due to the superior average thermal efficiency of central power stations as opposed to smaller industrial power plants. Moreover, important savings of fossil fuel should be realized over the longer term because utilities will increasingly depend on nuclear energy for new generating capacity, whereas industrial power plants are expected to continue to use fossil fuels for many years.

Industrial Lighting

There is a broad range of opportunities for making economic choices among generally more costly lighting systems which have lower power requirements (see Table 32). Higher energy costs would increase economic incentives to recover waste heat from lighting systems and to integrate lighting and heating engineering plans. The rising cost of electrical energy also would encourage industrial/commercial users to economize on lighting by making greater use of natural lighting or simply increasing efforts to shut off lights when they are not needed. (In some instances, it is cheaper at the present time to leave fluorescent lights on than to incur the higher material and labor costs of bulb replacement, which is related primarily to start-ups rather than illumination time.)

TABLE 32

LIGHTING EFFICIENCY

	Lumens per Watt
Incandescent	
100-watt, Inside-frost	17
150-watt, Inside-frost	19
Fluorescent	
48", 40-watt Cool White	80
48", 40-watt CW Deluxe	56
Mercury	
400-watt DeLuxe White	48
High Pressure Sodium	
1,000-watt Lucalox*	130

* General Electric trade name.

Mechanical Energy

Mechanical energy requirements of industry represent a relatively small fraction of total energy use. Nevertheless, the cost of energy is an important parameter in the design and application of mechanical energy to industrial purposes. Higher energy costs would encourage the evolution and application of relatively more efficient equipment in terms of energy inputs.

Metallurgical Coal

A recent study indicates that metallurgical coal use would be affected by two factors related to an energy price increase:

- First, energy use would decline with lower steel output. An overall energy price increase would reduce the amount of money the consumer will have to spend for durable goods, thus tending to lower steel output. Previous studies indicate that this effect would be about a 3-percent reduction in industrial output for a 100-percent increase in the "primary" energy price.

- Secondly, metallurgical coal use will decline because of increased iron and steel scrap and decreased pig iron content in raw steel. Raw steel is produced by feeding pig iron and scrap to open hearth, oxygen reduction or electric furnaces. Pig iron is produced in a blast furnace which uses metallurgical coal as one of the feed components. The ratio of pig iron to scrap in the feed is determined by the relative cost of these materials. From 1967 through 1970, raw steel contained between 35.4- and 37.6-percent scrap, while the pig iron/scrap price-ratio varied from 1.7 to 2.5. The relationship between scrap content and the price ratio is almost linear. Apparently 16 percent of the price of pig iron can be directly credited to the metallurgical coal cost. Using the previously discussed relationship between pig iron/scrap price-ratio and raw steel scrap content, assuming an average raw steel scrap content in 1985 and a doubling of the expected price of coal, the result would be a decrease in metallurgical coal consumption of approximately 2 percent for constant raw steel output. The decrease is not very sensitive to either the scrap content assumption or the pig iron price assumption and should, therefore, be representative of the 1985 situation over a wide base case range.

Processing of Industrial Waste

Many industrial wastes may be burned as a means of disposal. Higher fuel costs will increase incentives to burn wastes and recover heat for industrial purposes. Waste heat generated from municipal refuse has been successfully utilized for years and recent experiments indicate this is economically feasible for smaller units in commercial buildings. In effect, this process both destroys wastes and reduces the net requirements for industrial energy.

Other Effects

Higher energy costs will also stimulate R&D investment by industrial energy users to find new methods of economizing on industry energy use. The first response will be an effort to optimize the application of the existing stock of capital equipment. This process will include both improved application and some modifications and improvements in the equipment itself. Secondly, industry will be more selective in the purchase of new equipment and will give greater weight to the energy costs of operating old equipment in making decisions to retire plants currently in production. Finally, R&D will be directed toward the objective of developing new equipment and industrial processes that consume less energy. To date, this effort has received relatively little emphasis, except in the development of new technology to reduce coke requirements per ton of steel manufactured. Similar efficiencies may be possible in many other industrial applications of hydrocarbons.

An important factor not generally recognized is the effect on total industrial energy consumption of shifts in available fuels. For example, a shift by industry from oil and gas to coal might increase overall energy requirements, depending on transportation distances. Greater reliance on synthetic fuels would increase energy requirements due to the energy intensive nature of most synthetic fuels' manufacturing processes. Moreover, use of synthetic fuels would result in relatively greater atmospheric emissions of heat and by-products due to release in the process of fuel manufacture.

Reductions in natural gas supplies are likely to necessitate replacement of industrial gas by oil or coal in most areas of the country. This will require larger investment in combustion equipment, fuel storage and handling facilities and precipitators. All of these efforts will add to energy consumption.

Increases in fossil fuel costs relative to electrical energy costs, a process which will proceed relatively rapidly in industrial energy markets, might encourage industry to consume relatively more energy in the form of electricity rather than primary fossil fuels. Over the longer term, as nuclear energy represents the major portion of additional generating capacity, this substitution will reduce net atmospheric emissions. It will also reduce total fossil fuel requirements. Total energy requirements measured on an input basis, however, may well increase depending upon the relative mechanical and thermal efficiency of electrical *versus* fossil fueled industrial plant and equipment, e.g., electric *versus* coal-or oil-fired steel making processes, and nuclear *versus* fossil fuel generating plants. Thus, most of the fuel-shift considerations tend to lean towards increase demand for industrial energy.

GOALS OF STUDY

A model for Industrial Energy Demand was developed which required the blending of a number of diverse goals. A suitable model should provide reasonable forecasting accuracy, mechanisms for sensitivity analysis, and insights into the interactions within the underlying system. In particular, it should show energy demand/price elasticity and economic trade-offs among highly aggregated factors of production, including energy, capital goods and labor. The success of any model really must be evaluated after the fact, in spite of the precision with which it is possible to cite regression statistics. Experience in this study shows again that the choice of the right type of model for the job is still a subjective decision and, hence, the model should be used to supplement rather than replace judgment.

The next section will provide a discussion of the results of the study, and the final section will present technical details of methodology and any other appropriate material.

SUMMARY OF MODEL FINDINGS

After experimenting with several thousand different models, the possibilities were reduced to the four promising candidates that were described in the body of the report beginning on page 35 in Chapter One. The models tested were relative price models, with explanatory variables and lagged prices entered in differing forms to test for fit to historical time series. They are all "double-log" models in that the logarithm of the independent variable is expressed as a linear combination of the logarithms of the independent variables. The findings demonstrate that energy cost does play a role in the determination of industrial energy demand, as do the prices of capital goods and labor. The notations and equations are given below for the models to be discussed:

Let $D_{E,T}$ = Demand for industrial energy in time period T

FRB_T = FRB index of industrial product in period T (electricity removed)

$P_{E,T}$ = Relative price of industrial energy in period T where the average price in 1957-1959 = 1.00

$P_{L,T}$ = Relative price of industrial labor in period T, 1957-1959 = 1.00

$P_{C,T}$ = Relative price of capital goods in period T, 1957-1959 = 1.00

GNP_T = Implicit GNP price deflator for period T, 1957-1959 = 1.00

The models to be discussed are:

A $\quad \mathrm{LOG}(D_{E,T}/FRB_T) = a_0 + a_1 \mathrm{LOG}(P_{E,T}/GNP_T) + a_2 \mathrm{LOG}(P_{C,T}/GNP_T) + a_3 \mathrm{LOG}(P_{L,T}/GNP_T)$

B $\quad \mathrm{LOG}(D_{E,T}/FRB_T) = a_0 + a_1 \mathrm{LOG}\ FRB_T + a_2 \mathrm{LOG}(P_{E,T}/GNP_T) + a_3 \mathrm{LOG}(P_{C,T}/GNP_T) + a_4 \mathrm{LOG}(P_{L,T}/GNP_T)$

C $\quad \mathrm{LOG}(D_{E,T}/FRB_T) = a_0 + a_1 \mathrm{LOG}\ FRB_T + a_2 \mathrm{LOG}(P_{E,T}/GNP_T) + a_3 \mathrm{LOG}(P_{C,T}/GNP_T) + a_4 \mathrm{LOG}(P_{L,T}/GNP_T) + a_5 \Delta \mathrm{LOG}(P_{C,T}/GNP_T)$

Where $\Delta \mathrm{LOG}(P_{C,T}/GNP_T) = \mathrm{LOG}(P_{C,T}/GNP_T) - \mathrm{LOG}(P_{C,T-1}/GNP_{T-1})$

D $\quad \mathrm{LOG}\ D_{E,T} = a_0 + a_1 \mathrm{LOG}\ FRB_T + a_2 \mathrm{LOG}(P_{L,T}/GNP_T)$

Models A, B and C are variants of the same approach. To remove the domination of the FRB level from total industrial energy demand, a number of regressions were run with energy per unit of FRB as the dependent variable. Model A represents the simplest model, based only on relative prices of three aggregate factors of production. (See Exhibit A for detailed statistics on the model.) In the experimentation, however, the level of production still seemed important, apparently due to an economy of scale consideration, resulting in Model B, shown in detail in Exhibit B. Finally, after working with combinations of lagged variables, Model C emerged as the most descriptive model of the system interactions. The price of capital goods lagged one year, seemed an important determinant of energy demand. Most important, the form of Model C appears stable in that coefficients of the variables stayed close to those found in Model C as other variables were added to test runs. In contrast, note the shift in the capital and labor coefficients in going from Model A to Model B (Exhibits A and B) and the shift in FRB and labor coefficients in going from B to C (Exhibits B and C). Consequently, Model C seems most representative of the system interactions in the historical period, and the best candidate for sensitivity studies.

Modeling for projections into the future involves a combination of experience and judgment not present in other regression models.

An equilibrium model seems safer than a dynamic one. Model C would require anticipating not only relative prices, but also movement in the price of capital in some future period. Table 16, p. 46 shows the time series used in developing the projections through 1990 for models A, B and D. From this vantage point, each projection contains important information, and each must be questioned critically. A specific choice of forecasting model will not be made. Instead each must be considered in the context of its view of system interactions.

SUMMARY OF RESULTS--INTERPRETATION

Careful analysis of Model C should offer insights into the strengths and weaknesses of the model and of the study. Examination first of the signs of coefficients reveal that demand for energy per unit of FRB would increase with an increase in the price of capital goods and would decrease with price increases in energy or labor, or with an increase in the FRB index. For similar outputs, it appears that industrial energy needs are higher in labor intensive than in capital intensive situations. In the historical period, the drastic increase in labor rates relative to other prices seems to have caused a shift into production using more capital equipment, which is more efficient in terms of energy and labor use. Time has not permitted a detailed study of this particular relationship but possibilities must be considered. Historically, energy prices have not varied to the extent found in capital and labor. Consequently, the driving force behind this effect to date has been the labor rates. However, if energy prices were to rise dramatically in the future, the energy price change could have important impacts on both capital goods and labor. Additional study in this area might prove highly enlightening.

The fit of lagged prices in the historical time period was interesting if not surprising. The lag effect on capital goods can have at least two possible interpretations: first, the lag could reflect an inertia associated with planning, justifying and ordering capital goods; and second, in view of the limited movement of energy prices and the steady upward movement of labor prices, the lag could reflect greater uncertainty in projecting capital prices, since perfect projections of future prices would eliminate any visible lag effect. With increased planning taking place in all forms of business, it seems likely that inertia exists in energy demand due to capital committed to specific methods of production. A conclusion derived from this model was that the response to energy prices based on a yearly time series was a short-term elasticity. The point elasticity of approximately -0.4 reflects the expected inelastic short run demand.

A cross-section study based on the 1963 Census of Manufactures was attempted to examine price elasticity on a state level. Since energy prices vary much more widely across states than when aggregated for the country, it was hoped that the cross section study would yield something approaching a long-term price elasticity.

Using a model similar to Model A, a regression was run which yielded an energy point elasticity of -1.1 with a standard error in the coefficient of 0.1. A one-tailed test on the coefficient would conclude that energy demand is relatively elastic at roughly an 84-percent level of confidence under conditions approximating long-run stability. In contrast, a similar test on the time series data used in Model A, B or C would conclude a relative inelastic demand at the 99-percent level of each model.

SUMMARY OF RESULTS--USE OF MODELS

Exhibits for each model, at the end of this Appendix, include tables of component effects of each variable, indicating the extent to which each variable affects the projection. In using the models, however, several limitations should be kept in mind: In developing inputs to the models, great care should be taken with the variables having the greatest influence--usually the FRB index and capital prices. Also, the range of variation experienced during the period under consideration (1947-1970) was sometimes limited. Extrapolation outside the price ranges used should not be done mechanically; if values too far out of the range are substituted, there is considerable potential loss of validity. If dramatic changes in the variables were to be studied, one approach would be to analyze a series of lesser changes and to observe the model behavior as projections of reasonable scope are tried. If, for example, the effect of an immediate doubling of energy price were to be analyzed, projections might also be made at prices of 1.25, 1.50 and 1.75 times the base price to determine whether extrapolation produces unacceptable results in the total system.

Consideration must also be given to many factors affecting energy demand that are not included in these models, such as environmental control measures. Another limitation is the fact that there are saturation levels beyond which further substitutions among energy, capital and labor are not tenable.

METHODOLOGY

Simultaneous *versus* Single Equation Modeling

A theoretical shortcoming in this study lies in the decision to work with a single equation rather than a simultaneous equations model. This decision was made because it was felt that more meaningful results could be obtained in the time available with a single equation model. In retrospect, this decision seems even more valid. The problems of the simultaneous equations approach are many. While a large amount of work has been done with the double log form of demand equation, econometric literature offers little guidance for suitable supply models. Most studies, going back to the Cobb-Douglas work, have been single equation models. Further, to allow suitable clearing of supply and demand, information on energy use in other sectors (which compete with industry for energy) would have to be included. The interactions among the different energy markets poses a level of complexity that could not be handled in the present study. Finally, the attempts to find a suitable supply model seemed to break down with the aggregation of energy and yet the development of models that would show individual fuels was beyond the scope of study.

Coefficient Stability

The criterion chosen for evaluating models was primarily coefficent stability: as was noted in the discussion of Model C, the addition of new variables seemed to have little effect on the coefficients found in Model C. In all double log runs, the intercept coefficient was in the range of 1.140 to 1.145. The coefficient of the price of energy ranged from -0.25 to -.40 in all models, with the smallest absolute coefficient values occurring in runs with a large number of explanatory variables--as many as 10 variables were tried in single models. The coefficient was significant in most cases at the 95-percent level. The coefficient of FRB index was stable in a range of -0.15 to -0.35 with little noticeable effect from presence or absence of their variables. The coefficient was typically significant at the 95-percent level. Coefficients for capital and labor prices stabilized only with the capital lag value included--the capital coefficient in the range of 0.30 to 0.40 and labor in the range of -0.50 to -0.65. With the lag, capital fails a 90 percent significance test and labor is significant at the 90 percent level. The coefficient for the capital lag ranged from 1.2 to 1.4 with a 95-percent level of significance. Since the point elasticity of demand is simply the log derivative, the regression coefficients themselves yield the elasticities in the double log model. Consequently, the stability of coefficients should offer a reasonable estimate of elasticity in spite of the fact that the single equation approach does not provide identification of a true demand equation.

Data Sources

The data on energy demand were derived from U.S. Bureau of Mines figures. The GNP deflator is the implicit price deflator for the GNP, while the capital price was approximated by the implicit price deflator for fixed non-residential investment. The energy price was developed from the annual survey of manufactures, and the labor price was approximated by the average hourly gross earnings for all manufacturing per production worker.

Durbin-Watson Test

Models B (1.659) and D (1.444) allow us to accept the Null Hypotheses at the 5-percent level against both positive and negative autocorrelation. Model A (1.399) is indeterminate for positive autocorrelation and Model C (2.193) is indeterminate for negative autocorrelation. In the regressions run, inclusion of the capital lag caused a Durbin-Watson statistic greater than 2.0 for all models, which may indicate an over-reaction to change in the model. The statistic for all equilibrium models with no lagged variables was less than 2.0.

Multicollinearity

As can be seen by the $R(I)^2$ values in the exhibits, the time series used have high degrees of multicollinearity. (The $R(I)^2$ statistic is a measure of how well a particular variable could be approximated by a linear combination of the other variables.) A number of runs were attempted using time as an additional variable to determine whether extraneous correlation was entering the runs. The coefficient for time proved insignificant using a variety of functional forms. While there is some disagreement in the technical literature, most authors seem to feel that multicollinearity is properly reflected in the variance term for individual coefficients, and the experience in the modeling done here has shown no reason to disagree with that. More random fluctuation in the time series would allow better regression fits, but aggregated time series data seldom allow that luxury.

Computational Considerations

The regression runs were made using a program available from the SHARE* Library (360D.-13.6.008), and run on an IBM 360 Model 85. A discussion of the program, the C_p search method, and relevant fitting criteria can be found in the book *Fitting Equations to Data* by Cuthbert Daniel and Fred S. Wood, Wiley-Interscience, 1971. Exhibit A contains a more complete set of output from the program to show the type of anlaysis used.

* A cooperative organization of IBM equipment users.

EXHIBIT A (MODEL A)

LINEAR LEAST-SQUARES CURVE FITTING PROGRAM

REL PRICE MODEL 1 DEP VAR 1: L2/3 MIN Y = 1.062D-00 MAX Y = 1.261D-00 RANGE Y = 1.990D-01

IND. VAR (I)	NAME	COEF. B (I)	S.E. COEF.	T-VALUE	R (I) SQRD	MIN X (I)	MAX X (I)	RANGE X (I)	REL. INF. X (I)
0		1.14433D-00							
1	L4/13	- 3.60632D-01	1.48D-01	2.4	0.8315	- 9.027D-02	5.156D-02	1.418D-01	0.26
2	L7/13	8.67304D-01	3.02D-01	2.9	0.7789	- 6.341D-02	2.301D-03	6.571D-02	0.29
3	L10/13	- 1.35677D-00	1.37D-01	9.9	0.9111	- 1.133D-01	7.019D-02	1.835D-01	1.25

NO. OF OBSERVATIONS	24
NO. OF IND. VARIABLES	3
RESIDUAL DEGREES OF FREEDOM	20
F-VALUE	199.6
RESIDUAL ROOT MEAN SQUARE	0.01083710
RESIDUAL MEAN SQUARE	0.00011744
RESIDUAL SUM OF SQUARES	0.00234886
TOTAL SUM OF SQUARES	0.07265972
MULT. CORREL. COEF. SQUARED	0.9677

Dependent Variable	LOG $(D_{E,T}/FRB_T)$
Independent Variable 1	LOG $(P_{E,T}/GNP_T)$
2	LOG $(P_{C,T}/GNP_T)$
3	LOG $(P_{L,T}/GNP_T)$

EXHIBIT A (CONT'D.)

LINEAR LEAST-SQUARES CURVE FITTING PROGRAM

REL PRICE MODEL 1 DEP VAR 1: L2/3

COMPONENT EFFECT OF EACH VARIABLE ON EACH OBSERVATION (IN UNITS OF Y)
(VARIABLES ORDERED BY THEIR RELATIVE INFLUENCE——OBSERVATIONS ORDERED BY INFLUENCE OF MOST INFLUENTIAL VARIABLE)

SEQ.	OBSV.	VARIABLES 1 L10/13	2 L7/13	3 L4/13
1	47	0.15	- 0.04	0.01
2	48	0.14	- 0.03	- 0.02
3	49	0.11	- 0.02	- 0.01
4	50	0.09	- 0.01	- 0.01
5	51	0.08	- 0.01	- 0.01
6	52	0.06	- 0.01	- 0.01
7	53	0.04	- 0.00	- 0.01
8	54	0.03	- 0.01	- 0.01
9	55	0.02	- 0.00	- 0.01
10	56	0.01	0.01	- 0.01
11	57	0.00	0.02	- 0.01
12	58	- 0.00	0.02	- 0.00
13	59	- 0.01	0.02	- 0.01
14	60	- 0.02	0.01	0.00
15	61	- 0.03	0.01	0.00
16	62	- 0.04	0.01	0.00
17	63	- 0.05	0.01	0.01
18	64	- 0.06	0.00	0.01
19	65	- 0.07	0.00	0.01
20	66	- 0.07	0.00	0.01
21	67	- 0.08	0.00	0.01
22	68	- 0.09	0.00	0.02
23	70	- 0.10	0.00	0.03
24	69	- 0.10	0.00	0.03

(EXHIBIT A (CONT'D.)

LINEAR LEAST-SQUARES CURVE FITTING PROGRAM

REL PRICE MODEL 1 DEP VAR 1: L2/3

STANDARD DEVIATION ESTIMATED FROM RESIDUALS OF NEIGHBORING OBSERVATIONS (OBSERVATIONS 1 TO 4 APART IN FITTED Y ORDER).

		ORDERED BY WSSD				ORDERED BY FITTED Y				
NO.	CUMULATIVE STD DEV	WSSD	OBSV.	OBSV.	DEL RESIDUALS	WSSD	DEL RESIDUALS	FITTED Y	OBSV.	SEQ.
1	0.02	0.03	69	70	0.02	0.65	0.00	1.06	69	1
2	0.01	0.20	67	66	0.01	0.65	0.02	1.07	68	2
3	0.01	0.49	64	63	0.00	4.88	0.02	1.07	70	3
4	0.01	0.49	54	53	0.01	0.20	0.01	1.07	67	4
5	0.01	0.52	65	64	0.01	0.61	0.01	1.08	66	5
6	0.01	0.59	61	60	0.01	0.52	0.01	1.09	65	6
7	0.01	0.61	66	65	0.01	0.49	0.00	1.09	64	7
8	0.01	0.65	69	68	0.00	0.90	0.01	1.10	63	8
9	0.01	0.65	68	70	0.02	1.08	0.00	1.11	62	9
10	0.01	0.80	51	50	0.01	0.59	0.01	1.12	61	10
11	0.01	0.90	63	62	0.01	1.35	0.01	1.13	60	11
12	0.01	1.06	56	57	0.01	11.15	0.03	1.14	59	12
13	0.01	1.08	62	61	0.00	1.57	0.00	1.14	55	13
14	0.01	1.12	57	58	0.00	1.06	0.01	1.14	56	14
15	0.01	1.35	60	59	0.01	1.12	0.00	1.14	57	15
16	0.01	1.48	67	65	0.00	15.15	0.02	1.15	58	16
17	0.01	1.57	59	58	0.02	0.49	0.01	1.16	54	17
18	0.01	1.57	55	56	0.00	5.58	0.02	1.16	53	18
19	0.01	2.01	65	63	0.01	3.95	0.02	1.19	52	19
20	0.01	2.10	59	57	0.03	0.80	0.01	1.20	51	20
21	0.01	2.10	68	67	0.01	2.85	0.02	1.20	50	21
22	0.01	2.25	66	64	0.02	7.98	0.01	1.22	49	22
23	0.01	2.36	56	58	0.01	10.11	0.00	1.22	48	23
24	0.01	2.70	64	62	0.01	0.03	0.02	1.25	47	24

EXHIBIT A (CONT'D.)

LINEAR LEAST-SQUARES CURVE FITTING PROGRAM

REL PRICE MODEL 1 DEP VAR 1: L2/3

ORDERED BY COMPUTER INPUT						ORDERED BY RESIDUALS				
IDENT.	OBSV.	WS DISTANCE	OBS. Y	FITTED Y	RESIDUAL	OBSV.	OBS. Y	FITTED Y	ORDERED RESID.	SEQ.
19	47	205.	1.261	1.254	0.006	56	1.161	1.144	0.017	1
19	48	171.	1.229	1.222	0.007	70	1.082	1.068	0.014	2
19	49	109.	1.221	1.220	0.000	55	1.154	1.141	0.013	3
19	50	77.	1.190	1.205	- 0.015	57	1.155	1.144	0.011	4
19	51	63.	1.202	1.203	- 0.001	64	1.101	1.092	0.009	5
19	52	35.	1.170	1.188	- 0.017	58	1.158	1.151	0.007	6
19	53	14.	1.161	1.160	0.000	63	1.107	1.100	0.007	7
19	54	10.	1.150	1.159	- 0.009	48	1.229	1.222	0.007	8
19	55	3.	1.154	1.141	0.013	47	1.261	1.254	0.006	9
19	56	3.	1.161	1.144	0.017	61	1.125	1.120	0.005	10
19	57	4.	1.155	1.144	0.011	62	1.111	1.110	0.001	11
19	58	2.	1.158	1.151	0.007	49	1.221	1.220	0.000	12
19	59	5.	1.117	1.135	- 0.018	53	1.161	1.160	0.000	13
19	60	7.	1.128	1.130	- 0.003	51	1.202	1.203	- 0.001	14
19	61	9.	1.125	1.120	0.005	68	1.065	1.066	- 0.001	15
19	62	16.	1.111	1.110	0.001	60	1.128	1.130	- 0.003	16
19	63	28.	1.107	1.100	0.007	69	1.062	1.065	- 0.003	17
19	64	30.	1.101	1.092	0.009	65	1.080	1.085	- 0.006	18
19	65	39.	1.080	1.085	- 0.006	67	1.065	1.074	- 0.009	19
19	66	49.	1.062	1.078	- 0.016	54	1.150	1.159	- 0.009	20
19	67	55.	1.065	1.074	- 0.009	50	1.190	1.205	- 0.015	21
19	68	77.	1.065	1.066	- 0.001	66	1.062	1.078	- 0.016	22
19	69	89.	1.062	1.065	- 0.003	52	1.170	1.188	- 0.017	23
19	70	88.	1.082	1.068	0.014	59	1.117	1.135	- 0.018	24

EXHIBIT A (CONT'D.)

CP VALUES FOR THE SELECTION OF VARIABLES

REL PRICE MODEL 1 DEP VAR 1: L2/3 — **SEARCH NUMBER 1**

SELECTION OF VARIABLES FOR BASIC EQUATION

CP = 8.5, VARIABLE ADDED 3 L10/13

CP = 8.0, VARIABLE ADDED 2 L7/13

CP = 4.0, VARIABLE ADDED 1 L4/13

NUMBER OF OBSERVATIONS	24
NUMBER OF VARIABLES IN FULL EQUATION	3
NUMBER OF VARIABLES IN BASIC EQUATION	1
REMAINDER OF VARIABLES TO BE CONSIDERED	2

EQUATION	P	CP	VARIABLES IN EQUATION		
	4	4.0	FULL EQUATION		
	2	8.0	BASIC SET OF VARIABLES		3 L10/13
1	4	4.0	BASIC SET PLUS	1 L4/13	2 L7/13

SWEEP NUMBER 4, DELTA Z(K,K) = 2.D - 18

EXHIBIT B (MODEL B)

LINEAR LEAST-SQUARES CURVE FITTING PROGRAM

REL PRICE MODEL 31 DEP VAR 1: L2/3 **MIN Y = 1.062D-00 MAX Y = 1.261D-00 RANGE Y = 1.990D-01**

IND. VAR (I)	NAME	COEF. B (I)	S.E. COEF.	T-VALUE	R (I) SQRD	MIN X (I)	MAX X (I)	RANGE X (I)	REL. INF. X (I)
0		1.14327D-00							
1	FRB	- 1.41400D-01	1.23D-01	1.2	0.9796	- 1.831D-01	2.312D-01	4.143D-01	0.29
2	L4/13	- 3.31209D-01	1.49D-01	2.2	0.8365	- 9.027D-02	5.156D-02	1.418D-01	0.24
3	L7/13	5.07032D-01	4.33D-01	1.2	0.8940	- 6.341D-02	2.301D-03	6.571D-02	0.17
4	L10/13	- 9.51067D-01	3.77D-01	2.5	0.9885	- 1.133D-01	7.019D-02	1.835D-01	0.88

NO. OF OBSERVATIONS	24
NO. OF IND. VARIABLES	4
RESIDUAL DEGREES OF FREEDOM	19
F-VALUE	152.5
RESIDUAL ROOT MEAN SQUARE	0.01074823
RESIDUAL MEAN SQUARE	0.00011552
RESIDUAL SUM OF SQUARES	0.00219496
TOTAL SUM OF SQUARES	0.07265972
MULT. CORREL. COEF. SQUARED	0.9698

Dependent Variable	LOG $(D_{E,T}/FRB_T)$
Independent Variable 1	LOG (FRB_T)
2	LOG $(P_{E,T}/GNP_T)$
3	LOG $(P_{C,T}/GNP_T)$
4	LOG $(P_{L,T}/GNP_T)$

EXHIBIT B (CONT'D.)

LINEAR LEAST-SQUARES CURVE FITTING PROGRAM

REL PRICE MODEL 31 DEP VAR 1: L2/3

COMPONENT EFFECT OF EACH VARIABLE ON EACH OBSERVATION (IN UNITS OF Y)
(VARIABLES ORDERED BY THEIR RELATIVE INFLUENCE——OBSERVATIONS ORDERED BY INFLUENCE OF MOST INFLUENTIAL VARIABLE)

		VARIABLES			
SEQ.	OBSV.	4	1	2	3
		L10/13	FRB	L4/13	L7/13
1	47	0.11	0.03	0.01	- 0.02
2	48	0.10	0.03	- 0.02	- 0.02
3	49	0.08	0.03	- 0.01	- 0.01
4	50	0.07	0.02	- 0.01	- 0.01
5	51	0.06	0.02	- 0.01	- 0.00
6	52	0.04	0.01	- 0.01	- 0.00
7	53	0.03	0.01	- 0.01	- 0.00
8	54	0.02	0.01	- 0.01	- 0.00
9	55	0.01	0.01	- 0.01	- 0.00
10	56	0.01	0.00	- 0.01	0.01
11	57	0.00	0.00	- 0.01	0.01
12	58	- 0.00	0.01	- 0.00	0.01
13	59	- 0.01	0.00	- 0.01	0.01
14	60	- 0.02	- 0.00	0.00	0.01
15	61	- 0.02	- 0.00	0.00	0.01
16	62	- 0.03	- 0.01	0.00	0.01
17	63	- 0.04	- 0.01	0.01	0.00
18	64	- 0.04	- 0.01	0.01	0.00
19	65	- 0.05	- 0.02	0.01	0.00
20	66	- 0.05	- 0.02	0.01	0.00
21	67	- 0.06	- 0.02	0.01	0.00
22	68	- 0.06	- 0.03	0.02	0.00
23	70	- 0.07	- 0.03	0.02	0.00
24	69	- 0.07	- 0.03	0.02	0.00

EXHIBIT B (CONT'D.)

LINEAR LEAST-SQUARES CURVE FITTING PROGRAM

REL PRICE MODEL 31 DEP VAR 1: L2/3

STANDARD DEVIATION ESTIMATED FROM RESIDUALS OF NEIGHBORING OBSERVATIONS (OBSERVATIONS 1 TO 4 APART IN FITTED Y ORDER).

		ORDERED BY WSSD				ORDERED BY FITTED Y				
NO.	CUMULATIVE STD DEV	WSSD	OBSV.	OBSV.	DEL RESIDUALS	WSSD	DEL RESIDUALS	FITTED Y	OBSV.	SEQ.
1	0.01	0.05	69	70	0.02	0.48	0.00	1.06	69	1
2	0.01	0.10	67	66	0.01	0.48	0.01	1.07	68	2
3	0.01	0.28	61	60	0.00	3.21	0.02	1.07	70	3
4	0.01	0.37	64	63	0.00	0.10	0.01	1.07	67	4
5	0.01	0.45	57	56	0.01	0.56	0.01	1.08	66	5
6	0.01	0.48	68	70	0.01	0.48	0.01	1.08	65	6
7	0.01	0.48	53	54	0.02	0.37	0.00	1.09	64	7
8	0.01	0.48	65	64	0.01	0.54	0.00	1.10	63	8
9	0.01	0.48	69	68	0.00	0.73	0.00	1.11	62	9
10	0.01	0.54	63	62	0.00	0.28	0.00	1.12	61	10
11	0.01	0.56	66	65	0.01	0.87	0.01	1.13	60	11
12	0.01	0.60	51	50	0.02	1.20	0.03	1.13	59	12
13	0.01	0.66	56	55	0.01	0.45	0.01	1.14	57	13
14	0.01	0.73	62	61	0.00	0.66	0.01	1.14	56	14
15	0.01	0.87	60	59	0.01	3.09	0.01	1.14	55	15
16	0.01	1.05	67	65	0.00	9.28	0.00	1.15	58	16
17	0.01	1.12	57	58	0.01	0.48	0.02	1.16	53	17
18	0.01	1.20	59	57	0.03	3.80	0.00	1.16	54	18
19	0.01	1.30	68	67	0.01	2.05	0.02	1.19	52	19
20	0.01	1.35	59	58	0.02	0.60	0.02	1.20	51	20
21	0.01	1.68	56	58	0.01	9.87	0.02	1.20	50	21
22	0.01	1.69	65	63	0.01	4.23	0.01	1.22	48	22
23	0.01	1.76	64	62	0.01	10.78	0.01	1.22	49	23
24	0.01	1.81	62	60	0.00	0.05	0.02	1.25	47	24

EXHIBIT B (CONT'D.)

LINEAR LEAST-SQUARES CURVE FITTING PROGRAM

REL PRICE MODEL 31 DEP VAR 1: L2/3

ORDERED BY COMPUTER INPUT						ORDERED BY RESIDUALS				
IDENT.	OBSV.	WS DISTANCE	OBS. Y	FITTED Y	RESIDUAL	OBSV.	OBS. Y	FITTED Y	ORDERED RESID.	SEQ.
19	47	107.	1.261	1.254	0.007	56	1.161	1.142	0.019	1
19	48	92.	1.229	1.221	0.008	70	1.082	1.068	0.014	2
19	49	62.	1.221	1.224	- 0.004	57	1.155	1.141	0.014	3
19	50	42.	1.190	1.204	- 0.014	55	1.154	1.144	0.010	4
19	51	34.	1.202	1.197	0.004	48	1.229	1.221	0.008	5
19	52	19.	1.170	1.185	- 0.015	47	1.261	1.254	0.007	6
19	53	8.	1.161	1.160	0.001	64	1.101	1.094	0.007	7
19	54	7.	1.150	1.165	- 0.015	58	1.158	1.153	0.005	8
19	55	2.	1.154	1.144	0.010	51	1.202	1.197	0.004	9
19	56	2.	1.161	1.142	0.019	63	1.107	1.103	0.004	10
19	57	2.	1.155	1.141	0.014	61	1.125	1.123	0.002	11
19	58	1.	1.158	1.153	0.005	53	1.161	1.160	0.001	12
19	59	2.	1.117	1.133	- 0.016	68	1.065	1.065	- 0.001	13
19	60	3.	1.128	1.130	- 0.003	62	1.111	1.112	- 0.001	14
19	61	5.	1.125	1.123	0.002	69	1.062	1.064	- 0.002	15
19	62	8.	1.111	1.112	- 0.001	60	1.128	1.130	- 0.003	16
19	63	12.	1.107	1.103	0.004	49	1.221	1.224	- 0.004	17
19	64	17.	1.101	1.094	0.007	65	1.080	1.085	- 0.005	18
19	65	22.	1.080	1.085	- 0.005	67	1.065	1.071	- 0.007	19
19	66	29.	1.062	1.075	- 0.013	66	1.062	1.075	- 0.013	20
19	67	33.	1.065	1.071	- 0.007	50	1.190	1.204	- 0.014	21
19	68	45.	1.065	1.065	- 0.001	54	1.150	1.165	- 0.015	22
19	69	54.	1.062	1.064	- 0.002	52	1.170	1.185	- 0.015	23
19	70	52.	1.082	1.068	0.014	59	1.117	1.133	- 0.016	24

EXHIBIT C (MODEL C)

LINEAR LEAST-SQUARES CURVE FITTING PROGRAM

REL PRICE MODEL 32 DEP VAR 1: L2/3

MIN Y = 1.062D-00 MAX Y = 1.261D-00 RANGE Y = 1.990D-01

IND. VAR (I)	NAME	COEF. B (I)	S.E. COEF.	T-VALUE	R (I) SQRD	MIN X (I)	MAX X (I)	RANGE X (I)	REL. INF. X (I)
0		1.14078D-00							
1	FRB	- 2.35807D-01	1.12D-01	2.1	0.9817	- 1.831D-01	2.312D-01	4.143D-01	0.49
2	L4/13	- 3.84284D-01	1.31D-01	2.9	0.8403	- 9.027D-02	5.156D-02	1.418D-01	0.27
3	L7/13	4.03963D-01	3.79D-01	1.1	0.8952	- 6.341D-02	2.301D-03	6.571D-02	0.13
4	L10/13	- 6.46012D-01	3.48D-01	1.9	0.9897	- 1.133D-01	7.019D-02	1.835D-01	0.60
5	18 - 19	1.38456D-00	5.21D-01	2.7	0.5682	- 4.004D-03	1.518D-02	1.918D-02	0.13

NO. OF OBSERVATIONS	24
NO. OF IND. VARIABLES	5
RESIDUAL DEGREES OF FREEDOM	18
F-VALUE	162.3
RESIDUAL ROOT MEAN SQUARE	0.00935841
RESIDUAL MEAN SQUARE	0.00008758
RESIDUAL SUM OF SQUARES	0.00157644
TOTAL SUM OF SQUARES	0.07265972
MULT. CORREL. COEF. SQUARED	.9783

Dependent Variable		LOG $(D_{E,T}/FRB_T)$
Independent Variable	1	LOG (FRB_T)
	2	LOG $(P_{E,T}/GNP_T)$
	3	LOG $(P_{C,T}/GNP_T)$
	4	LOG $(P_{L,T}/GNP_T)$
	5	ΔLOG $(P_{C,T}/GNP_T)$

EXHIBIT C (CONT'D.)

LINEAR LEAST-SQUARES CURVE FITTING PROGRAM

REL PRICE MODEL 32 DEP VAR 1: L2/3

COMPONENT EFFECT OF EACH VARIABLE ON EACH OBSERVATION (IN UNITS OF Y)
(VARIABLES ORDERED BY THEIR RELATIVE INFLUENCE––OBSERVATIONS ORDERED BY INFLUENCE OF MOST INFLUENTIAL VARIABLE)

		VARIABLES				
SEQ.	OBSV.	4	1	2	5	3
		L10/13	FRB	L4/13	18 - 19	L7/13
1	47	0.07	0.05	0.01	0.01	- 0.02
2	48	0.07	0.04	- 0.03	0.01	- 0.01
3	49	0.05	0.05	- 0.01	0.02	- 0.01
4	50	0.04	0.03	- 0.01	0.00	- 0.01
5	51	0.04	0.03	- 0.01	0.00	- 0.00
6	52	0.03	0.02	- 0.01	0.00	- 0.00
7	53	0.02	0.01	- 0.01	0.00	- 0.00
8	54	0.02	0.02	- 0.01	- 0.01	- 0.00
9	55	0.01	0.01	- 0.01	0.00	- 0.00
10	56	0.00	0.01	- 0.01	0.01	0.00
11	57	0.00	0.01	- 0.01	0.01	0.01
12	58	- 0.00	0.01	- 0.00	- 0.01	0.01
13	59	- 0.01	0.00	- 0.01	- 0.00	0.01
14	60	- 0.01	- 0.00	0.00	- 0.01	0.01
15	61	- 0.01	- 0.00	0.00	- 0.01	0.01
16	62	- 0.02	- 0.01	0.00	- 0.01	0.00
17	63	- 0.02	- 0.02	0.01	- 0.01	0.00
18	64	- 0.03	- 0.02	0.01	- 0.01	0.00
19	65	- 0.03	- 0.03	0.01	- 0.00	0.00
20	66	- 0.04	- 0.04	0.01	- 0.00	0.00
21	67	- 0.04	- 0.04	0.01	- 0.00	0.00
22	68	- 0.04	- 0.04	0.02	- 0.01	0.00
23	70	- 0.05	- 0.04	0.03	- 0.00	0.00
24	69	- 0.05	- 0.05	0.03	- 0.00	0.00

EXHIBIT C (CONT'D.)

LINEAR LEAST-SQUARES CURVE FITTING PROGRAM

REL PRICE MODEL 32 DEP VAR 1: L2/3

STANDARD DEVIATION ESTIMATED FROM RESIDUALS OF NEIGHBORING OBSERVATIONS (OBSERVATIONS 1 TO 4 APART IN FITTED Y ORDER).

		ORDERED BY WSSD				ORDERED BY FITTED Y				
NO.	CUMULATIVE STD DEV	WSSD	OBSV.	OBSV.	DEL RESIDUALS	WSSD	DEL RESIDUALS	FITTED Y	OBSV.	SEQ.
1	0.00	0.12	67	66	0.00	0.90	0.01	1.06	68	1
2	0.00	0.19	61	60	0.00	4.40	0.00	1.07	69	2
3	0.01	0.19	69	70	0.01	0.12	0.00	1.07	67	3
4	0.00	0.62	57	56	0.00	4.96	0.02	1.07	66	4
5	0.00	0.73	64	63	0.00	9.02	0.01	1.07	70	5
6	0.00	0.73	63	62	0.01	1.00	0.01	1.08	65	6
7	0.00	0.90	68	69	0.01	0.73	0.00	1.09	64	7
8	0.00	1.00	65	64	0.01	0.73	0.01	1.10	63	8
9	0.00	1.04	68	70	0.01	1.13	0.01	1.11	62	9
10	0.01	1.09	51	50	0.02	0.19	0.00	1.12	61	10
11	0.01	1.12	66	65	0.01	1.97	0.02	1.12	60	11
12	0.01	1.13	62	61	0.01	4.38	0.03	1.13	59	12
13	0.01	1.58	53	54	0.01	2.37	0.00	1.14	55	13
14	0.01	1.60	67	65	0.00	4.93	0.00	1.15	57	14
15	0.01	1.61	52	51	0.02	7.33	0.00	1.15	58	15
16	0.01	1.78	55	53	0.01	5.83	0.00	1.15	56	16
17	0.01	1.79	68	67	0.01	1.58	0.01	1.16	53	17
18	0.01	1.94	62	60	0.00	2.85	0.00	1.16	54	18
19	0.01	1.97	60	59	0.02	1.61	0.02	1.18	52	19
20	0.01	2.15	68	66	0.01	1.09	0.02	1.19	51	20
21	0.01	2.25	59	57	0.02	9.38	0.02	1.20	50	21
22	0.01	2.37	55	57	0.00	4.23	0.02	1.22	48	22
23	0.01	2.44	64	62	0.01	10.69	0.02	1.24	49	23
24	0.01	2.47	55	56	0.00	1.79	0.01	1.26	47	24

EXHIBIT C (CONT'D.)

LINEAR LEAST-SQUARES CURVE FITTING PROGRAM

REL PRICE MODEL 32 DEP VAR 1: L2/3

ORDERED BY COMPUTER INPUT						ORDERED BY RESIDUALS				
IDENT.	OBSV.	WS DISTANCE	OBS. Y	FITTED Y	RESIDUAL	OBSV.	OBS. Y	FITTED Y	ORDERED RESID.	SEQ.
19	47	90.	1.261	1.256	0.005	51	1.202	1.192	0.010	1
19	48	82.	1.229	1.221	0.008	55	1.154	1.144	0.009	2
19	49	67.	1.221	1.237	- 0.016	70	1.082	1.074	0.008	3
19	50	39.	1.190	1.198	- 0.008	48	1.229	1.221	0.008	4
19	51	29.	1.202	1.192	0.010	64	1.101	1.094	0.007	5
19	52	17.	1.170	1.180	- 0.010	63	1.107	1.100	0.007	6
19	53	9.	1.161	1.157	0.004	58	1.158	1.152	0.007	7
19	54	9.	1.150	1.159	- 0.009	56	1.161	1.154	0.006	8
19	55	3.	1.154	1.144	0.009	57	1.155	1.149	0.006	9
19	56	5.	1.161	1.154	0.006	47	1.261	1.256	0.005	10
19	57	4.	1.155	1.149	0.006	61	1.125	1.120	0.005	11
19	58	3.	1.158	1.152	0.007	53	1.161	1.157	0.004	12
19	59	2.	1.117	1.133	- 0.016	60	1.128	1.125	0.003	13
19	60	3.	1.128	1.125	0.003	68	1.065	1.064	0.001	14
19	61	4.	1.125	1.120	0.005	62	1.111	1.111	- 0.000	15
19	62	7.	1.111	1.111	- 0.000	69	1.062	1.066	- 0.004	16
19	63	11.	1.107	1.100	0.007	65	1.080	1.085	- 0.005	17
19	64	16.	1.101	1.094	0.007	67	1.065	1.072	- 0.007	18
19	65	23.	1.080	1.085	- 0.005	50	1.190	1.198	- 0.008	19
19	66	33.	1.062	1.073	- 0.010	54	1.150	1.159	- 0.009	20
19	67	36.	1.065	1.072	- 0.007	52	1.170	1.180	- 0.010	21
19	68	50.	1.065	1.064	0.001	66	1.062	1.073	- 0.010	22
19	69	61.	1.062	1.066	- 0.004	49	1.221	1.237	- 0.016	23
19	70	57.	1.082	1.074	0.008	59	1.117	1.133	- 0.016	24

EXHIBIT D (MODEL D)

LINEAR LEAST-SQUARES CURVE FITTING PROGRAM

REL PRICE MODEL 8 DEP VAR 1: MIN Y = 1.037D-00 MAX Y = 1.299D-00 RANGE Y = 2.612D-01

IND. VAR (I)	NAME	COEF. B (I)	S.E. COEF.	T-VALUE	R (I) SQRD	MIN X (I)	MAX X (I)	RANGE X (I)	REL. INF. X (I)
0		1.14062D-00							
1	FRB	8.41537D-01	7.68D-02	11.0	0.9407	- 1.831D-01	2.312D-01	4.143D-01	1.33
2		- 6.34748D-01	1.78D-01	3.6	0.9407	- 1.133D-01	7.019D-02	1.835D-01	0.45

NO. OF OBSERVATIONS	24
NO. OF IND. VARIABLES	2
RESIDUAL DEGREES OF FREEDOM	21
F-VALUE	478.8
RESIDUAL ROOT MEAN SQUARE	0.01150263
RESIDUAL MEAN SQUARE	0.00013231
RESIDUAL SUM OF SQUARES	0.00277852
TOTAL SUM OF SQUARES	0.12948788
MULT. CORREL. COEF. SQUARED	0.9785

Dependent Variable	LOG $D_{E,T}$
Independent Variable 1	LOG FRB_T
2	LOG $(P_{L,T}/GNP_T)$

EXHIBIT D (CONT'D.)

LINEAR LEAST-SQUARES CURVE FITTING PROGRAM

REL PRICE MODEL 8 DEP VAR 1:

COMPONENT EFFECT OF EACH VARIABLE ON EACH OBSERVATION (IN UNITS OF Y)
(VARIABLES ORDERED BY THEIR RELATIVE INFLUENCE––OBSERVATIONS ORDERED BY INFLUENCE OF MOST INFLUENTIAL VARIABLE)

		VARIABLES	
SEQ.	**OBSV.**	**1**	**2**
		FRB	
1	69	0.17	- 0.05
2	70	0.16	- 0.05
3	68	0.16	- 0.04
4	67	0.14	- 0.04
5	66	0.14	- 0.03
6	65	0.11	- 0.03
7	64	0.08	- 0.03
8	63	0.05	- 0.02
9	62	0.04	- 0.02
10	61	0.01	- 0.01
11	60	0.01	- 0.01
12	59	- 0.00	- 0.01
13	57	- 0.02	0.00
14	56	- 0.02	0.00
15	55	- 0.03	0.01
16	58	- 0.05	- 0.00
17	53	- 0.05	0.02
18	54	- 0.08	0.02
19	52	- 0.08	0.03
20	51	- 0.09	0.04
21	50	- 0.12	0.04
22	48	- 0.16	0.06
23	47	- 0.17	0.07
24	49	- 0.18	0.05

EXHIBIT D (CONT'D.)

LINEAR LEAST-SQUARES CURVE FITTING PROGRAM

REL PRICE MODEL 8 DEP VAR 1:

STANDARD DEVIATION ESTIMATED FROM RESIDUALS OF NEIGHBORING OBSERVATIONS (OBSERVATIONS 1 TO 4 APART IN FITTED Y ORDER).

		ORDERED BY WSSD				ORDERED BY FITTED Y				
NO.	CUMULATIVE STD DEV	WSSD	OBSV.	OBSV.	DEL RESIDUALS	WSSD	DEL RESIDUALS	FITTED Y	OBSV.	SEQ.
1	0.02	0.11	68	70	0.02	2.88	0.02	1.04	49	1
2	0.01	0.12	66	67	0.01	1.87	0.02	1.07	47	2
3	0.01	0.14	57	56	0.00	10.94	0.01	1.07	48	3
4	0.01	0.14	61	60	0.00	22.45	0.00	1.09	50	4
5	0.01	0,88	59	60	0.02	6.56	0.02	1.10	54	5
6	0.01	1.09	55	56	0.01	1.94	0.02	1.11	51	6
7	0.01	1.13	70	69	0.02	15.67	0.02	1.11	52	7
8	0.01	1.61	59	61	0.02	2.92	0.02	1.12	58	8
9	0.01	1.64	54	52	0.01	3.67	0.01	1.13	53	9
10	0.01	1.79	68	69	0.00	1.79	0.01	1.14	55	10
11	0.01	1.79	55	57	0.01	0.14	0.00	1.15	57	11
12	0.01	1.87	47	48	0.02	3.32	0.03	1.15	56	12
13	0.01	1.94	51	52	0.02	1.61	0.02	1.16	59	13
14	0.01	2.06	67	68	0.01	0.14	0.00	1.16	61	14
15	0.01	2.13	58	55	0.01	7.42	0.00	1.16	60	15
16	0.01	2.28	57	59	0.03	2.48	0.00	1.18	62	16
17	0.01	2.48	62	63	0.00	3.97	0.00	1.20	63	17
18	0.01	2.88	49	47	0.02	6.74	0.01	1.21	64	18
19	0.01	2.92	58	53	0.02	7.58	0.01	1.24	65	19
20	0.01	3.06	67	70	0.03	0.12	0.01	1.27	66	20
21	0.01	3.15	66	68	0.01	2.06	0.01	1.27	67	21
22	0.01	3.32	56	59	0.03	0.11	0.02	1.28	68	22
23	0.01	3.67	53	55	0.01	1.13	0.02	1.28	70	23
24	0.01	3.97	63	64	0.00	4.61	0.00	1.29	69	24

EXHIBIT D (CONT'D.)

LINEAR LEAST-SQUARES CURVE FITTING PROGRAM

REL PRICE MODEL 8 DEP VAR 1:

ORDERED BY COMPUTER INPUT						ORDERED BY RESIDUALS				
IDENT.	OBSV.	WS DISTANCE	OBS. Y	FITTED Y	RESIDUAL	OBSV.	OBS. Y	FITTED Y	ORDERED RESID.	SEQ.
19	47	255.	1.086	1.066	0.021	47	1.086	1.066	0.021	1
19	48	214.	1.071	1.074	- 0.003	70	1.299	1.279	0.020	2
19	49	258.	1.037	1.040	- 0.003	56	1.163	1.148	0.015	3
19	50	129.	1.071	1.086	- 0.015	57	1.159	1.146	0.013	4
19	51	78.	1.118	1.111	0.006	58	1.129	1.117	0.012	5
19	52	56.	1.101	1.114	- 0.013	51	1.118	1.111	0.006	6
19	53	23.	1.126	1.131	- 0.005	64	1.219	1.215	0.005	7
19	54	46.	1.086	1.105	- 0.018	61	1.163	1.160	0.003	8
19	55	9.	1.142	1.140	0.002	63	1.198	1.195	0.003	9
19	56	4.	1.163	1.148	0.015	69	1.293	1.291	0.003	10
19	57	3.	1.159	1.146	0.013	55	1.142	1.140	0.002	11
19	58	17.	1.129	1.117	0.012	60	1.163	1.161	0.002	12
19	59	0.	1.141	1.155	- 0.015	68	1.278	1.279	- 0.000	13
19	60	1.	1.163	1.161	0.002	62	1.182	1.182	- 0.001	14
19	61	2.	1.163	1.160	0.003	48	1.071	1.074	- 0.003	15
19	62	13.	1.182	1.182	- 0.001	49	1.037	1.040	- 0.003	16
19	63	26.	1.198	1.195	0.003	53	1.126	1.131	- 0.005	17
19	64	50.	1.219	1.215	0.005	65	1.234	1.241	- 0.007	18
19	65	93.	1.234	1.241	- 0.007	67	1.260	1.269	- 0.010	19
19	66	153.	1.254	1.268	- 0.015	52	1.101	1.114	- 0.013	20
19	67	161.	1.260	1.269	- 0.010	50	1.071	1.086	- 0.015	21
19	68	199.	1.278	1.279	- 0.000	59	1.141	1.155	- 0.015	22
19	69	239.	1.293	1.291	0.003	66	1.254	1.268	- 0.015	23
19	70	208.	1.299	1.279	0.020	54	1.086	1.105	- 0.018	24

APPENDIX H

MAJOR FACTORS IN ELECTRICITY DEMAND VARIABILITY

The following tables in this Appendix indicate the variability that might be expected in the future for various uses of electric power. Table 33 shows estimated ranges for significant applications of electricity for the years 1980 and 1985. Figure 3 and Table 34 show trends of market saturation for major electrical appliances.

TABLE 33

SUMMARY OF SOME FACTORS AFFECTING ELECTRICITY DEMAND PROJECTIONS

Residential/Commercial

Space Heating*

	Installations (Millions)	Annual Consumption/Unit (KWH)	Range of Potential Consumption (Billion KWH)
1970	4.4	9,000	39.6
1980	8 - 12	12,000	96 - 144
1985	12 - 18	15,000	80 - 270

Central Residential Air Conditioning†

	Installations (Millions)	Annual Consumption/Unit (KWH)	Range of Potential Consumption (Billion KWH)
1970	7.0	4,900	34.3
1980	11 - 14	4,500	49.5 - 63.0
1985	14 - 17	4,500	63.0 - 76.5

Residential Air Conditioning (Room Units)‡

	Installations (Millions)	Annual Consumption/Unit (KWH)	Range of Potential Consumption (Billion KWH)
1970	24.5 x 2 = 49.0	1,390	68
1980	(40 - 50) x 2 = 80 - 100	1,390	111.2 - 139
1985	(50 - 60) x 2 = 100 - 120	1,390	139 - 166.8

Efficiency Ranges—Room Units	4.0 - 8.0 BTU/Watthour
Average Efficiency 1970	5.5 BTU/Watthour

If units in 1980 and 1985 were to have average efficiencies of 8.0 BTU/watthour, the ranges of potential consumption, based on the units projected above, could be:

1980 $\frac{5.5}{8.0} \times (111.2 - 139) = 76.5 - 95.6$ Billion KWH

1985 $\frac{5.5}{8.0} \times (139 - 166.8) = 95.6 - 114.7$ Billion KWH

Lighting—Efficacy §

	Light Output, Lumens	Efficacy: Lumens per Watt
Incandescent		
60-watt, Inside frost	900	15
100-watt, Inside-frost	1,700	17
150-watt, Inside-frost	2,850	19
Fluorescent		
24", 20-watt Cool White	1,220	61
48", 40-watt Cool White	3,200	80
48", 40-watt Cool White Deluxe	2,250	56
96", 215-watt Cool White	15,500	72

TABLE 33 (Cont'd.)

	Light Output, Lumens	Efficacy: Lumens per Watt
Mercury		
400-watt Deluxe White	19,200	48
High Pressure Sodium		
1,000-watt Lucalox‖	130,000	130

Transportation

Electric Road Vehicles **

	Vehicles (Millions)	Annual Consumption/Vehicle (KWH)	Range of Potential Consumption (Billion KWH)
1980	0.4 - 1.6	10,000	4 - 16
1985	1.0 - 6.0	10,000	10 - 60

Electric Railways (Freight)††

	1980	1985
Estimated Ton Miles (Billion)	1,000	–
Percent Carried on Electrifiable Lines (Percent)	60	–
Electricity Consumption per 1,000 Ton Miles (KWH)	30	–
Potential Electricity Consumption (Billion KWH)	18	20 - 25

Industrial

Electric Steel Production

Assuming steel output grows @ 2.3 percent per year (sufficient to double production by 2,000 AD), output in 1985 would be about 185 million tons. Electric production could account for from 15 to 25 percent of this total.‡‡

At 500 KWH per ton of steel produced, a 1985 range of potential electricity production would be: 185 million tons x (0.15 to 0.25) x 500 KWH/ ton = 13.9 to 23.1 Billion KWH

* Annual consumption per unit, calculated from data reported in the *FPC Survey of All-Electric Homes,* FPC R-77. Values for 1980 and 1985 are assumed to rise because of an increasing number of installations in northern areas.

† Average consumption per installation in 1970 estimated on basis of the FPC survey. Values for 1980 and 1985 are assumed to decline because of increased number of installations in northern areas and in apartment dwellings.

‡ Estimate of 2 units per household. Average number of households equipped in 1970 from *Merchandising Week* magazine. Constant efficiency assumed at 5.5 BTU/watthour.

§ Better Light—Better Sight Bureau, EEI.

‖ General Electric trade name.

** Annual consumption assumes 1 KWH per vehicle mile and 10,000 miles per vehicle year. Source: According to P. D. Agarwal of General Motors, a full-sized U.S. car with air conditioning would require 0.5 KWH per mile of travel measured at the output of the electric motor. Assuming motor and control efficiency at 70-percent battery discharge efficiency at 80-percent and charging efficiency at 90-percent, the requirement at the "wall plug" would approximate 1 KWH per vehicle mile. See "Electric Car and Air Pollution" Paul D. Agarwal, Society of Automotive Engineers, Automotive Engineering Congress, Detroit, Michigan (January 11 - 15, 1971), p. 4.

†† *Railroad Electrification* Vol. 1, Chapter 2, EEI, 1970.

‡‡ Battelle Memorial Institute has estimated that in 25 years nearly half of the U. S. steel production will be electric.

TABLE 34

PRODUCT SATURATION LEVELS

Products	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Air Conditioners, Room	19.4	20.2	24.2	27.9	30.7	33.5	36.7	40.6	44.5	46.7
Bed Coverings, Electric	29.6	32.4	34.7	38.7	42.3	45.6	47.5	49.5	51.1	52.7
Blenders	9.9	11.0	13.0	16.0	20.0	25.9	31.7	36.5	40.0	41.5
Can Openers	15.0	19.7	24.7	29.8	34.5	39.4	43.2	45.5	48.1	49.5
Coffeemakers	65.5	68.5	71.7	76.0	79.6	82.9	86.4	88.6	91.0	93.1
Dishwashers	9.0	11.8	13.5	15.7	18.1	20.8	23.7	26.5	29.6	32.0
Dryers, Clothes, Elec. & Gas	23.5	24.2	26.4	30.5	34.6	38.8	40.3	44.6	47.6	51.0
Disposers, Food Waste	13.4	13.5	13.6	15.9	18.0	20.5	22.9	25.5	28.4	31.9
Freezers, Home	26.4	26.7	27.2	27.5	27.7	28.5	29.6	31.2	32.7	34.3
Frypans	48.9	49.0	49.2	50.3	51.8	53.4	55.2	56.2	58.0	59.4
Hotplates & Buffet Ranges	22.4	22.5	22.7	23.0	23.4	23.7	24.1	24.5	24.8	25.0
Irons, Total	97.4	98.3	99.1	99.3	99.3	99.5	99.5	99.7	99.8	99.9
Irons, Steam & Steam/Spray	70.6	73.9	77.5	81.2	83.3	85.8	87.1	88.2	90.1	91.4
Mixers, Food	68.3	70.4	72.8	76.0	78.5	80.5	81.7	82.4	84.4	85.2
Radios	97.9	99.3	99.5	99.5	99.5	99.7	99.7	99.8	99.8	99.9
Ranges, Elec. Free-Standing	31.7	31.9	32.1	32.4	34.1	36.2	38.3	40.5	42.6	44.1
Ranges Elec. Built-in	8.4	9.5	10.3	12.2	12.9	13.7	14.4	15.0	15.7	16.6
Refrigerators	99.1	99.3	99.5	99.6	99.7	99.8	99.8	99.8	99.8	99.9
Television, B&W	93.4	94.1	97.1	97.8	98.1	98.5	98.7	98.7	99.8	99.8
Television, Color	–	5.1	9.5	15.0	26.2	35.7	38.2	42.5	51.1	60.7
Toasters	79.9	81.1	83.6	86.3	87.6	89.3	91.0	92.6	94.2	95.1
Vacuum Cleaners	79.5	81.2	83.5	85.6	87.0	89.1	90.7	92.0	94.4	96.9
Washers, Clothes*	86.5	86.9	87.4	88.2	89.3	90.8	91.9	92.1	94.3	96.9
Water Heaters, Electric	22.9	23.2	23.4	24.7	26.1	27.8	29.6	31.6	33.8	36.3
(Base) Total Number Wired Homes	**54,890,000**	**56,410,000**	**57,580,000**	**58,845,000**	**60,062,000**	**61,296,500**	**62,699,000**	**64,025,000**	**65,550,000**	**67,307,000**

* 20% of these households don't actually own washers but have access to them in basements of apartment houses.

Note: Saturation – The percentage of U.S. homes with one or more of the products listed. Theory – High saturation means good replacement sales, low saturation good initial sales. Replacement potential exists in coffeemakers, irons, radios, refrigerators, b/w tv, toasters, vacuum cleaners, and clothes washers. Still ripe for initial sales are dishwashers, food waste disposals, home freezers, hot plates, water heaters, and built-in electric ranges. Strong growth possibilities exist in color tv, blenders and room air conditioners. Saturation levels in the table above are to December 31 of the year indicated. The saturation levels as of December 31, 1973 are detailed in the saturation index on Figure 3.

Source: *Merchandising Week 1974 Statistical and Marketing Report.*

WIRED HOMES WITH Number	%		WIRED HOMES WITHOUT %	Number
33,960,000	48.9	ROOM AIR CONDITIONERS	51.1	35,488,000
37,433,000	53.9	BED COVERINGS (ELEC.)	46.1	32,015,000
29,793,000	42.9	BLENDERS	57.1	39,655,000
35,210,000	50.7	CAN OPENERS	49.3	34,238,000
65,837,000	94.8	COFFEEMAKERS	5.2	3,611,000
23,821,000	34.3	DISHWASHERS	65.7	45,627,000
37,432,000	53.9	DRYERS, CLOTHES (ELEC. & GAS)	46.1	32,016,000
24,515,000	35.3	DISPOSERS, FOOD WASTE	64.7	44,933,000
26,321,000	37.9	FREEZERS, HOME	62.1	43,127,000
42,085,000	60.6	FRYPANS	39.4	27,363,000
17,431,000	25.1	HOTPLATES & BUFFET RANGES	74.9	52,017,000
69,379,000	99.9	IRONS (TOTAL)	0.1	69,000
64,795,000	93.3	IRONS (STEAM & STEAM/SPRAY)	6.7	4,653,000
60,628,000	87.3	MIXERS	12.7	8,820,000
69,379,000	99.9	RADIOS	0.1	69,000
32,224,000	46.4	RANGES, FREE-STANDING (ELEC.)	53.6	37,224,000
12,015,000	17.3	RANGES, BUILT-IN (ELEC.)	82.7	57,433,000
69,379,000	99.9	REFRIGERATORS	0.1	69,000
69,379,000	99.9	TELEVISION, B & W	0.1	69,000
46,600,000	67.1	TELEVISION, COLOR	32.9	22,848,000
67,017,000	96.5	TOASTERS	3.5	2,431,000
67,712,000	97.5	VACUUM CLEANERS	2.5	1,736,000
67,900,000	97.8	WASHERS, CLOTHES*	2.2	1,548,000
26,460,000	38.1	WATER HEATERS, (ELEC.)	61.9	42,988,000

Note: All figures based on 69,448,000 domestic and farm electric customers.

* 20% of these households don't actually own washers but have access to use them in basements of apartment houses.

SOURCE: *Merchandising Week 1974 Statistical and Marketing Report.*

Figure 3. Saturation Index for Key Products (as of December 31, 1973).

CHANGES IN ENERGY REQUIREMENTS THROUGH EFFICIENCY CHANGES

INTRODUCTION

This Appendix attempts to analyze changes in primary fossil-fuel requirements caused by changes in efficiency in use. There are two separate areas where efficiency can change significantly: (1) in chemical transformation and (2) through improved energy conversion devices. The former concept has had largely an academic meaning in the period up through 1970 in that we have depended on natural supply--e.g., natural gas, natural gas liquids and petroleum.

As shown in Table 35, refining losses do occur for petroleum when it is converted into prime fuels. It is estimated that the manufacture of prime fuels, viz. gasoline and No. 2 distillate, requires between 10 and 15 percent of the original crude energy--more for gasoline because more steps are involved. In general, more energy is required to make lighter fuel products.

The lack of hydrogen in coal means that in converting coal to products rich in hydrogen, such as methane, distillates, etc., a significant portion of the coal must be burned to supply the energy to make hydrogen. This is mainly a stoichiometric and thermodynamic constraint. Technology improvements cannot significantly change this situation. However, excellent engineering of heat transfer equipment, recovery of heat through more expensive techniques, etc. might allow the efficiency of coal conversion to methane to increase up

TABLE 35

REFINING OR EFFICIENCY OF CONVERSION OF FOSSIL FUELS – COLD PRODUCT EFFICIENCY

Initial Energy Form	Methane	60° API Gasoline	30° API Distillate	5° API Distillate	Low BTU Gas 150-250 BTU/SCF*
LPG	94	–	–	–	–
Naphtha	91	98	–	–	–
Residue – 3-percent Sulfur	82	78	75	92	95
Crude Oil – 2-percent Sulfur	84	85	90	–	95
Coal – 3-percent Sulfur	68	65	75	80	93
Bitumen from Tar Sands	82	78	75	92	95
Shale Coker Distillate	86	85	90	–	–

* Includes sensible heat.

to 72 to 75 percent. The 68-percent efficiency level noted in Table 35, however, might represent a compromise that could be achieved by 1985. If the need for hydrogen can be bypassed, as in the manufacture of producer gas (CO, H_2, CH_4 mixtures), the thermal efficiency is very high. The losses would represent mainly radiation losses and energy lost through sensible heat in the ash.

Energy conversion devices such as thermionics, MHD, fuel cells, etc. have been examined in a study by the New Energy Forms Task Group, and reasons have been given as to why none of these devices can have any significant impact before 1985.* One energy conversion device does promise significant improvement in efficiency in the 1972-1985 period. This is the combined cycle which employs a gas turbine and steam turbine to generate electric power. The projected efficiency could reach a potential of 48 percent by 1985. This would be through improved tolerance of gas turbines to inlet gas temperature. Industrial gas turbines now have temperature tolerance of 1,600 to 1,700°F. Aircraft-type turbines have the capability of reaching 2,000 to 2,200°F for peaking-type duty. If a base-loaded gas turbine could tolerate a 2,100°F temperature, the efficiency of the combined cycle would be about 45 percent. Low-cost gas turbines used in combined-cycle plants are available from four manufacturers in the United States. These turbines have heat rates of about 9,400 BTU's per KWH. Inlet gas temperatures to the gas turbine are confined to about 1,550 to 1,600°F. However, in Japan, heat rates of 8,500°F are already achieved with combined-cycle plants.

High-temperature gas turbines might not be simultaneously tolerant to high temperature and corrosive chemicals. However, a producer gas can be made in a gasifier with removal of the corrosive elements prior to inlet to the turbines. High efficiency is then possible with dirty fuels such as coal, residual fuels, coke, etc. We can consider the general case of some energy conversion device being available by 1985 which would have the capability of converting coal to electricity at an efficiency of about 48 percent (heat rate = 7,000 BTU's per KWH).

It is relatively unimportant in this analysis as to the exact nature of the energy conversion device. It could be a MHD-topped Rankine cycle, a thermionic-topped Rankine cycle, a fuel cell or a combined Brayton-Rankine cycle. At this writing, the latter device seems to have the greater chance for achieving the status of commercial availability in 1985.

Because of the large generating capacity having a low efficiency now in use and about to be installed, it will be many years after 1985 before a significant improvement in average efficiency in the U.S. can occur. (This will be proved with examples in a later section.) However, for present purposes we will identify the period when the heat rate reaches 7,000 as "post-1990." The heat rate in 1972 is taken as 10,666 BTU's per KWH. Nuclear power

* See NPC, *U.S. Energy Outlook--New Energy Forms* (March 1974).

plants are not considered in this analysis, since they are unique. All of the nuclear energy generated will be converted directly to electrical power, although options exist for converting fossil fuels to either electric power or refined fuels.

CHANGES IN COMMERCIAL SECTOR

Case Study I: Fossil Fuel *Versus* Electricity in Large Commercial Complexes (Warm Climates)

Gas engines can be used with or without heat recovery to run absorption air-conditioners. This can be illustrated by recent data from the county government complex of Pima County, which includes the city of Tucson. The government complex consists of a 10-story administrative building, a health and welfare building, parking garage, etc.

The systems considered by the consulting engineers included: (1) electric motor driven centrifugal chillers (2) gas engine driven centrifugal chillers and (3) gas engine driven centrifugal chillers with reclaimed engine heat available to power an absorption chiller for additional refrigeration effect. Using data provided by the consulting engineers for this building complex, the quantities of primary energy that would be required by the different systems are compared in Table 36.

TABLE 36

MONTHLY AND ANNUAL ENERGY REQUIREMENTS (MM/BTU's)

Month	Electric Motor Driven Chiller*	Gas Engine Driven Chiller	Gas Engine With Heat Recovery
January	725	570	420
February	940	732	567
March	1310	1040	787
April	1920	1490	1160
May	2470	1925	1490
June	3035	2380	1830
July	3480	2710	2100
August	3310	2670	2000
September	2920	2360	1825
October	2240	1735	1340
November	1360	1060	820
December	905	705	543
Total	**24,615**	**19,377**	**14,884**

* Assuming heat rate of 10,666 BTU's/KWH.

The heat rate of electrical generation was assumed to be 10,666 in column 1, or an efficiency of 32 percent. If we assume that electrical generation could reach the efficiency level of 48 percent post-1990, substantially less energy would be required on an annual basis if all-electric systems were used. This comparison is shown in Table 37. The comparison shown in this table assumes that gas would have to be made from coal at a thermal efficiency of 68 percent. Accordingly, the complex in Tucson, Arizona would require only 57 percent of the coal energy if an electric system were built.

Case Study II: Heat Engines *Versus* Electric Motors in Large Scale Space Cooling

A detailed analysis of the energy required for large scale air-conditioning equipment has recently been made at Southern Methodist University (SMU). In the SMU study, careful observation was made of the operation of two 2,000-ton refrigeration machines, both of the same manufacture and practically identical except for the drive. One system was steam driven, and the other was electric motor drive.

All of the energy consumed in the form of natural gas was carefully metered over a 6-month period. Also, for electric power consumption, meters were used to record main power electricity plus that required for auxiliaries, pumps, etc. The results as recently published by SMU are compared in Table 38. The energy required for the electric motor was calculated on the basis of 10,666 BTU's per KWH. It is clear from the above comparison that the electric motor-driven, large-scale refrigeration unit has a thermal efficiency 4 to 5 times that of the natural gas steam-driven system. This efficiency advantage would increase from a factor of 4-5 in 1972 to 8-9 post-1990 in favor of the electric drive. The latter assumes synthetic gas from coal and an improvement in electrical efficiency from 32 percent in 1972 to 48 percent post-1990.

TABLE 37

COMPARISON OF ENERGY REQUIREMENTS IN DIFFERENT SYSTEMS 1972 VERSUS POST-1990

1972	**ANNUAL BTU (x 10^6)**
Electric Motors	24,615
Gas Engines	19,377
Gas Engines with Heat Recovery	14,884
Post-1990	
Electric Motors	16,410
Gas Engines	28,495
Gas Engines with Heat Recovery	21,888

TABLE 38

COMPARISON OF GAS AND ELECTRIC SYSTEMS

	Gas-Steam Turbine System		Electric Motor System	
Month	Refrigeration Produced, Ton-Hrs.	Required BTU/Ton-Hrs.	Refrigeration Produced, Ton-Hrs.	Required BTU/Ton-Hrs.
May	518,046	68,310	935,037	13,108
June	598,792	55,340	929,750	12,831
July	725,958	55,990	1,103,552	12,596
August	1,332,425	40,420	634,374	13,524
September	656,913	61,610	1,022,910	12,909
October	151,018	19,490	789,411	14,164

TABLE 39

OBSERVED ANNUAL ENERGY CONSUMPTION

Project	1	2	3	4
Area, square feet	200,000	74,000	161,000	80,000
Electricity, KWH/sq. ft.	22.2	25.2	23.3	21.7
Fuel for Electricity*	240,000	272,500	252,000	235,000
Other fuel	66,200	105,000	60,500	217,000
Total	**306,200**	**377,500**	**312,500**	**452,000**
Relative Efficiency	100	81	98	67

* Heat rate = 10, 833 BTU/KWH as used in this table.

Case Study III: Efficiency of Energy Conversion in Commercial Office Buildings

A recent article in the *ASHRAE JOURNAL* has given a listing of annual energy requirements for a number of commercial office buildings.* These data are shown in Table 39. Project 4 in this table has an absorption refrigeration and gas heating system. All of the others have electric refrigeration and gas heating. Direct comparisons are not possible according to the *ASHRAE JOURNAL* article, because of variations in occupancy levels, condition of equipment, weather experience and ventilation system quality. However, there is the suggestion that the buildings using a greater fraction of their energy as electric power are more efficient.

* Amercian Society of Heating, Refrigeration and Air-Conditioning Engineering, *ASHRAE JOURNAL* (September 1971), pp. 64-72.

The efficiency factors can be extrapolated to post-1990 assuming an increase in the electrical efficiency to 48 percent. The gas requirement, since it is made from coal, has an efficiency of 68 percent. Buildings which use a larger fraction of their energy as gas would tend to decrease in efficiency while buildings with a larger fraction of electric energy would increase in efficiency.

TABLE 40

1972 ENERGY CONSUMPTION –– PROJECTED BEYOND 1990

	1972	Relative Efficiency (Percent)	Post-1990	Relative Efficiency (Percent)
Project 1	306,000 BTU's	100	252,000	121
Project 2	377,000 BTU's	81	330,000	99
Project 3	312,000 BTU's	98	252,000	120
Project 4	452,000 BTU's	67	472,000	64

Case Study IV: An Examination of Fossil Fuel--Electric Energy Variations for Large Commercial Buildings

The article referred to in the Case III study has also provided some energy balances for the design of a large commercial building in Chicago. Inasmuch as this location is in an area with a high heating load (6,155 annual degree days) this case study should tend to show advantages of heating in favor of gas. Comparative data are shown in Table 41 for the 1972 situation. Conditions at this time include the basic assumptions of natural gas availability and an electrical efficiency of 32 percent for Chicago. It can be seen that the gas heating cases result in the lowest primary energy consumption.

TABLE 41

COMPARISON OF FUEL USAGE IN VARIOUS ENERGY SYSTEMS –– 1972

	All Gas*	Gas Heat Absorption Refrigeration	Gas Heat Electric Refrigeration	All Electric
Electricity, KWH Use	3,562,610	3,562,610	4,114,098	7,093,435
Fuel for Electricity, MM BTU	50,600†	38,600	44,600	76,900
Boiler Fuel, MM BTU's	15,000‡	3,325	1,569	–
Total, MM BTU's	**65,600**	**41,925**	**46,169**	**76,900**

* Estimated
† Assumes heat rate of 14,240 BTU/KWH for on-site heat engine.
‡ Forty percent of cooling load is heat recovered from engine; 60 percent of heating load is heat recovered from engine.

The all-gas building was not considered in the article; however, estimates have been made as shown in column 1 of Table 41 for an all-gas building or total energy (TE) plant. The amount of primary energy used by the TE plant is not significantly different from the all-electric building. This results from the fact that the design building has an extremely high lighting load (5.0 watts per square root). Also a considerable power loading for fans, blowers, pumps, etc., are a part of a large building complex. Because the efficiency of an on-site engine would typically be low (14,000 to 17,000 BTU's per KWH), the power load can be generated off-site at considerably higher efficiency. In the comparison, off-site electricity has a heat rate of 10,833 BTU's per KWH. Even though the TE plant would recover some engine waste heat to supply the heating and cooling load, the high power load rules against any significantly improved efficiency over all-electric for TE. As stated in the earlier reports, TE can only have high efficiency when heating loads are high and electric loads are low. The reverse seems to be true in most large commercial buildings.

With the stated changes in efficiency for post-1990, the relative amounts of primary energy required by the several energy-options would shift to the values shown in Table 42. The building designs using gas for heating result in the lowest primary energy requirements. Presumably, the all-electric building employs resistance heating. If heat pumps were employed, the all-electric requirement should be considerably reduced, perhaps to a level of about 40,000 MM BTU's per year.

CHANGES IN RESIDENTIAL ENERGY CONSUMPTION

It is difficult to isolate the impact of technology on efficiency because energy consumption in homes will vary with the local weather, size of home, insulation standards, construction, direction orientation, window area and temperature of the occupied space. To arrive at some basis for evaluating changes in technology, gas consumption patterns for 16 cities were obtained from the American Gas Association

TABLE 42

ENERGY CONSUMPTION PROJECTED BEYOND 1990
(MM BTU)

	I All Gas	II Gas Heat Absorption Refrigeration	III Gas Heat Electric Refrigeration	IV All Electric
1972	65,600	41,925	46,169	76,900
Post-1990	96,300	30,590	32,010	51,200

(AGA) data described in Table 43, and three variations of gas-heated homes were compared: (1) space heating only; (2) space heating, range, water heater, clothes dryer; (3) complete gas home with air-conditioning. The efficiency of conversion in home-type units was assumed to be the following:

- Space heating, gas -- 70 percent
- Air-conditioning, gas -- 35 percent
- Space heating, electric -- 100 percent
- Air-conditioning, electric -- 200 percent.*

The above percentages are believed to be average values that would prevail on an annual basis. No doubt, some types of absorption direct gas-fired air-conditioning units have 45- to 50-percent efficiency at full load. However, at 40- to 50-percent load, the 35-percent value is believed to be typical of home units.

TABLE 43

ESTIMATED GAS CONSUMPTION FOR AVERAGE SINGLE-FAMILY DWELLING

	1969 Average Gas Cost* (Dollar/Therm)	Average Degree Days †	Gas Consumption A ‡ (Therms/Yr.)	B § (Therms/Yr.)	C ‖ (Therms/Yr.)
Boston	0.181	5,625	1,080	1,515	2,265
New York City	0.132	4,858	930	1,405	2,100
Baltimore	0.137	4,965	950	1,370	2,070
Philadelphia	0.148	4,824	925	1,400	2,095
Pittsburgh	0.095	5,291	1,015	1,490	2,185
Cincinnati	0.086	4,806	920	1,400	2,300
Detroit	0.089	6,232	1,195	1,675	2,525
Chicago	0.106	6,155	1,180	1,660	2,510
Kansas City, Mo.	0.069	4,711	900	1,365	2,590
Houston	0.106	1,367	260	705	2,860
Dallas	0.081	2,331	445	890	2,805
Atlanta	0.096	3,198	615	1,035	2,950
Los Angeles	0.090	1,728	330	825	1,905
San Francisco	0.077	4,070	780	1,270	2,185
Memphis	0.072	3,232	620	1,110	2,515
Denver	0.067	6,174	1,185	1,720	3,155

* Calculated from sales and revenue data supplied to American Gas Association on uniform statistical report.
† As reported to American Gas Association by companies.
‡ Space heating only.
§ Space heating range, water heater, and clothes dryer.
‖ All-gas home, including air conditioning (excluding gas light, grilles and incinerators.)

* Typical motor-driven air-conditioners consume from 1.2 to 1.8 KWH per 10,000 BTU's of sensible heat removed. The average efficiency at the point of consumption thus works out to be about 200 percent.

Energy consumption patterns for process heat loads in the home were taken from AGA publications and data published by the EEI. Process heat load for an average gas home is 435 therms per year. The energy requirement for an electric home is 745 therms per year. This value was calculated from the average KWH-data reported by EEI and was converted to therms using the heat rate of 10,666 BTU's per KWH.

Inasmuch as both gas and electric homes have an additional load for lighting, refrigerator, television and small appliances, it is necessary to add an additional 400 therms per year to the requirements for each home. This is referred to as *base load* requirements or *power load* requirements. In this manner we have divided energy consumption in homes into 4 categories: (1) process heat, (2) space heat (3) space cooling and (4) power load. This permits a more logical discussion of efficiency of energy conversion and allows us to relate the types of energy usage in homes to those which occur in industrial and commercial markets.

Using gas consumption data as supplied by the AGA for 16 cities across the United States, Figure 4 has been plotted with annual required therms as a function of annual degree days. It is commonly recognized that energy requirements for space heating is linearly related to annual degree days. (There is a suggestion that the data given by the AGA were obtained from some kind of chart, since the energy requirements for space heating for all 16 cities agrees well with the straight-line relationship.) Furthermore,

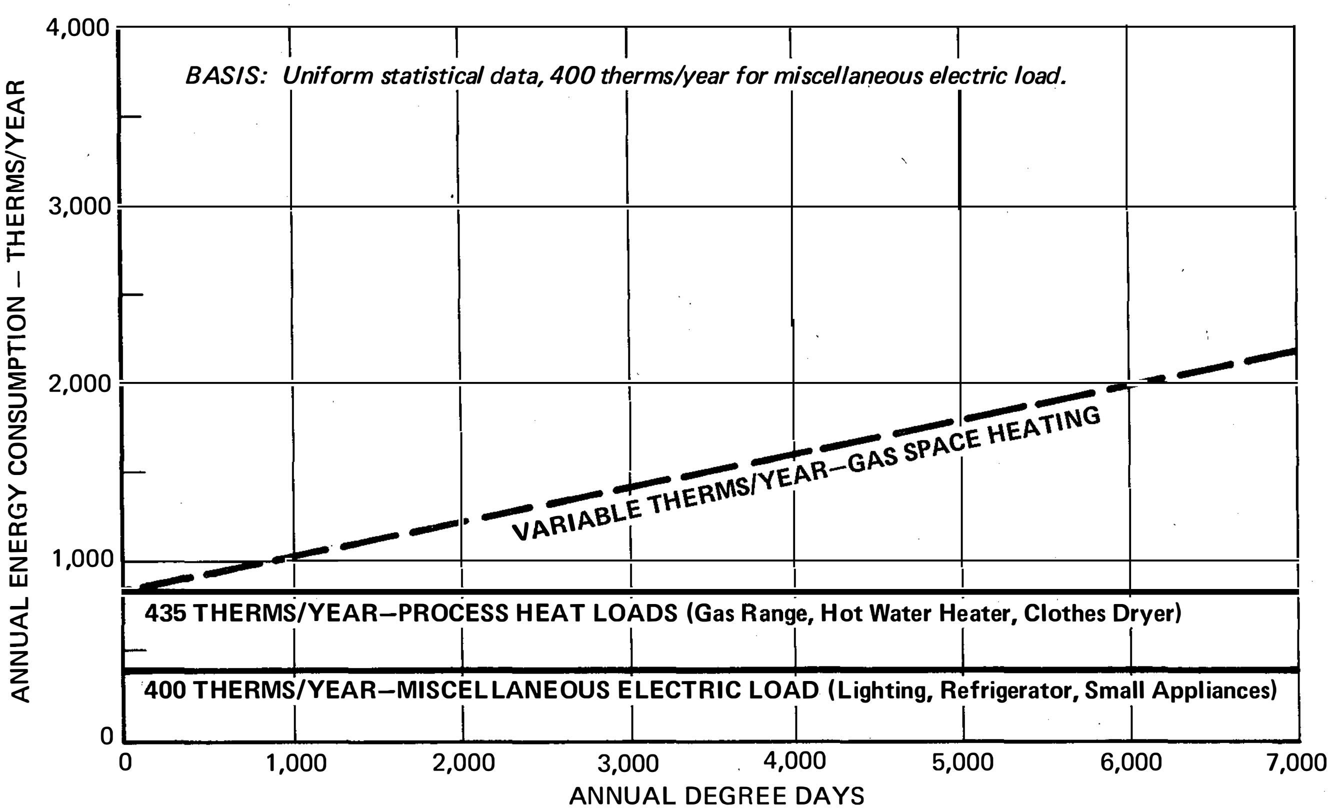

Figure 4. Annual Required Primary Energy for Gas Homes in the United States --1972.

Figure 5 shows the variations in annual energy requirements throughout the country. Energy used for heating varies with nearness to mountains, large inland lakes and the sea shore. The highly populated belt regions--ChiPitts and BosWash--also lie along areas where the annual degree days are high, thus accounting for the substantial energy requirements of these regions.

Using the gas consumption data for various homes across the United States, comparable data have been calculated for electric homes. The calculated energy consumption for electric homes is shown in Figure 6. This includes the 400 therms per year and 745 therms per year for power load and process heat loads, respectively. The required energy for electric homes has been calculated from the assumed efficiencies noted above, with the added stipulation that the net efficiency of electric power generation is 10,666 BTU's per KWH, corresponding to an efficiency of 32 percent. The amount of primary energy required back at the power plant for space heating an electric home then works out to be:

$$\text{Therms of fuel} = \text{Therms of gas} \cdot \frac{70}{32} .$$

It should be stressed that this is a "calculated value" and does not represent the actual amount of energy requirement for space heating in an electric home. Electric homes consume less energy than would be calculated by this method. This difference results for several reasons:

- Electric homes generally are better insulated.
- Use of heat pumps occurs in some electric homes.
- Electric homes may be smaller in size.
- The efficiency of gas-fired boilers may be less than the 70-percent value used in the calculations.
- Basement or garage space may not be heated in electric homes.

These variations often account for much of the controversy which occurs in the calculation of energy requirements for space heating in electric *versus* gas homes.

In order to arrive at some method for estimating this difference in "philosphy of space heating," we have taken some published data for electric home energy consumption in Portland, Oregon using 4,760 degree days. These data indicated that approximately 12,000 KWH of electric energy was used in single-family dwellings in Portland, as shown in Figure 7. The calculated therms would be 1,985 per year, using the equation above, while the actual consumpiton for space heating is 1,280 therms. (This assumes 12,000 annual KWH at a net heat rate of 10,666 BTU's per KWH.) Thus, the actual consumption for space heating in electric homes is about 64.5 percent of that calculated by the equation stated above. There is no way

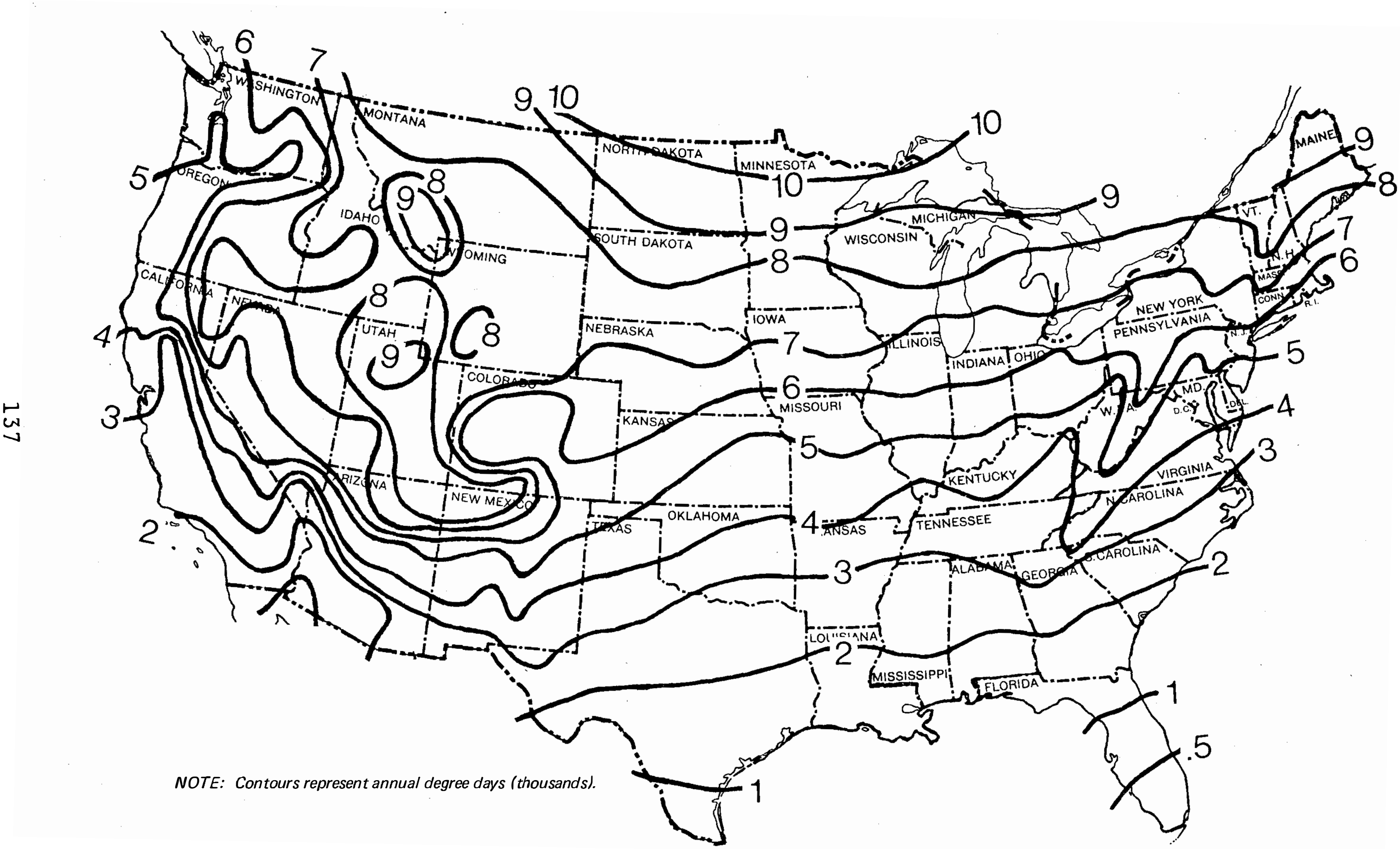

Figure 5. Relative Energy Requirements for Space Heating in the United States.

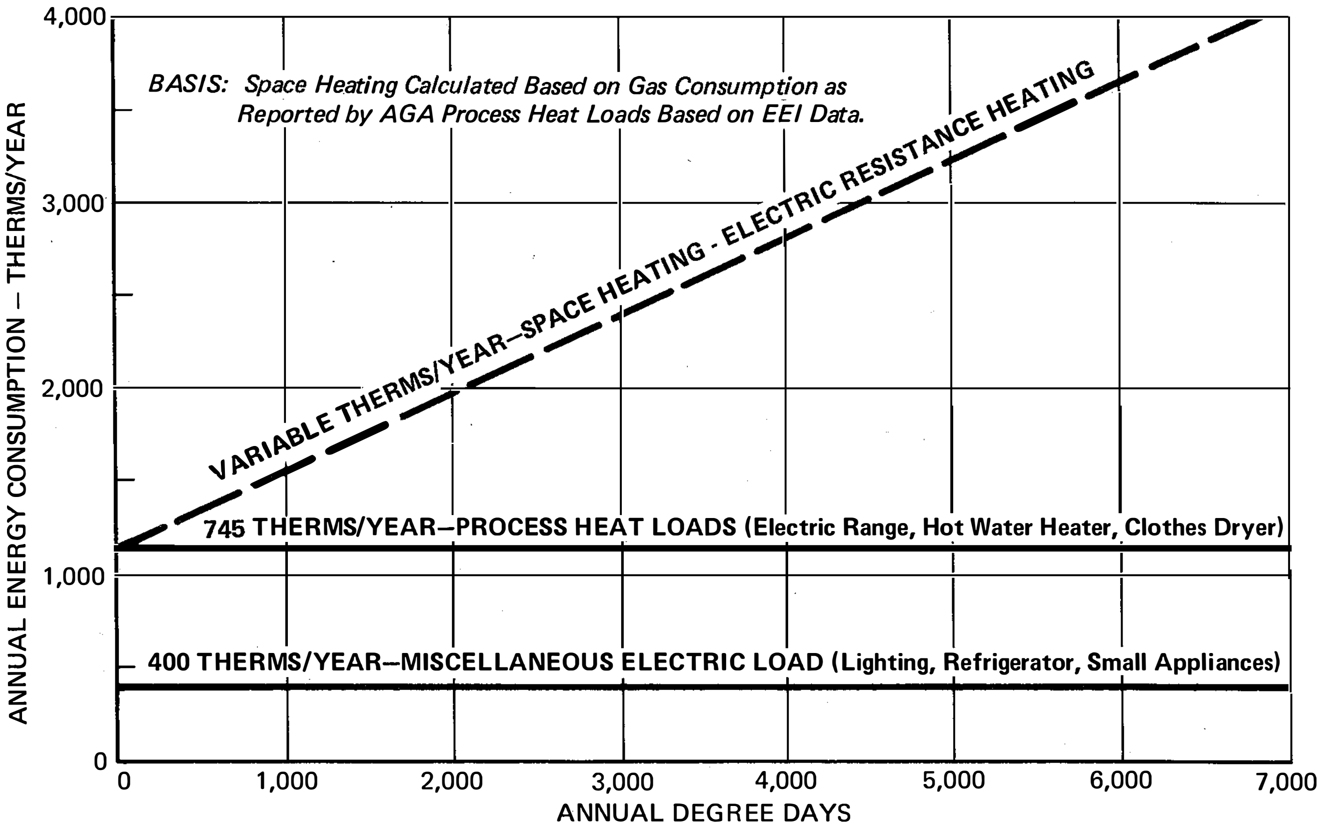

Figure 6. Annual Required Primary Energy for Electric Homes.

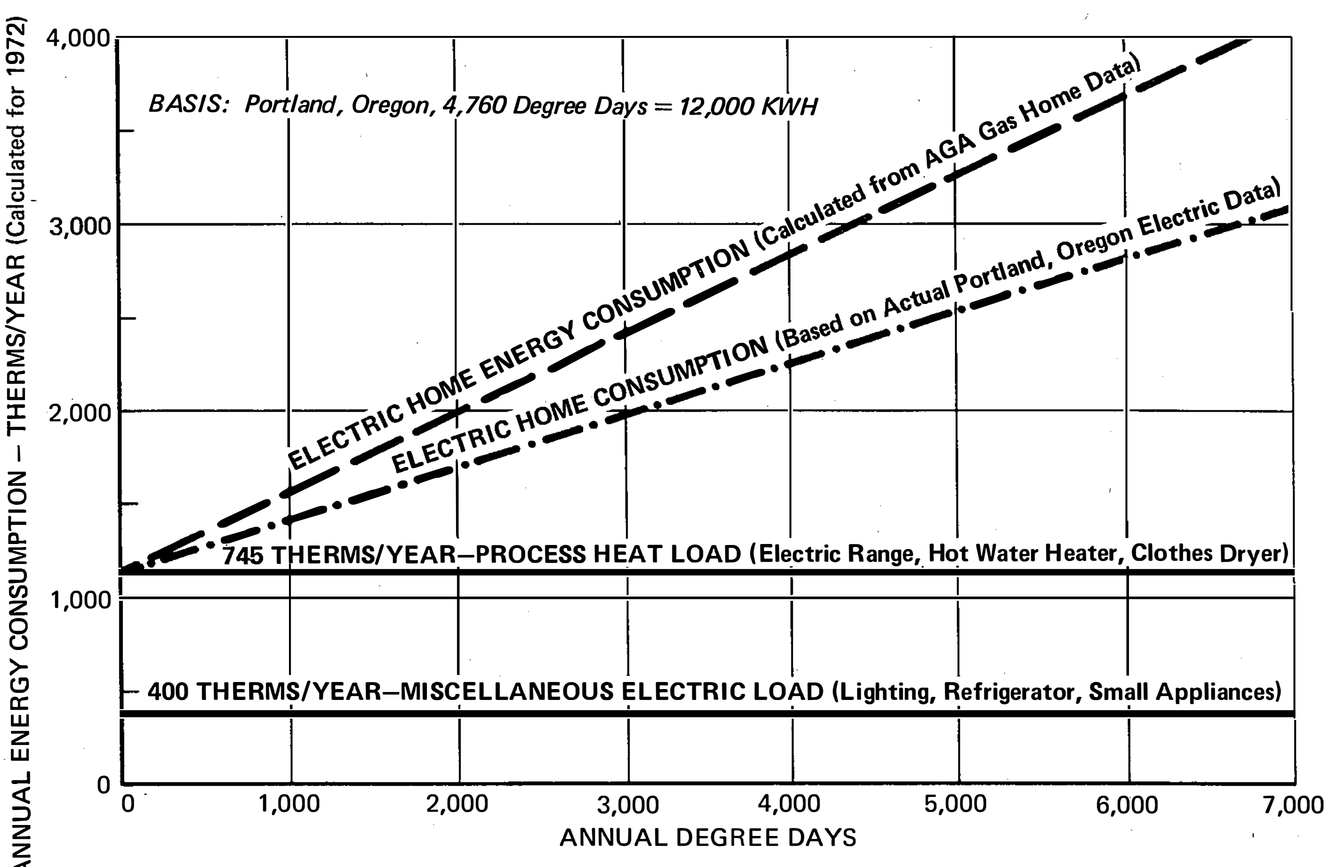

Figure 7. Correction of Electric Home Energy Consumption.

to make certain in this analysis what factors prevail in Portland, Oregon to account for this difference. Probably many factors contribute to some extent.

However, the relationships for space heating are:

Space heat, gas = 0.191 x annual degree days

Space heat, electric = 0.269 x annual degree days.

These equations give the amount of annual primary energy for space heating in single-family dwellings in 1972. A comparison of these linear relationships is made in Figure 8, and it can be seen that the gas homes tend to require less energy. However, this comparison is not strictly vaild for some homes because no account has been taken thus far of the air-conditioning load.

Table 44 summarizes energy requirements for both gas air-conditioning and electric air-conditioning in 16 U.S. cities. The

TABLE 44

RELATIVE ANNUAL ENERGY FOR WHOLE HOUSE AIR CONDITIONING

	Fossil Fuel Electric Power Heat Rate = 10,666 BTU/KWH		
	Gas (Therms/Yr.)	Electric COP = 2.0	Electric COP = 3.0
New York City	695	380	253
Philadelphia	695	380	253
Pittsburgh	695	380	253
Baltimore	700	383	255
Boston	750	410	273
Detroit	850	465	310
Chicago	850	465	310
Cincinnati	900	492	328
San Francisco	915	500	333
Los Angeles	1,080	591	394
Kansas City, Mo.	1,225	670	446
Memphis	1,405	768	512
Denver	1,435	785	523
Dallas	1,915	1,047	598
Atlanta	1,915	1,047	598
Houston	2,155	1,180	786

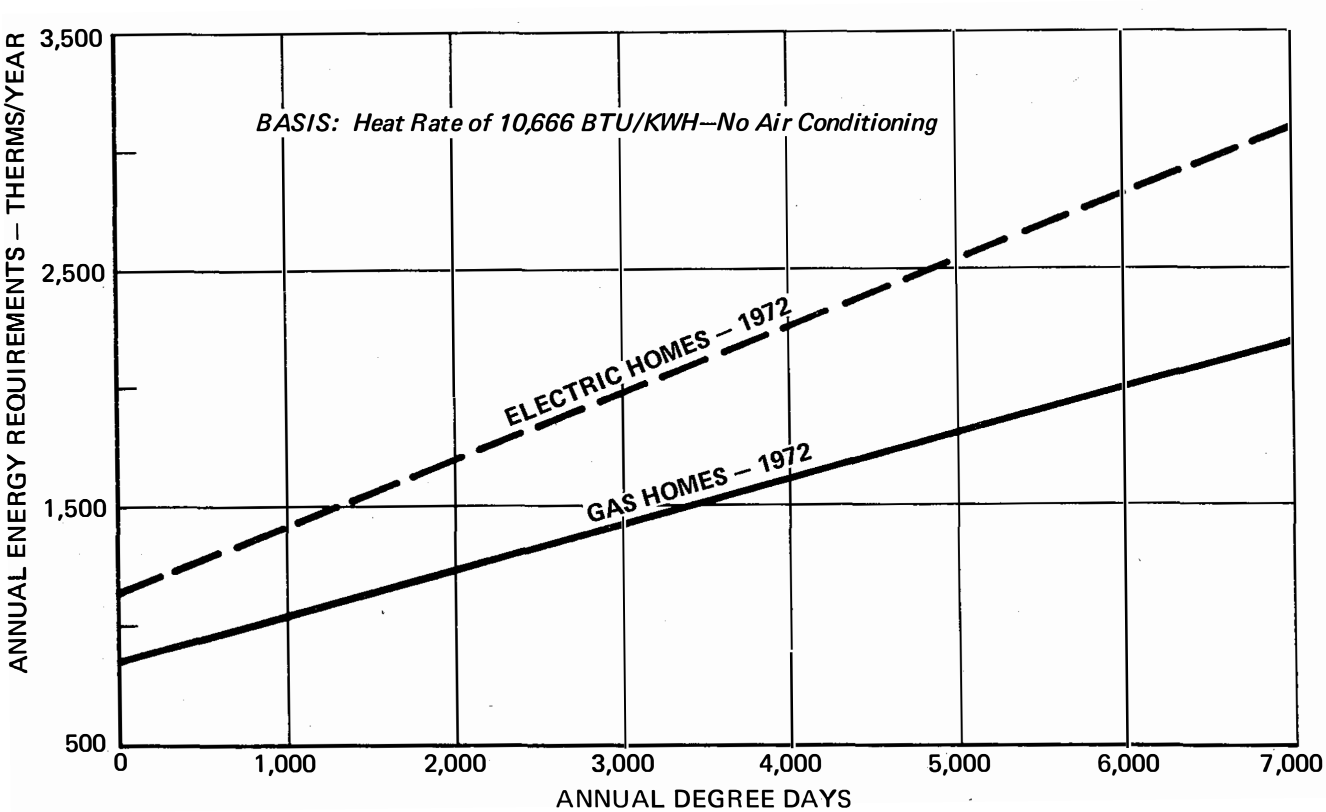

Figure 8. Comparison of Electric vs. Gas Homes in Primary Energy Requirement--Single-Family Dwelling.

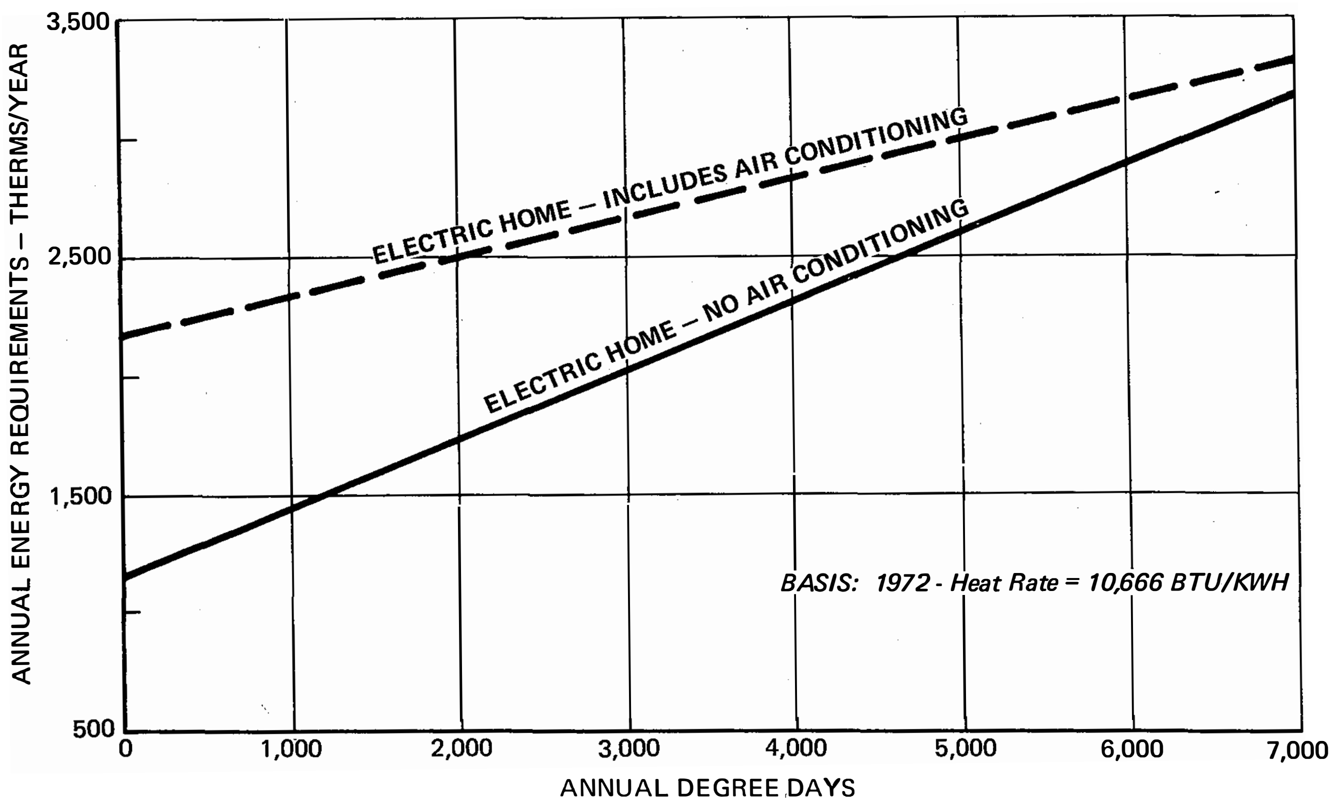

Figure 9. Additional Requirements for Air Conditioning--Single-Family Homes.

gas consumption data were obtained from the AGA. The electric data were calculated from the gas consumption data in Table 43. Since electric air-conditioning units for the home tend to be of the direct expansion (DX) heat pump type, the efficiency can vary widely. In general, the coefficient of performance (COP) is a measure of the amount of sensible and latent heat that can be pumped per hour relative to the energy consumption rate. For example, a COP of 2.0 would have a true efficiency of twice the electrical efficiency, or 2 x 32 = 64 percent. Some electric air-conditioners are better than this, but there are indications that economy-type models are most frequently sold, which have COP of no better than 2.0. Relatively large condensers and heat exchange surfaces are required to approach the high COP, and since this means greater bulk and higher cost, the trend in recent years has been for electrical manufacturers to sell the less efficient units.

It is estimated therefore, that whole-house air-conditioning energy requirements range from 2,000 therms in Houston to about 700 therms in New York City for gas-type air-conditioning. Electric air-conditioning is estimated to vary from 1,000 therms in Houston to 400 therms in New York City. An example of the addition of annual requirements for air-conditioning is shown in Figure 9.

Future Trends in Residential Energy Consumption Patterns

One can superimpose the technological trends for electrical conversion and the need for synthetic gas from coal on residential energy requirements. This can be done following the convention used above for various kinds of homes and the four categories for energy consumption. For example, Figure 10 shows energy consumption for total space-conditioned homes in 1972. Homes which employ gas for process heat and space heat and electric power for air-conditioning are the most efficient all across the United States. It should be noted that the wider use of heat pumps in certain geographical areas in the South might show improved efficiency relative to gas. The all-gas home becomes more efficient in the North as the air-conditioning load decreases. The all-electric home becomes inefficient relative to the all-gas home as the heating load increases.

The amount of energy in all-gas homes will increase significantly as gas must be made from coal (see Figure 11). Figure 12 indicates that the all-electric home will increase in efficiency as the heat rate improves from 10,666 BTU's per KWH in 1972 to 7,000 BTU's per KWH at some time after 1990. A comparison of mixed use of gas and electric power is shown in Figure 13. Efficiency will improve in the South if electrical air-conditioning is used. However, the efficiency will decrease in the North because more synthetic gas is needed for space heating requirements. All of these trends are shown in Figure 14. In general, the all-electric home would be the most efficient throughout the United States if the heat rate of 7,000 BTU's per KWH could be achieved from coal. Greater use of heat pumps and improvements in the efficiency of heat pumps would tend to decrease the energy requirements for electric homes.

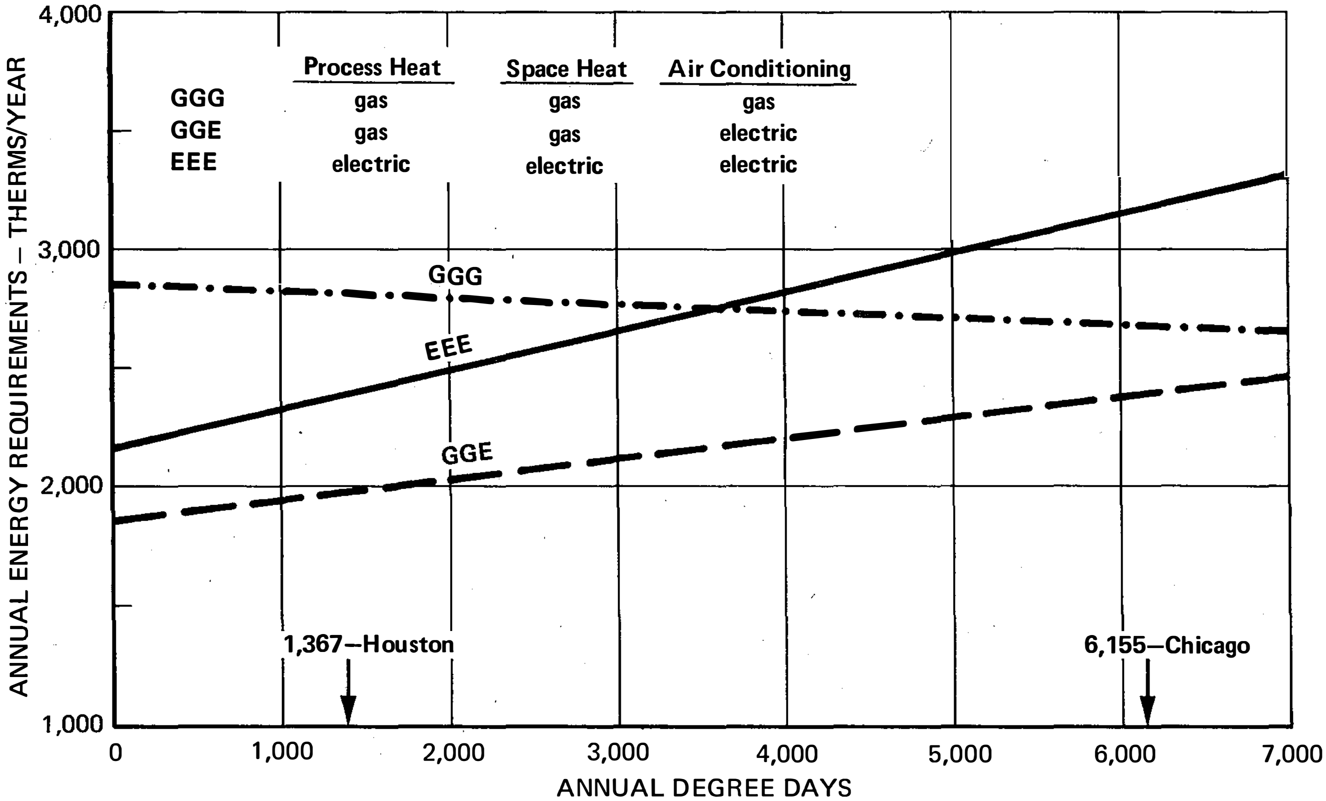

Figure 10. Comparison of Various Types of Single-Family Dwellings --1972.

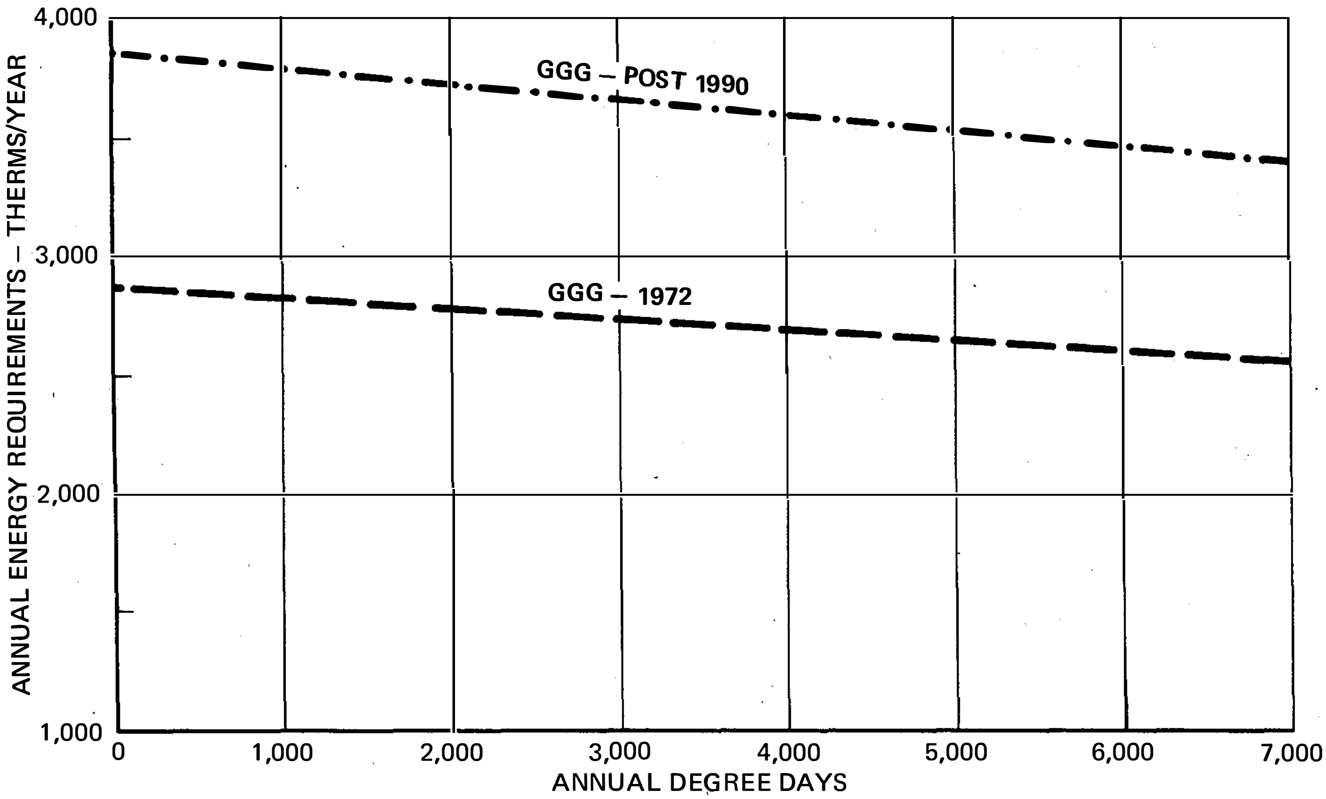

Figure 11. Comparison of Energy Requirements of All-Gas Home Evolution from Natural Gas to Synthetic Gas from Coal.

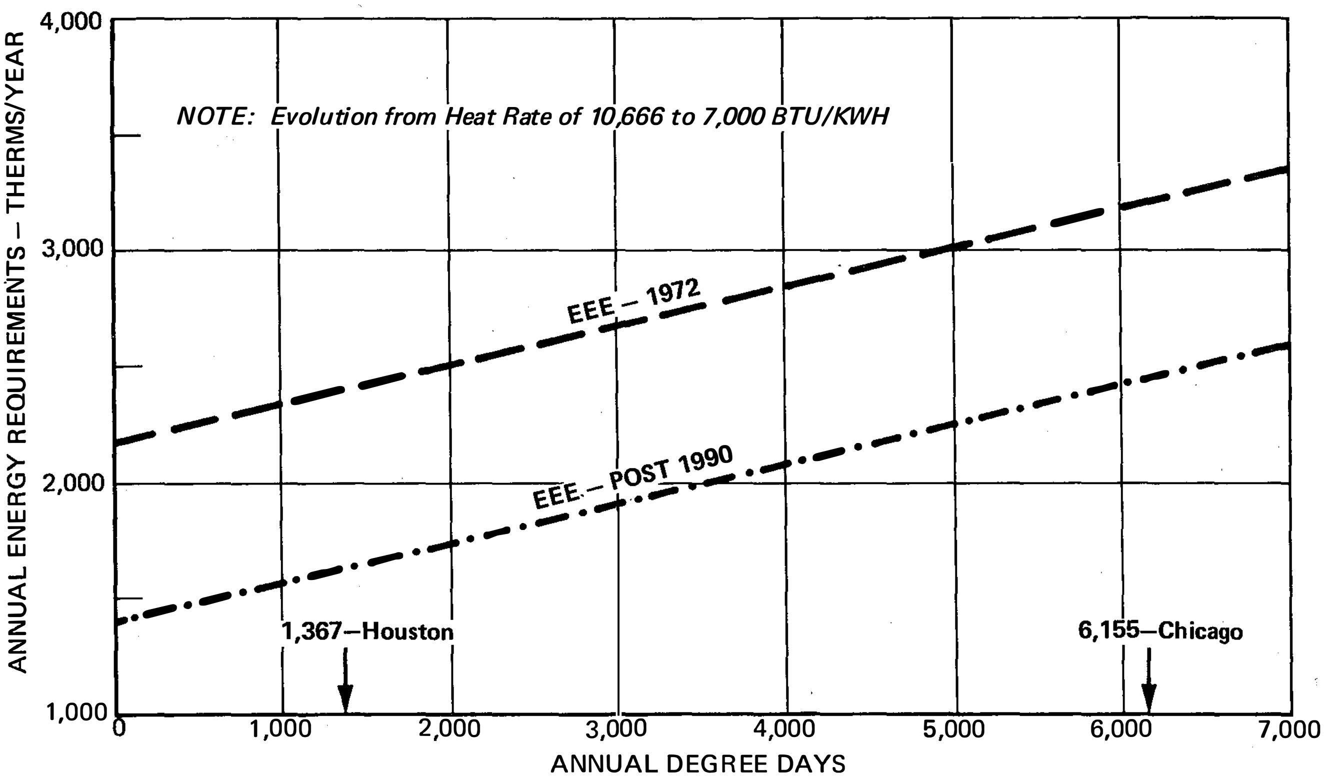

Figure 12. Comparison of Energy Requirements of All-Electric Home.

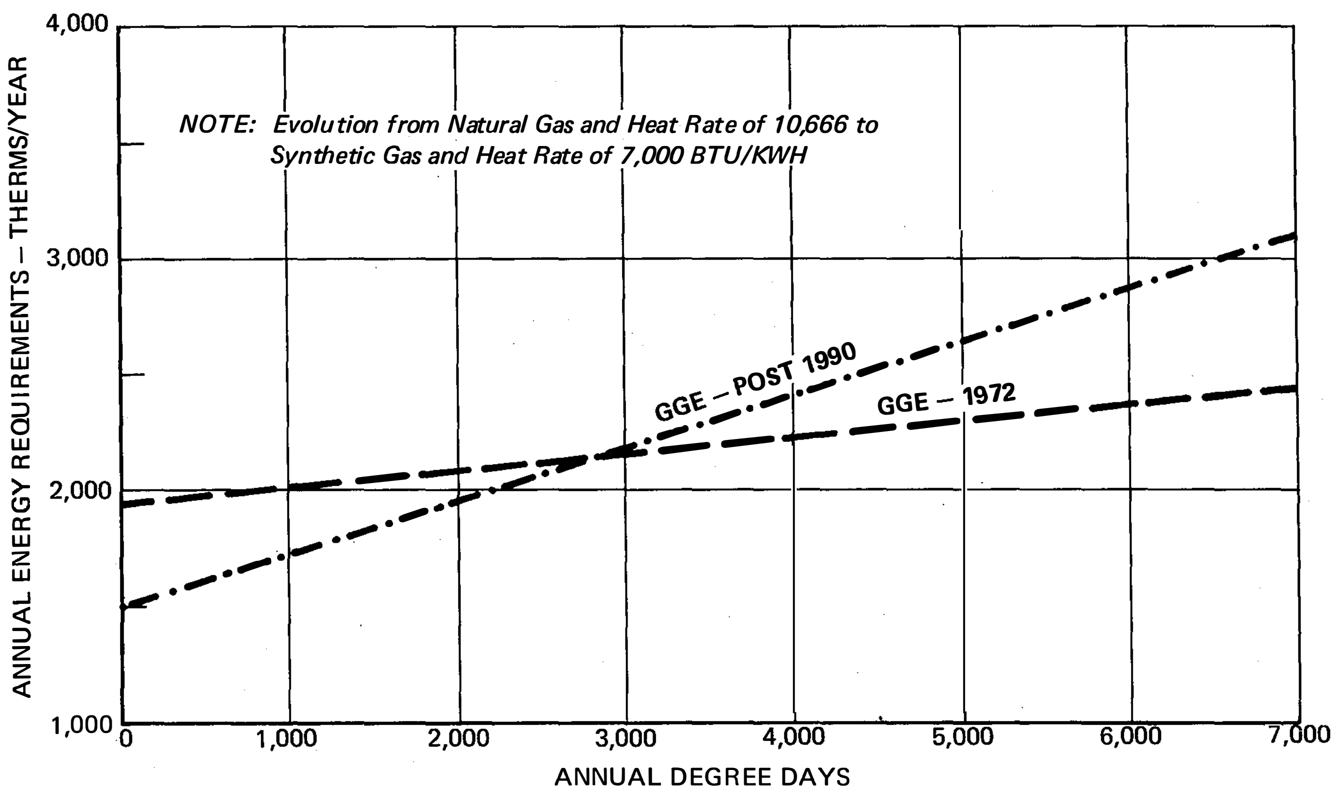

Figure 13. Comparison of Energy Requirements of Mixed Gas-Electric Home.

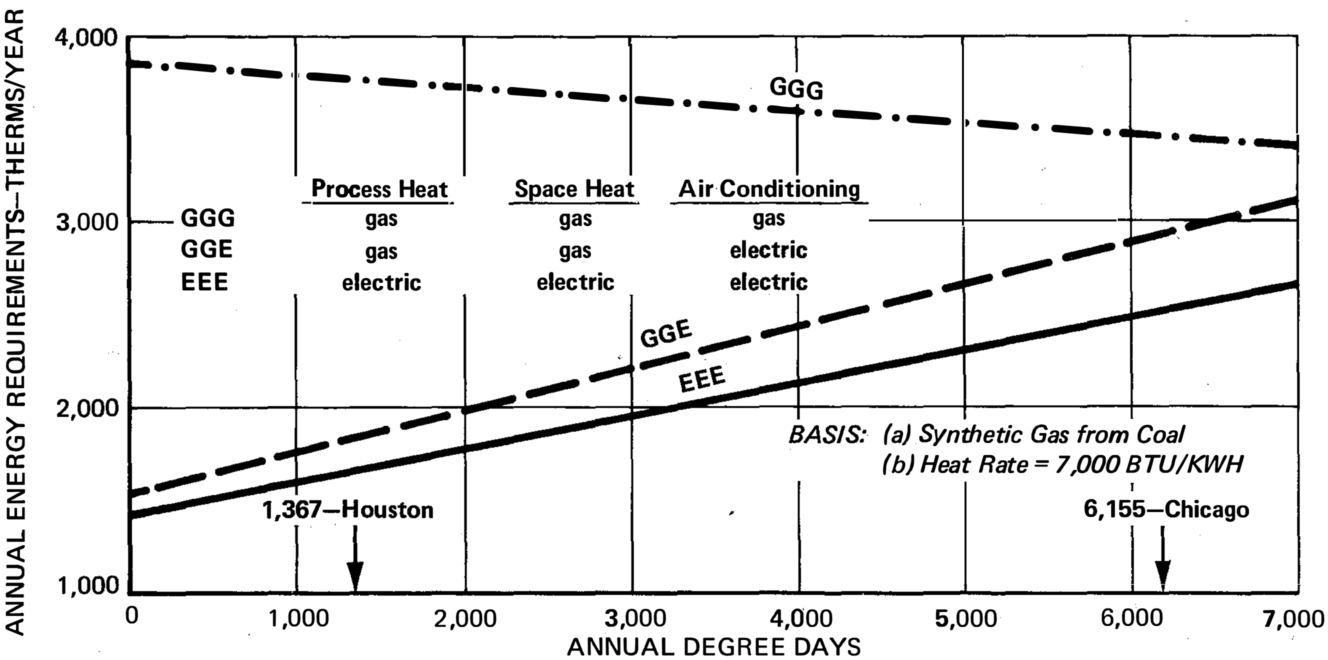

Figure 14. Comparison of Various Types of Single-Family Dwellings--1990-2000?

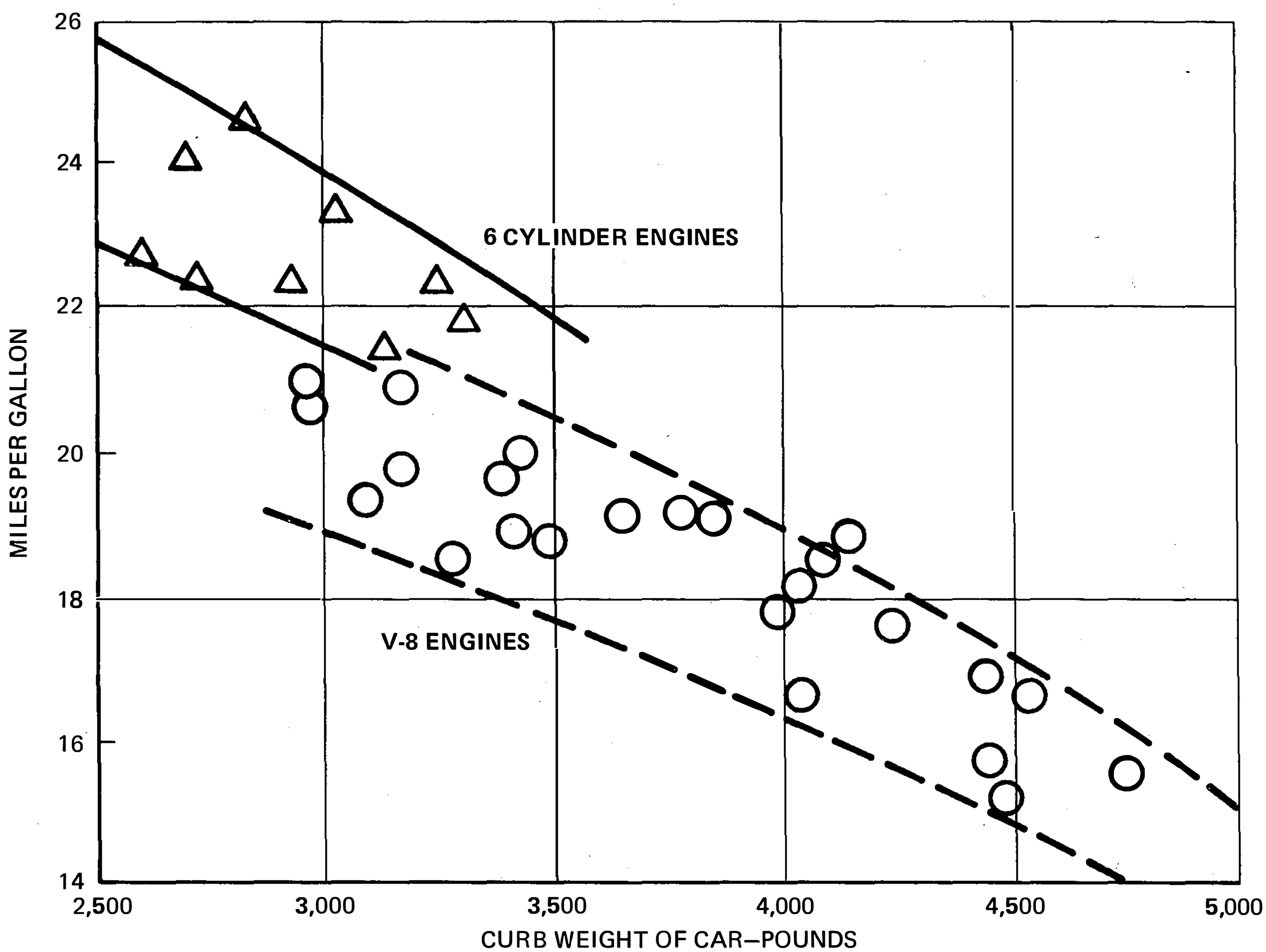

Figure 15. Car Weight and Engine Size are Two Most Important Factors Affecting Road Economy (1967 Mobil Economy Run--Los Angeles - Detroit).

No technological improvement in the direct use of gas for air-conditioning or the direct conversion of gas to electric power at high efficiency can now be foreseen.

The use of fuel cells which require reforming of methane prior to use in the fuel cell would require more energy than shown in Figure 14 because the electrical efficiency would be 25 to 26 percent from coal, in contrast to 48 percent which has been projected for a large power plant. While heat recovery from a fuel cell is possible, it would be impractical because electrical loads are small and the majority of the required heat would have to be provided by supplemental burning of gas. The overall efficiency of heating water or space heating should be only slightly improved over that experienced with direct burning of gas.

In this analysis, no anticipation has been made of increased energy for new electrical appliances. These increases would occur for all kinds of homes, however, and all of the curves in Figure 14 should increase as a result of new power loads. A recent FPC forecast has suggested that the all-electric home in 1990 will be using double the 1972 KWH per year. Inasmuch as the all-electric home would already be completely air-conditioned in 1972, it is difficult to imagine what these additional energy-consuming devices would be. Electric cars, large electric toys for children, electronic anti-burglar devices, electric equipment for melting snow from walks, electrically heated lawns and gardens are possibilities.

This analysis has discussed only single-family dwellings, but it is anticipated that the same relative energy consumption would prevail for apartments and mobile homes. In general, the amount of energy required for space-conditioning would be proportional to the space which is conditioned.

ENERGY FOR TRANSPORTATION

Automobiles are the most important consumers of energy in the transportation sector, and this trend should continue through 1985 and toward the year 2000. As shown in Figure 15, the weight of the automobile and the engine size are the two most important factors affecting road economy. In order to obtain fairly reliable figures on gasoline consumption as a function of other variables, data from the Mobil Economy Run from Los Angeles to Detroit in 1967 were used. This test was made before emissions controls caused reductions in road economy.

In addition to car weight and engine size, road economy is affected by axle ratio, carburetor, timing, etc. In general, the data from Figure 15 can be broken down into a range of car types--performance cars to economy cars (Figure 16). An intermediate car with balanced economy and performance would be somewhere in-between in road economy. This allows a reliable estimate of fuel consumption in turnpike-type driving prior to emissions controls.

Only a fraction of the driving in the United States is done under turnpike conditions, and it is necessary to correct the data shown

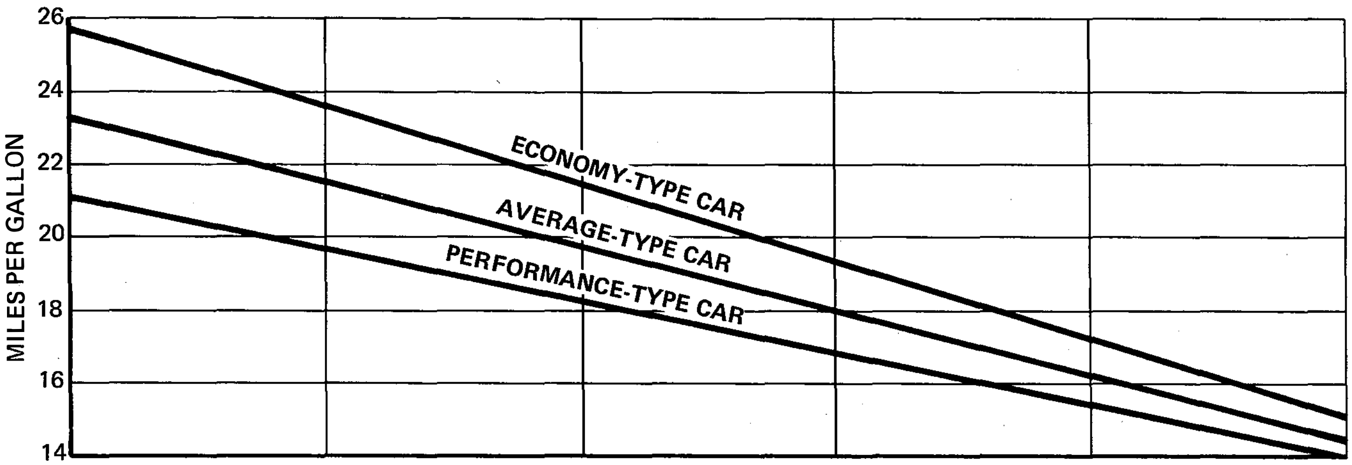

Figure 16. Variation in Road Economy with Car Type--Turnpike Driving--Pre-1967 Cars.

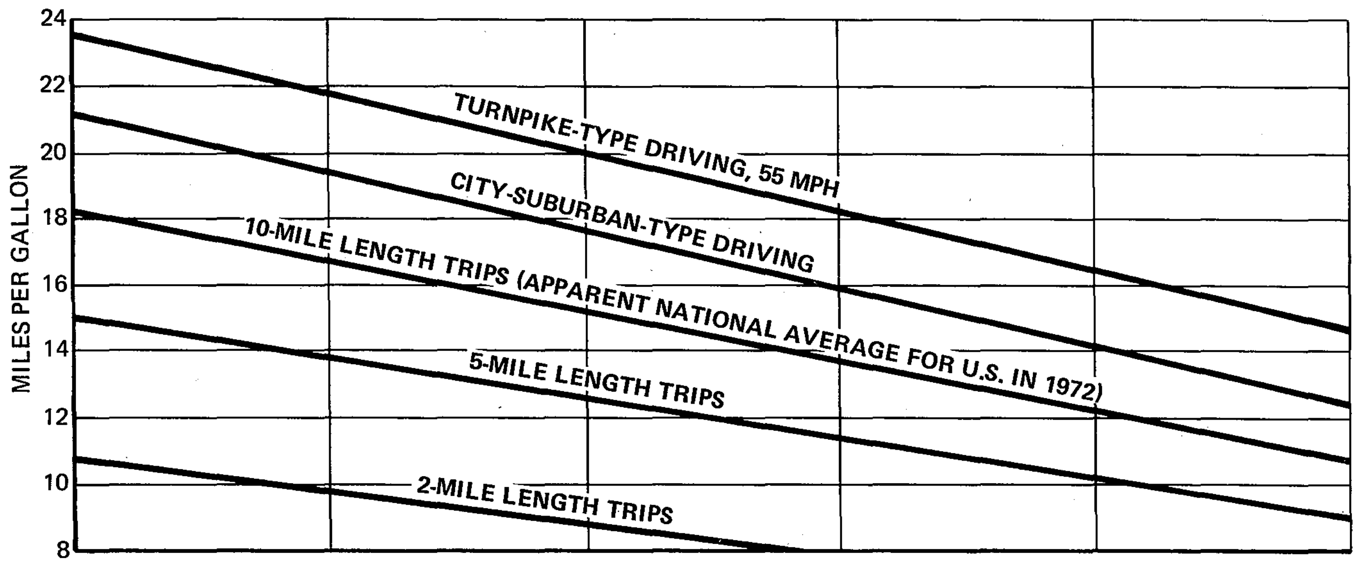

Figure 17. Corrections in Road Economy Due to Type of Driving--Pre-1967 Cars (Average of Types).

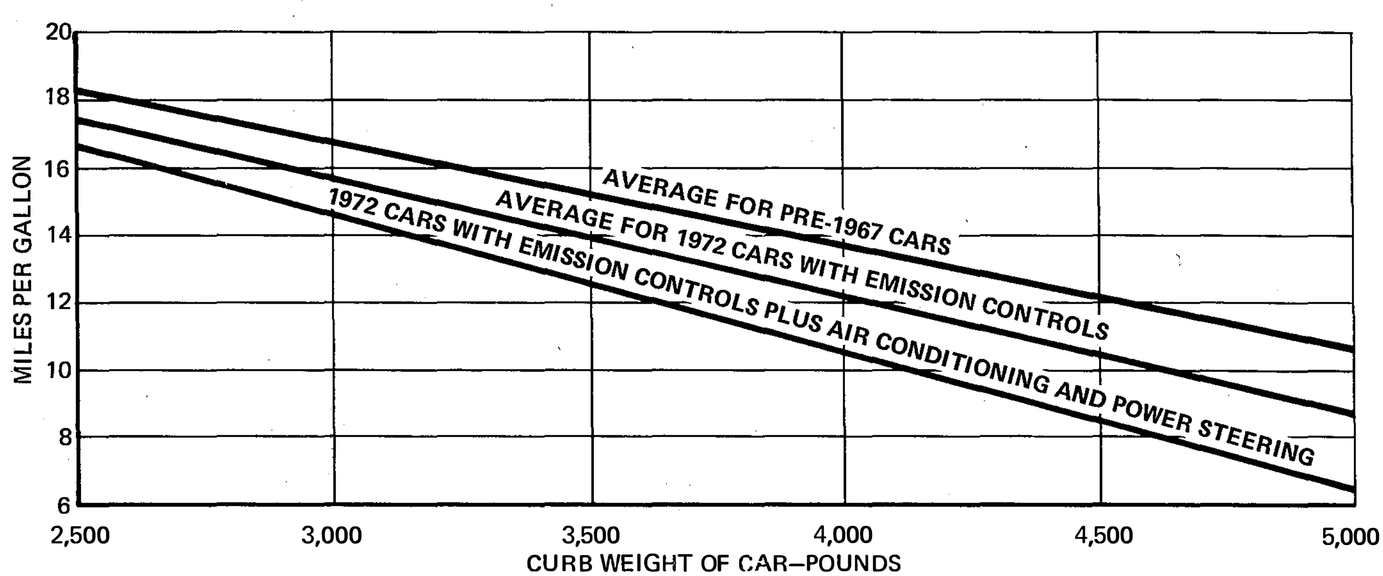

Figure 18. Corrections in Road Economy for Emission Control and Power Accessories.

in Figure 16 for other driving modes. This has been done in Figure 17 using published correlations. Short trips result in considerably lower miles per gallon than turnpike or city-suburban driving at relatively constant speed. The apparent national average for miles per gallon can be approximated by the line shown for 10-mile trips. For a 3,500-pound car, approximately 15 miles per gallon (mpg) would have been obtained prior to 1967. (This has not been corrected for power accessories.)

Due to emissions controls, automobiles became less efficient in the period from 1967 to 1972. The average data in Figure 18 have been corrected for the efficiency loss. This loss has been estimated to be 5 percent for a 2,500 pound car, 10 percent for a 3,500-pound car and about 15 percent for a 4,500-pound car. The corrected curve for 1972 cars is shown in Figure 18. Also shown is a correction for air-conditioning and other power accessories. In general, a 3,500-pound car (1972 model), operating with its power accessories a fraction of the time, would obtain about 13 mpg. A 2,500-pound car would obtain about 17 mpg, while the 4,500-pound car would obtain about 10 mpg for 1972 models. These numbers are annual averages which are estimated to be vaild for 1972 models. The 1971 edition of *Automobile Facts and Figures* indicates that 13.63 mpg were obtained in 1969 for all cars on the road. The estimate of 13 mpg is believed to be representative of 1972 models, however.

Trends in energy consumption from 1972 to 1985 and in the period up to the year 2000 cannot be stated quantitatively because there are too many unknowns. A factor of great importance related to what types of solutions will be forthcoming on the control of emissions. Otto-cycle engines have experienced relatively large losses in efficiency in the 1967 to 1972 period in that controls have been applied on particulates, carbon monoxide and nitric oxide. Each of these controls has an effect on economy.

Estimates are shown in Table 45 for changes in fuel economy which occurred in the 1967-1972 period. Estimated prospective changes in fuel economy for nitric oxide control between 1972 and 1976 are also shown. These losses are substantial; however, a reasonable view is that the losses will not be as severe as those shown in Table 45. If catalytic devices are used in 1975 and later models, substantial recovery of the losses could occur. Losses will also be reduced by improved ignition and air-fuel carburetion and induction.

A substantial portion of the losses from 1967 to 1972 models is due to the difficulty with air-fuel ratios under part throttle and transient conditions. Prior to 1967, engines ran relatively rich. Even though drastic variations of air-fuel ratios in time(cycle to cycle) and in geometry (cylinder to cylinder) have always occurred in the reciprocating Otto-cycle engines, no significant losses in economy occurred due to this phenomenon. Under lean air-fuel ratios (which are required to reduce carbon monoxide), variances in air-fuel ratio bring about decreased fuel economy. The losses are greater on large displacement engines, because they must run at part throttle conditions a larger fraction of the time. When cat-

TABLE 45

ESTIMATED LOSSES IN FUEL ECONOMY ATTRIBUTABLE
TO EMISSION CONTROLS BETWEEN 1967 AND 1972

	2500 lb. Car	3500 lb. Car	4500 lb. Car
Comp. Ratio Change (Percent)	8.7 to 8.2	9.3 to 8.2	10.0 to 8.2
Particulate Control (Percent)	-2	-4	-6
Carbon Monoxide Control (Percent)	-3	-6	-9
Total Losses in 1972 Models (Percent)	**-5**	**-10**	**-15**
Additional Losses for 1976 Models Versus 1967 (Percent)	-4	-4	-4
Total Potential Losses for 1976 Models (Percent)	**-9**	**-14**	**-19**

alyst devices are used to control carbon monoxide, it is reasonable to believe that engines can run under the proper air-fuel ratio to give better economy.

Substantial losses in economy are also possible if engines must use exhaust gas recirculation to reduce nitric oxide. This has a similar effect to leaning-out the engine so that optimum burning for good economy is not likely to be achieved. However, the use of catalytic devices to control nitric oxide would not significantly detract from engine economy.

Improvements in ignition and carburetion which are necessary to control emissions, should also be effective in partially restoring the road economy which was lost during the period from 1967 to 1972. Over-drive gears, which were used a number of years ago, may provide a mechanical approach to road economy.

The relatively high cost of emission control devices, safety items, emissions testing procedures, improved crash resistance and more careful attention to checks against recall of the auto, all tend to indicate that the average weight of cars will decrease. This will have the effect of improving the fuel economy.

In summary, the following trends will have the effect of countering the losses of economy observed in the 1967-1972 models and anticipated as a result of government standards for future models:

- Use of catalytic devices to control carbon monoxide
- Use of catalytic devices to control nitric oxides
- Improved ignition

- Improved air-fuel induction and carburetion
- Reduced weight of cars
- Use of over-drive gears
- Improved aerodynamic styling
- Reduced transmission losses (as front wheel drive).

A more important need is for improvement in economy under part-throttle conditions. In this case, two developments which could have the effect of improved economy under part-throttle conditions are stratified charge and inlet valve-throttled engines.

A number of new power plants are presently in various research and development stages. The engines which seem closest to commercial availability for the 1970-1985 period are the Wankel and the gas turbine. Both of these systems are said to have a lower efficiency than the reciprocating gasoline Otto-engine. However, it seems almost certain that these problems can be overcome by mechanical improvements. Gas turbine-powered engines can be built today which have comparable road economy to piston engines at speeds higher than 40 mph. What remains to be improved is part-throttle economy. Improvements in materials of construction, use of blade cooling, improved regeneration and air-fuel flow management are all possibilities for improving economy in the gas turbine.

Because the Wankel operates at lower effective pressures, its indicated thermal efficiency is lower than the piston engine. However, many people believe that the economy can be considerably improved. The possibility of inlet air-fuel throttling or stratified charge induction are extremely promising for the Wankel. At a low nitric oxide level (0.4 to 1.0 g/mile), it seems certain that the economy of the Wankel engine is equal or better than that of the piston engine.

From a longer range point of view (1980 and beyond), there is every reason to believe that the fuel economy of car operation must still relate to the weight of the car. In general, heavy cars moving at high speed or accelerating at high speed, will take much more energy per mile than small cars moving at more modest speeds. Improved road economy ultimately will be achieved through a general lowering of car weight and a reduction of speed limits on the highways. Any trends toward smaller cars for city driving (particularly for electric cars) would have a major effect on reduced energy consumption.

TRENDS TOWARD COAL AS AN ENERGY SOURCE

We can consider the general problem of using coal as a primary fuel to make gasoline for the automobile, if and when petroleum supplies become short. Technology does not exist in 1972 to convert coal to gasoline economically; however, by 1980 or 1985 some acceptable coal-to-gasoline process may be available.

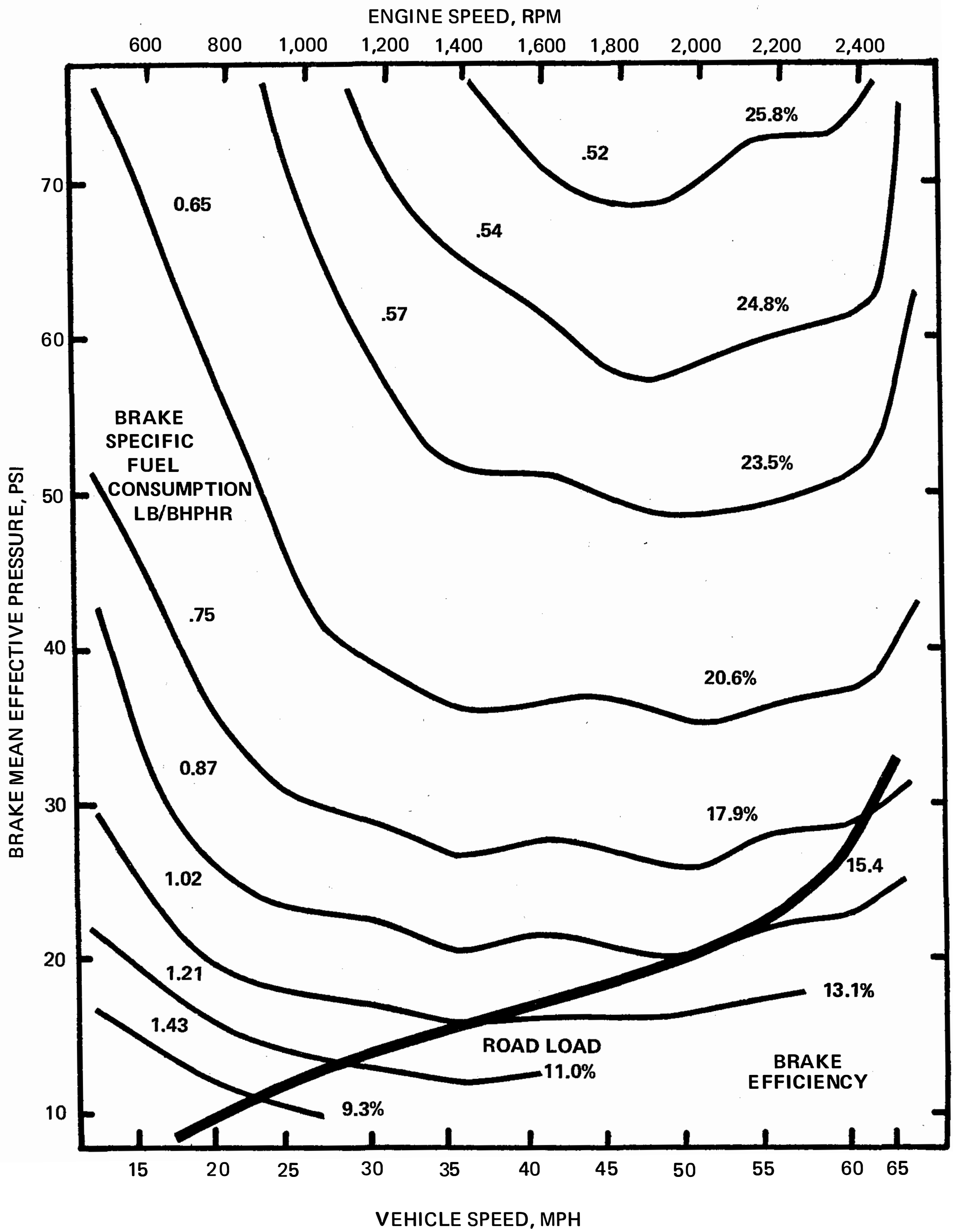

Figure 19. Typical Operating Characteristics of Passenger Car (9.2 CR, 283 Cubic Inch, 3.1 Axle ratio, fuel injection at 14.5 in all modes).

The amount of coal energy required to run automobiles can be calculated from the average efficiency of automobiles now running on petroleum-derived gasoline. Figure 19 is a plot of fuel consumption and effective efficiency of an average passenger car in 1967. At this time, the average compression ratio was 9.2, so the characteristics shown should be fairly representative of the average car on the road at that time.

The average efficiency under low-speed driving conditions is quite low. The average automobile has its highest efficiency at high speed and when accelerating under full throttle conditions. It will be assumed that the average efficiency is 11 percent in city driving (low speed, part throttle with frequent idling periods) and 17 percent in turnpike driving (high speed, fuller throttle). Depending on the relative mix of city and suburban driving, the efficiency of a pre-1967 value would have varied from 11 to 17 percent. An average value would have been about 14 percent. These values have been plotted in Figure 20.

As a result of emission controls, a 10-percent loss in efficiency is assumed between 1972 and 1985. Losses of crude oil occur in refining to produce gasoline and this loss has been assumed to be 15 percent. The average efficiency of the automobile, based on crude oil energy charged to the refinery, works out to be 10.8 percent. This value can be compared to the use of gasoline from coal in Figure 21. Since the efficiency of coal conversion to gasoline is 65 percent, the average efficiency of converting coal to usable brake horsepower would be about 8 percent.

The relative advantage of the electric car in a coal-based energy economy can be noted in Figure 21. Even with the technology of electrical conversion in 1972, the electric car would have double the efficiency of the gasoline car. As the efficiency of electrical generation improves, the relative advantage of the electric car will improve even more. For example, as the national heat rate for fossil fuels decreases from 10,666 in 1972 to 7,000 BTU's per KWH at some time after 1990, the electric battery car would be 3 times as efficient as the gasoline car. As the electric car efficiency should be relatively independent of speed, the use of battery cars in city-type driving would be very effective in reducing energy consumption.

The current potential range of electric cars between battery charges is low because the maximum energy per unit weight of batteries is low. Any improvements in the KWH-per-pound of battery-packs is likely to encourage the use of electric cars. The advent of the Wankel, with its lower engine weight, should make a more ideal complement for the electric car. Either the Wankel-electric or gas turbine-electric may be acceptable hybrids after 1985. Hybrids would have impressive efficiency advantages by about a factor of two over conventional engine-driven cars.

Other trends in transportation energy requirements can be seen in Table 46.

Aircraft and personal automobiles probably will continue to be the most important means of transporting people. These are the

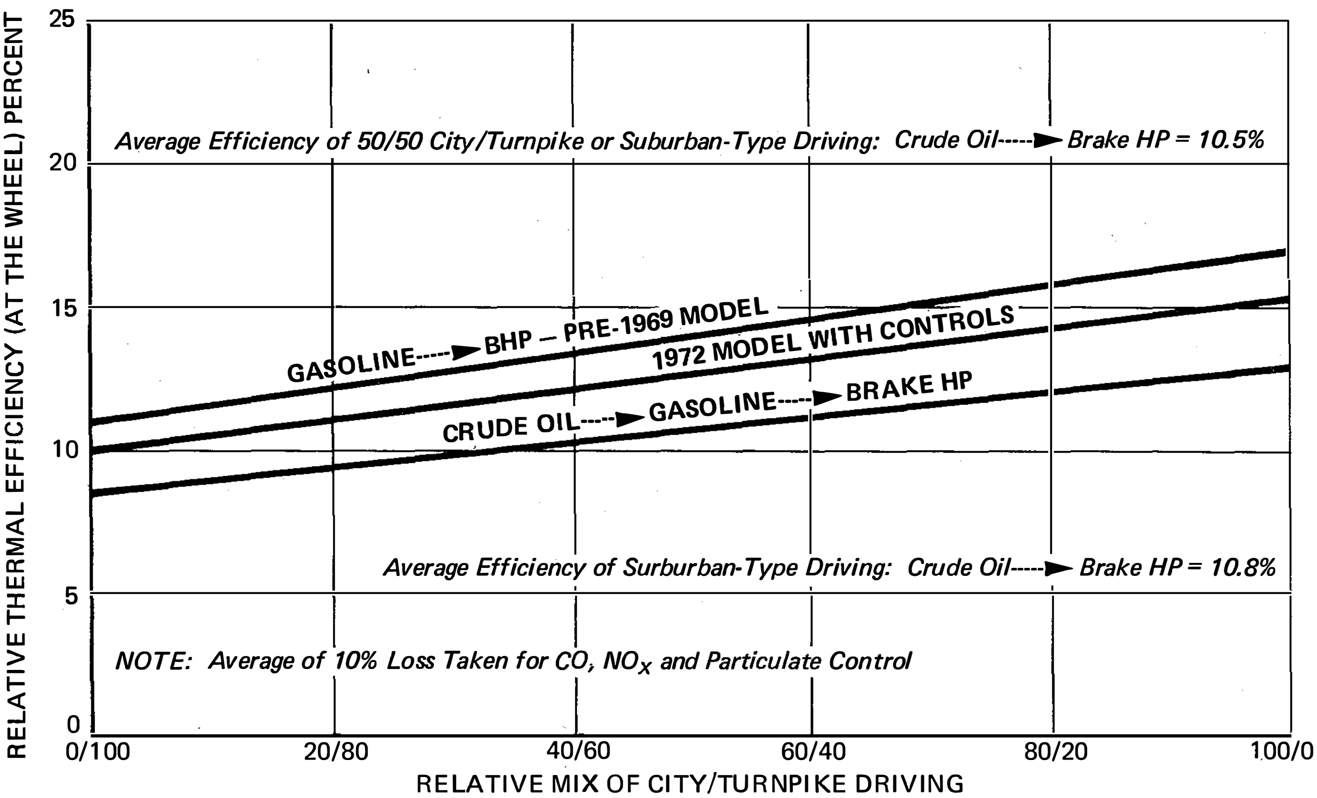

Figure 20. Relative Efficiency of Automobile--Corrections for Refining Losses and Emission and Environmental Controls.

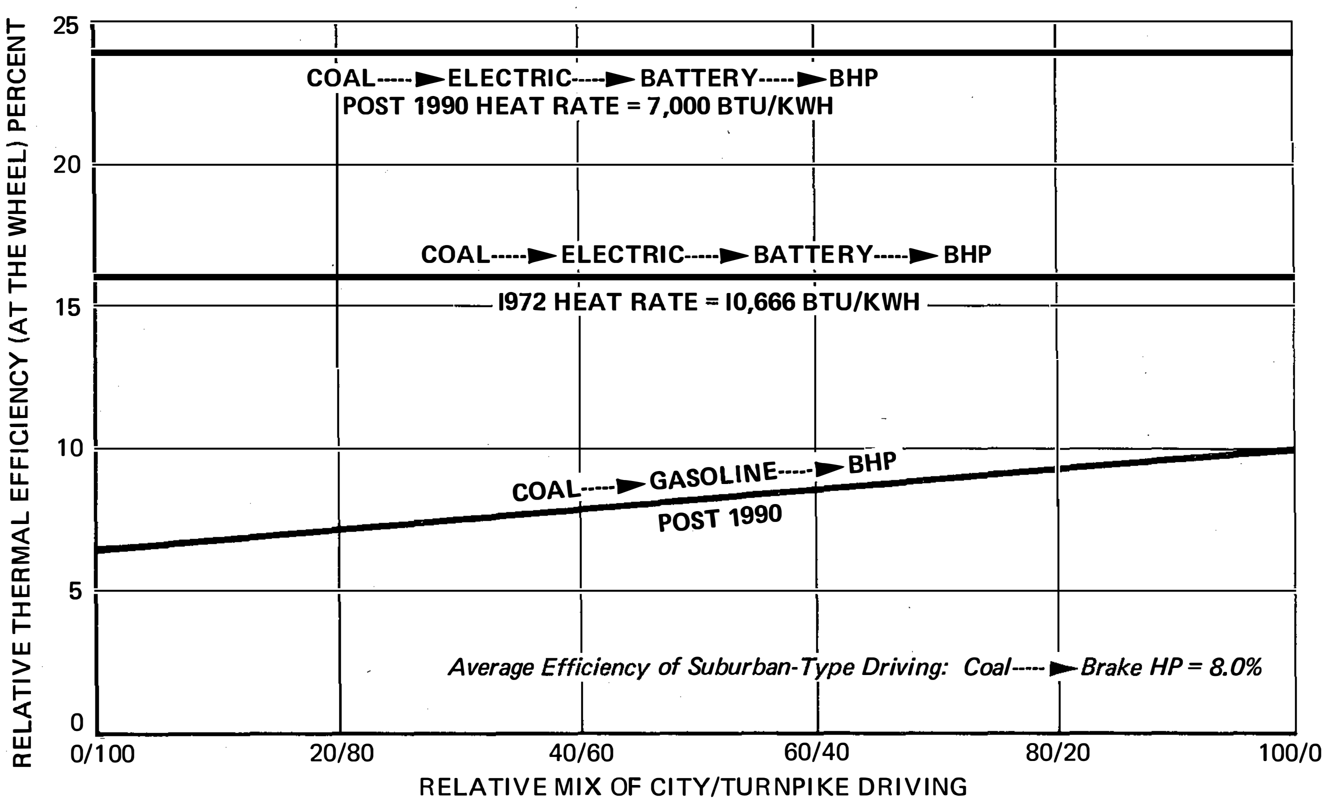

Figure 21. Relative Efficiency of Automobile in a Coal-Based Energy Economy.

TABLE 46

RELATIVE EFFICIENCY TRENDS IN TRANSPORTATION

Passenger Movement	1972 Passenger-Miles/ 10^6 BTU (Crude)	Post-1990 Syn Fuels Case Passenger-Miles/ 10^6 BTU (Coal)	Post-1990 Electric Case Passenger-Miles/ 10^6 BTU (Coal)
Automobile, City-1 Passenger	60	46	180
Automobile, Highway-2 People	200	152	450
Bus	650	540	1,080
Commuter Train – Diesel	550	460	–
Electric Train	–	–	920
Electric Subway			
707 Jet	150	115	–
747 Jet	120	92	–
SST	60-90	46-69	–

Freight Movement	Ton-Miles/ 10^6 BTU (Crude)	Ton-Miles/ 10^6 BTU (Coal)	Ton-Miles/ 10^6 BTU (Coal)
Pipeline	5,070	3,550	–
Barge	1,450	1,020	–
Supertanker	7,240	–	–
100-Car Freight Train – Diesel	1,300	1,080	–
40-Car Freight Train – Diesel	650	540	–
Air-Freight	32-64	12-25*	–
40-Ton Truck	320	250	–
Electric Train-40 Car	600	600	1,080
Electric Truck	300	300	500

* SST-type

most inefficient of all possibilities, which accounts for the rapid increase in energy for transportation in the past. Any trends to mass transit or electric automobiles should tend to improve efficiency. As noted earlier, the electric car should tend to be about 3 to 4 times as efficient as the gasoline car in a coal-based economy.

For moving freight, trucks tend to be about 25 percent as efficient as trains. The electric train had about the same efficiency as the diesel train in moving freight in 1972. However, the trend is likely to be toward an improvement in electric and a decline in fossil-fuel efficiency in hauling freight. Greater use of electric trains in lieu of truck freight would result in improved efficiency in the period after 1985.

TRENDS IN INDUSTRIAL ENERGY USE

General

Industrial uses for energy are highly variable, and no simple assessment of changing energy demands with new technology is possible. However, industry makes continual decisions on the types and forms of energy it will use for a given application based on the three cost factors: (1) energy cost per unit of production, which reflects efficiency of use, among other things; (2) capital charges for energy storage, conversion and use--interest, depreciation, taxes and return; and (3) operating and maintenance costs.

Some degree of flexibility and interchangeability exists for oil and gas fuels. However, coal-fuel or electric power cannot be so easily interchanged with liquid or gaseous fuels. Changes in any of the 3 factors will cause a reassessment of the entire system of energy use. This is not likely to happen in the short term because the capital equipment used for burning the fuel or converting it to a useful form (hot air, steam, etc.) typically is depreciated over a 15 to 25-year period, and there will be a tendency to use the equipment for such a period of time. In the longer term, it seems reasonably certain that improvements in a number of specific areas can reduce the quantity of energy needed for industry to do a given job. Higher efficiency of energy use is frequently possible, and it becomes more probable as fuel costs rise.

Specific areas can be examined to see how improved technology can reduce consumption of industrial energy.

- Improvements in Engines: Engines are used for compression, pumping liquids and gases, motion and driving electrical generators. Reciprocating engines (both diesel and spark-ignition) are likely to decrease in efficiency to meet emission standards. On the other hand, improvements in gas turbines are likely to counter this trend, so the overall efficiency in industrial engines should increase gradually in time. However, additional energy will be needed to handle pollution problems.

- Improvements in Boilers: Small industrial boilers have tended to be less efficient (50 to 70 percent) than boilers used in electric power plants (80 to 85 percent). As energy costs rise, the optimum industrial boiler will tend to be a more efficient boiler.

- Insulation: There has always existed in industry the classic interplay of energy cost and insulation costs. For a given energy cost, there exists an optimum thickness of insulation for a pipe or a vessel. If energy increases in cost, the optimum thickness of insulation will be higher and efficiency of energy use will increase automatically.

  Another route to higher efficiency through insulation practice is the development of lower cost methods for insulating pipes and vessels. These developments are likely from a competitive viewpoint as energy increases in cost.

- Improved Burners: A large number of types of burners are used in industry, depending on the application: air heating, incineration, radiant heating, infrared heating, etc. With rising fuel costs, increased thermal efficiencies of burners are continually being sought. For example, multiple burner installations and recuperative radiant tube designs are starting to be used on a large scale. Incoming combustion air gains heat through exchange with the exhaust. One conservative estimate has been that the capital costs of recuperation can be justified, since a 20- to 25-percent fuel savings is effected by heating air to 600°F. This may be an extreme case, but this concept when applied more widely could decrease energy consumption 10 to 15 percent.

- Makeup Air: One of the most demanding energy uses in industry is the heating of makeup air which is needed to replace exhausted air. Odors, vapors, fumes, and furnace heat are common problems in industry calling for extensive exhausting of internal air. A number of new techniques are being applied in industry such as recirculation of air, rotary heat exchangers, push-pull ventilation, air curtains, etc. All of these are designed to improve efficiency of energy use through reductions in makeup air. Although no precise estimates can be made, potential energy savings are probably in the 10- to 20-percent range.

- Recovery of Heat from Water, Steam and Air: Many industries now make efficient use of energy. This is particularly true in the process industries. For example, steam is used for mechanical power, and exhaust steam is then used for process heat. The use of heat exchangers and economizers is very common. These trends are expected to continue at an accelerating rate as energy becomes a more costly item.

  Smaller industries probably have not incorporated heat recovery systems for the reason that economics ruled against it. It is expected that regenerators, and economizer-heat exchangers will become available in smaller sizes for more industrial applications.

Electrical energy is likely to become more widely used, particularly in process heat applications. The advent of nuclear power and the economic incentive for utilities to increase load factors, will accelerate this trend. When considering the use of electric power for industrial heat applications, the required primary energy may not be significantly higher than that needed in the direct use of the fossil fuel. For example, gasification of coal and the production of a high quality liquid fuel from coal would have thermal efficiencies in the 65- to 75-percent range. Many process heat applications, involving direct flame heating or the generation of steam, may have thermal efficiencies of 30 to 60 percent. The overall efficiency, based on direct use of refined fossil fuels from coal is 25 to 45 percent. As electrical generation evolves to a more efficient level, less primary energy may be required through the use of direct electric heating. Electric energy can be more readily converted to induction, radiative and convection heating modes and may be preferred in some instances. Burners and boilers tend to be costly for small users, and it seems reasonable that overall costs for electric process heat may be no higher than fossil fuels in many instances.

Because the generation and distribution of electric power has been much more capital intensive than the production and refining of crude oil, electric energy in the industrial sector has typically cost 3 to 8 times as much as fossil fuels. The necessity to make synthetic fuels out of coal also will create a highly capital intensive fuel industry. There is a likelihood that the historic cost ratio between electric power and fuels will decrease.

It is judged that a critical cost ratio of electricity:fossil fuel will be in the 3.0 to 3.5 range. Because capital costs and operating and maintenance costs are frequently lower when using electric power, overall costs would be the same if electric power were 3.0 to 3.5 times that of fossil fuels.

In many heating applications, electric power has about twice the efficiency of fossil fuels. If electric heating is properly designed, there is reason to believe that its primary energy requirements will not be significantly higher. For these reasons, electric power should come into increasing use in many industrial applications for energy.

TRENDS IN ELECTRIC POWER PLANT EFFICIENCY

If suitable assumptions are made, it is possible to estimate trends that might be obtained in the efficiency of electric power plants as new technology is introduced. Changes in the national average of heat rate (BTU's required per KWH) cannot happen very fast for the reason that much installed capacity cannot be scrapped immediately. The total replacement of current power plants and those which are on order through about 1980 will not occur until considerably beyond the year 2000. Any new technology which can affect the heat rate in the United States in a significant way would have to be available in 1972. Only the combined Brayton-Rankine cycle (gas turbine and steam turbine in combination) can qualify for this distinction in 1972.

Improvements in the efficiency of the gas turbine-steam turbine are possible through increases in the tolerance of the gas turbine to higher temperature. It is difficult to predict accurately how popular this power plant will be in the coming years. However, the new power plant appears to fill a unique role in promising an intermediate-duty load factor of 40 to 60 percent.

It may be assumed that the combined cycle would be in demand for about 25 percent of the new annual capacity added in the period 1985 to 1990. This permits the tabulation of installed capacity growing from 1,000 MW in 1973 to about 130,000 MW in 1990 as shown in Table 47. Estimates have also been made of the heat rate which might be achieved through improvements in the gas turbine. This heat rate is allowed to improve from 9,200 in 1972 to 7,000 in

TABLE 47

ESTIMATED TRENDS IN POWER PLANT TYPES AND EFFICIENCIES

	Thousand Megawatts—New Plant Capacity			Heat Rate—BTU's per KWH	
	Rankine Cycle	Brayton-Rankine Cycle	Total New Fossil Plants	Heat Rate Rankine Cycle	Heat Rate Brayton-Rankine Cycle
1972	22	0	22	9800	9200
1973	21	1	22	9800	9000
1974	20	2	22	9800	8800
1975	20	2	22	9800	8600
1976	18	4	22	9800	8400
1977	17	5	22	9800	8100
1978	16	6	22	9700	7800
1979	16	7	23	9700	7500
1980	15	8	23	9600	7300
1981	15	9	24	9500	7250
1982	15	9	24	9500	7200
1983	15	9	24	9400	7150
1984	15	9	24	9400	7100
1985	15	9	24	9300	7050
1986	15	10	25	9300	7000
1987	15	10	25	9200	7000
1988	15	10	25	9200	7000
1989	15	10	25	9000	7000
1990	15	10	25	9000	7000
Total	**315**	**130**	**445**	**9532***	**7286***

* Average.

1985. A more rapid improvement in efficiency is assumed in the 1975 to 1980 period, presumably as new alloys and cooling techniques are applied to gas turbines. Improvements would be slower in the 1980-1990 period approaching a materials limit of about 7,000 BTU's per KWH in 1985.

Table 47 also shows installed capacity of other Rankine-cycle fossil-fuel plants. Approximately 22,000 MW of fossil-fuel plants have already been committed through the year 1976. Because the delivery time of the combined-cycle plant is only about 18 months to two years, it seems reasonable to believe that the number of orders could total 4,000 MW for the year 1976. The yearly installed capacity grows steadily upward and reaches 10,000 MW in 1986.

The average heat rate of all fossil-fuel plants installed in 1972 is assumed to be 9,800 BTU's per KWH. This is based on 50-percent coal--at 9,000; 30-percent residual oil--at 11,000 and 20-percent gas--at 10,000 BTU's per KWH. The average is assumed to stay constant at 9,800 BTU's per KWH for installed steam plants through 1977. This may appear to be high, but it is believed that the use of cooling towers and stack gas scrubbing will tend to result in relatively high heat rates of this order. After 1978, the heat rate of conventional Rankine-cycle steam plants should begin to improve somewhat. This would be through the introduction of higher pressure steam (about 1975) and the use of fluid-bed combustion for residual oil and coal boilers (about 1980). The use of residual oil containing sodium and vanadium will tend to keep the overall efficiency of the steam cycle low, unless residual oil is severely refined, gasified or used in fluid-bed boilers. Gasification technology, which could lead to more rapid improvements in the Rankine-cycle, would be available no sooner than 1980.

Trends of heat rate have been plotted in Figure 22. It has been assumed that 300,000 MW capacity of fossil-fuel plants existed in 1971, with a heat rate of 10,666 BTU's per KWH. The annual operating factor for this capacity was taken as 60 percent in 1972 and was

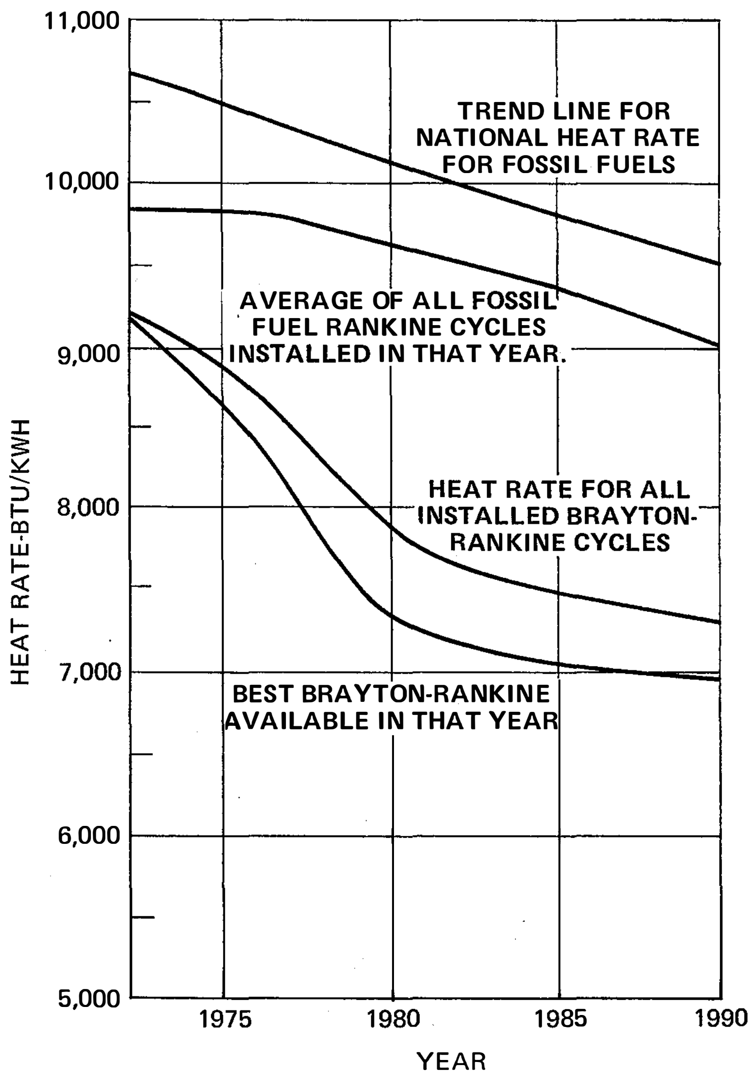

Figure 22. Estimated Trends for Efficiency of Electric Power Generation from Fossil Fuels--1972-1990.

depreciated to 40 percent annual factor in 1990. This would occur because more use would be made of the newer, more efficient fossil plants and nuclear capacity. The conventional Rankine-cycle capacity added after 1972 was assumed to have an annual operating factor of 70 percent, and the combined-cycle annual operating factor was 50 percent. On the basis of these assumptions, the national heat rate should decrease from 10,666 in 1972 to 9,798 in 1985 and 9,507 in 1990. This is an improvement in overall efficiency of fossil-fuel plants of about 8 percent over a 13-year period.

As shown in Table 47, the average heat rate for the combined-cycle plants in 1990 would be about 7,300 based on the schedule shown. This is an optimistic schedule for the installed capacity and efficiency trends for combined-cycle plants. Despite the optimism, it can be readily seen that the change in the national heat rate over an 18-year period is relatively small. If MHD or thermionic topping becomes feasible (sometime after 1985), presumably more rapid improvements in heat rate could occur beginning about 1990. It is clear, however, that the national heat rate would not decrease below about 9,000 BTU's per KWH for fossil fuels before the year 2000.

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