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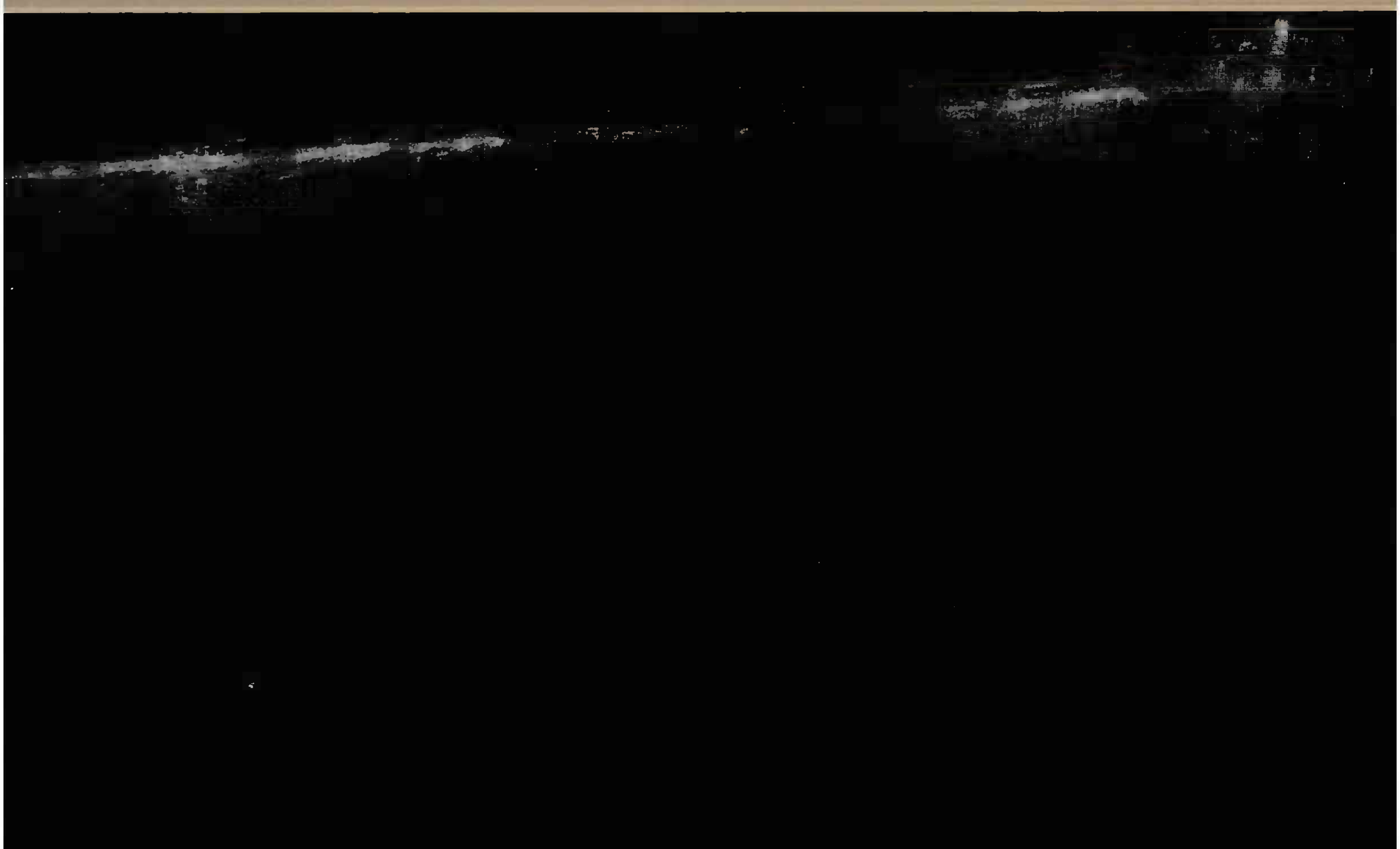

ELECTRIC POWER RESEARCH INSTITUTE

Demand 77:
EPRI Annual Energy Forecasts and Consumption Model

EA-621-SR, Volume 1
Forecasts and General Description of the Model

Special Report, March 1978

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ABSTRACT

This report presents forecasts of end-use consumption of electricity, petroleum, natural gas, and coal for the years 1980-2000. The forecasts are based on an econometric model whose equations represent energy consumption of each form of energy in each end-use sector. They will be updated and modified annually by the staff of EPRI's Demand and Conservation Program. The forecasts are based on a forecast of long-run economic growth coupled with three scenarios concerning energy prices and conservation policy. Each of the scenarios was coupled with two scenarios concerning natural gas availability, one in which natural gas supplies are restricted at the assumed price and the second in which natural gas is freely available at the assumed price.

The scenarios were: (1) a baseline scenario, which assumed that the most likely energy prices would prevail and that no significant new conservation policies would be adopted; (2) a high electricity consumption scenario, with low oil prices and minimal obstacles to the use of coal and nuclear energy for electricity generation; and (3) an energy conservation scenario, which embodied the proposals in President Carter's <u>National Energy Plan</u>.

Assuming that there will be shortfalls of natural gas supplies, the baseline case indicated growth in electricity from 1.9×10^{12} kWh in 1975 to 7.4×10^{12} kWh in 2000. Total energy consumption grows from 70×10^{15} Btu to 159×10^{15} Btu in the same period. In the high electricity consumption case, the corresponding figures for 2000 are 9.2×10^{12} kWh and 196×10^{15} Btu. In the energy conservation case, they are 6.6×10^{12} kWh and 146×10^{15} Btu.

Forecasts are presented for each of the sectors and for each of the forms of energy by five-year periods. The structure of the econometric model is described, along with plans for further development.

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SUMMARY

EPRI's Demand and Conservation Program has recently completed its second annual forecast of energy consumption in the United States.* This is the first of two volumes. Volume 2 will be titled Technical Documentation of the Model and Forecasts.

The forecasts cover each end-use sector of the economy and are conditional upon a number of alternative assumptions concerning national economic growth, energy prices, other prices, and energy policy. The forecasts also include forms of energy other than electricity, to take into account the more comprehensive energy picture. Although the forecasts proceed through time in one-year increments, their primary focus is on the period from 1985 to 2000.

The long-run nature of the forecasts is particularly important to EPRI's internal R&D planning, given the long lead times between research and commercial operation and the long useful lives typically associated with electric equipment. In addition to EPRI's internal use, the forecasts serve also to augment the general state of knowledge of possible U.S. energy growth.

DEMAND 77 FORECASTS

The Demand 77 forecasts all use projections of economic growth and nonenergy variables from the Wharton Econometric Forecasting Associates' annual model. Also, all energy price forecasts are based on estimates from EPRI's Supply Program. In addition, the Supply Program furnished estimates of natural gas availability at the forecast price levels. Our assumptions concerning natural gas restrictions are that electric utility use will be phased out by 2000, and that when the demand for natural gas exceeds supply, 10% of the shortfall is allocated to the residential and commercial sectors and 90% to the industrial sector. It is assumed that 65% of the shortfall in each of the sectors will be taken up by

*The first forecast was A Preliminary Forecast of Energy Consumption Through 1985. Special Report prepared by Larry J. Williams, March 1976. SR-37.

petroleum, 15% by coal, and 20% by electricity. It is assumed that 1 Btu of electricity at the point of final consumption substitutes for 2 Btu of natural gas.

The baseline scenario used the Supply Program's energy prices without modification. The high electricity consumption scenario modified prices to make them similar to the high electrification, $8/bbl oil case of the Federal Energy Administration's National Energy Outlook, 1976. We regard this scenario as approaching the upper limit of plausibility. The energy conservation scenario is based primarily on the objectives and policy stated in President Carter's energy plan. Although most observers of energy analysis and policy would not regard this as being as much an "outside" representation of conservation as the high electricity consumption scenario is of high consumption, it is of interest to real decisions now being made. Account has been taken of different prices and of a number of legislative standards that do not have their impact through the pricing mechanism.

Baseline Results

The figure shows that total energy growth is forecast to be somewhat under 3.5%/yr for the baseline case for each of the 5-year periods, slightly less than the 3.6% rate of the 20 years before the 1973 oil embargo. This leads to total energy consumption of 159 x 10^{15} Btu by the year 2000. In the case of electricity, consumption grows from 1.9 x 10^{12} kWh to 7.4 x 10^{12} kWh in the year 2000. Growth is postulated to be fairly robust during the next 5 years, but gradually falls off to a rate of less than 5%/yr in the 1990s. Although the growth rates are much lower for fuel (1.6-2.4%), it is interesting and somewhat disconcerting to note that the rate accelerates in the future and that the most rapid growth (from 29 x 10^{15} Btu to 54 x 10^{15} Btu in the 1975-2000 period) is in the consumption of petroleum, which pulls the growth rate for total energy up in the period 1990-2000 compared with 1975-1990.

In examining this case by sector, it appears that the most vigorous growth for fossil fuel consumption is in the industrial sector, in spite of the curtailment of natural gas. Electricity growth is forecast to be especially robust in the residential-commercial sector.

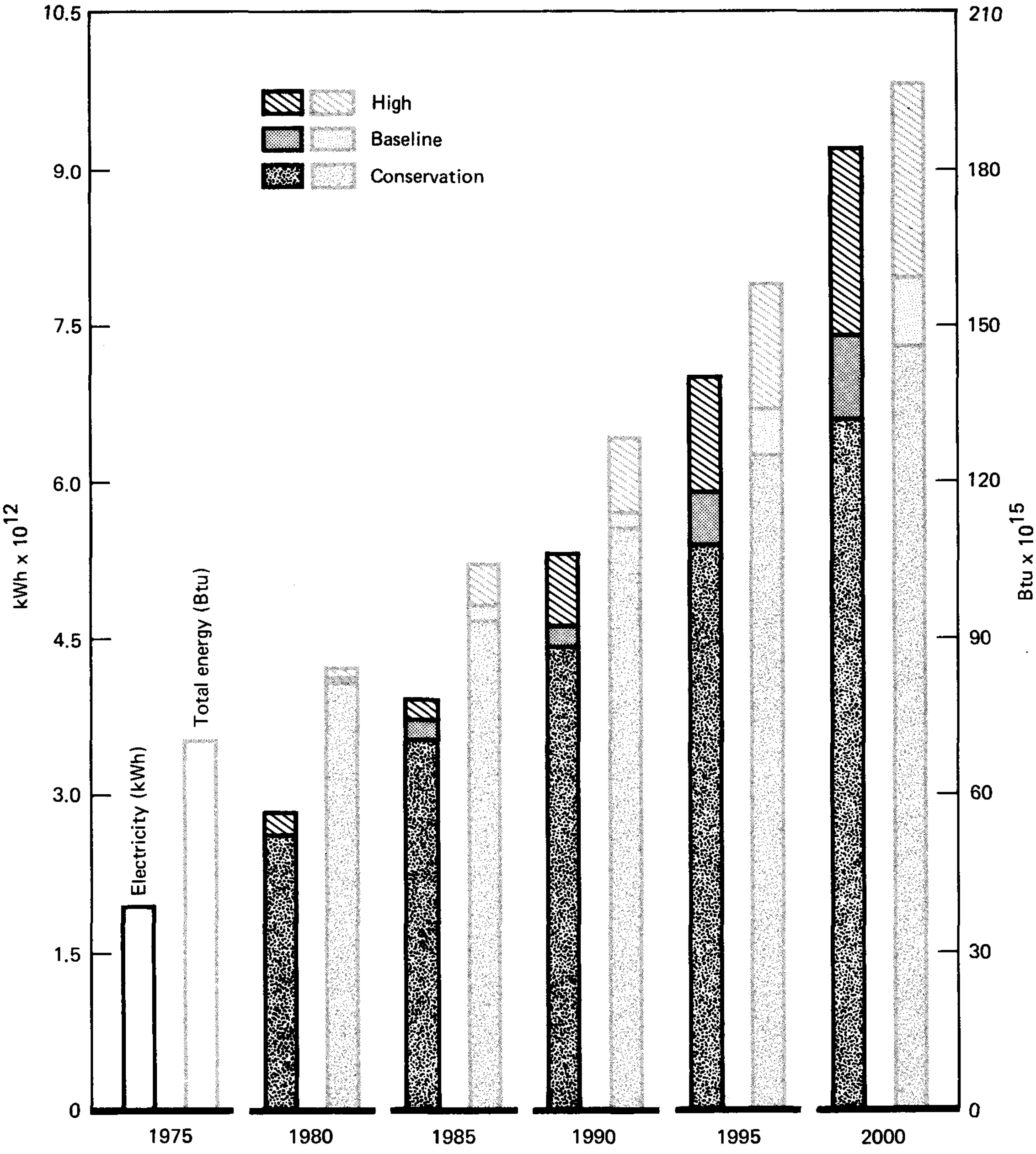

Figure S-1 Demand 77 forecasts substantial growth in electricity for all three scenarios. In each scenario, the rate of electricity growth is higher than that of total energy. Electricity's share of total energy also will continue to grow, but at a declining rate.

High Consumption Results

In the high electricity consumption case, the growth rate in total energy consumption is never less than 4%/yr for any period after 1975-1980. The total energy consumption of 196 x 10^{15} Btu is definitely in the high range of energy consumption forecasts. Electricity consumption grows to 9.2 x 10^{12} kWh under this scenario and repeats the pattern of a high growth rate in the initial years, with a gradual decline throughout the period. Unlike the baseline case, however, the projected growth rate of electricity consumption is almost 6% well into the 1990s. The general pattern of growth in fuel also follows the baseline case. Most of the growth to 2000, of course, is accounted for by petroleum, since natural gas is restricted to grow only by about 27% over this period, whereas petroleum is forecast to be approximately two and a half times its 1975 consumption. As in the baseline case, the direct consumption of coal grows relatively slowly.

Conservation Results

The implications of the energy conservation scenario are to drop the rate of growth of total energy consumption to approximately 3% annually between now and the year 2000.

The underlying patterns of this scenario are familiar: relatively high rates of electricity growth from 1975 to 1980 (which would be little affected by the conservation policy in any case), dropping throughout the rest of the period to over 4% in the 1990s. This results in electricity consumption of 6.6 x 10^{12} kWh by the year 2000. Fuels also show their familiar path of relatively low rates of growth in the first part of the period and increases in the latter part, but in no case do they approach the growth rate of electricity. A major difference, however, between the energy conservation case and the other cases is that coal consumption is roughly 4.5 times its 1975 level by the year 2000, whereas in the baseline case the level of consumption in 2000 is approximately 1.7 times the 1975 consumption. It is also interesting to note that natural gas never has to be restricted in the energy conservation scenario.

Two principal difficulties in quantifying President Carter's policy are the difficulty of assessing the effects of standards and that of assessing the effects of incentives to invest in new capital equipment and improvements such as weatherproofing. Also, it is necessary to estimate how much conservation would be a result of government action and how much would have taken place in the market without any incentive other than increased energy prices. Our approach in handling the problem was to take the best engineering information available on the potential of the Carter policy to reach its objective and apply it, along with a subjective assessment of how much adjustment would take place without the policy, to arrive at our estimated impact. Of course many of President Carter's policy recommendations would have a direct impact on energy prices. These were reflected as adjustments to the baseline energy prices provided by the Supply Program.

Generally, but not consistently, our results tend to be somewhat higher than other forecasts, for both electricity consumption and total energy growth. It must be recognized that none of these results are completely comparable because they all involve somewhat different assumptions concerning the rate of economic growth, levels of energy prices, and the role of energy policy.

Several things have emerged from Demand 77 that are of interest to those concerned with energy policy, production, and planning. One is that energy consumption in general, and electricity in particular, appears likely to maintain a rather robust growth rate. For example, it appears unlikely that President Carter's proposals, even if they were all enacted, would reduce energy consumption to his goal of a 2% increase per year. However, it does appear that President Carter's policy may have a good prospect of success in shifting fuel consumption from petroleum to coal, thereby reducing oil imports from what they would have been otherwise.

A second major finding is that although the three scenarios would have different implications for electricity growth rates, they have similar implications in that an initial high rate of electricity growth is likely to be followed by slower rates of growth for the rest of the century. Also, electricity growth throughout the rest of the century is expected to be much higher than the growth of fossil fuel consumption, even though the latter growth rate is expected to increase.

DEMAND 77 FORECASTING MODEL

The forecasts of Demand 77 are based on an econometric model of energy consumption behavior. The model consists of a series of equations relating the energy consumption of various classes of users to important explanatory variables affecting consumption. It is important to note that this approach emphasizes how people actually use energy rather than how they could or should use it.

One critical assumption behind such an approach is that the primary motivating factors are measurable variables such as income, prices, and weather. It does not make allowance for such factors as an energy conservation ethic or other intangible changes in values or tastes. A related, but somewhat different, assumption is that the response of energy users to these measurable variables does not change markedly over time. In other words, changes in the explanatory variables themselves--rather than changes in the way people react to them--cause changes in the consumption of energy.

Demand 77 illustrates the eclectic approach to forecasting adopted by the Demand and Conservation Program. It embodies the best approaches from EPRI-sponsored research and other research. Each equation is treated as a module that may be replaced by a superior equation when it becomes available. Thus, Demand 77 retains a number of the features of last year's forecasts, while incorporating major innovations in most of the forecasting model structure.

An important goal is to increase the model's ability to assess the implications of a variety of potential changes, such as different public policies, technologic breakthroughs, and a renewed oil embargo. This makes increased detail important.

Residential Sector

In the residential model, kilowatthour sales are related to personal income, electric utility rates, natural gas prices, population, and climate variables (1). Its major innovation is its treatment of the declining block structure of electricity rates, permitting a more precise estimate of the responsiveness of consumption to the way electricity is actually priced and also providing a means to assess the impact on kilowatthour sales of different rate structures.

The residential model also takes into account the fact that electricity consumption does not adjust instantaneously to changes in income and prices. Ingrained consumption habits and previously acquired houses and appliances more suitable for a former income and price situation imply that adjustments to new circumstances take place only gradually. It is unlikely, for example, that "inefficient" refrigerators will be replaced by "efficient" ones until the former have ended their useful lives.

Commercial Sector

There has been little work done on the commercial sector. Perhaps the best work is that done by Mount, Chapman, and Tyrrell, which was reestimated and evaluated along with other state-of-the-art electricity consumption models in RP333 (2). Like the residential model, it consists of a single equation relating kilowatthour sales to the price of electricity, the price of natural gas, personal income per capita, and population. Another similarity to the residential model is that it takes account of the time lags in adjustment of consumption to changes in explanatory variables.

Demand 77 has combined the residential and commercial sectors in dealing with petroleum and natural gas. Our forecasts are taken from the Federal Energy Administration's National Energy Outlook, 1976. Although the model used in that document was not directly linked with our own, care was taken to ensure that its forecasts were compatible with the rest of Demand 77.

Industrial Sector

Industrial energy use is treated as a derived demand for factors of production. The manufacturing sector is disaggregated into nine industries, which are modeled separately. The industrial model proceeds on a two-step basis. The first step is separate forecasting equations for electricity and fossil fuels, derived from a formal representation of cost-minimizing behavior for a given level of output (3). The second step is a split of the fossil fuel total among natural gas, petroleum, and coal. Both electricity and fossil fuels are taken as functions of the level of output and the relative prices of all factors of production: electricity, fossil fuels, capital, labor, and materials. The fossil-fuel-split model estimates relative shares as a function of relative prices.

Transportation Sector

The forecast for gasoline demand uses a model developed by James Sweeney (4) for the Federal Energy Administration. It takes account of total vehicle miles traveled, average miles per gallon in the fleet of all gasoline-powered vehicles, and differences in mileage for vehicles of different vintages. The model also takes account of the retirements of vehicles over time and forecasts miles per gallon of new cars as a function of the price of gasoline and legislated efficiency standards. Other transportation energy consumption is carried over more or less intact from EPRI's 1976 forecasting effort.

Future Research Priorities

In producing Demand 77 we also learned or reaffirmed a great deal about our future research priorities on annual energy consumption. Three major issues can be identified: (1) the need for functional disaggregation, (2) the importance of sectoral disaggregation, and (3) the need for additional work on natural gas and petroleum consumption.

While much remains to be done, Demand 77 has made major strides in advancing the state of the art. Demand 78 and subsequent efforts should further improve the accuracy and meaningfulness of national energy consumption forecasts.

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Section 1
INTRODUCTION

Demand 77 is the second annual report of forecasts of national energy consumption by the EPRI Demand and Conservation Program. These forecasts cover each end-use sector of the economy and are conditional upon a number of alternative assumptions concerning national economic growth, energy prices and other prices, energy policy, and the pace and direction of technologic change. Although these forecasts proceed in one-year increments, their primary focus is on the long run: 1985-2000.

One of the principal functions of the forecasts is to provide information for internal R&D planning by EPRI's Planning Staff and the technology divisions. The long-run nature of the forecasts is particularly important in this regard, given the long lead time necessary for a research idea to reach the stage of commercial use, long construction time, and the long useful life associated with electric generating, transmission, and distribution equipment. It is important that such forecasts analyze electricity as one form of energy among others so that substitutability can be taken into account in predicting the effect that price and availability of other fuels will have on the consumption of electricity.

In addition to their internal use by EPRI, the forecasts augment the general state of knowledge concerning possible future levels of energy consumption in the U.S. and the implications of various assumptions concerning fuel prices, availability, and economic growth. Insofar as the research of the Demand and Conservation Program has followed directions different from those of other energy demand research, the resulting forecasts should provide additional insight and awareness of energy issues and should help to inform the general public, as well as electric utility decision makers, about energy consumption prospects.

Finally, the forecasting process itself provides valuable information to the staff of the Demand and Conservation Program, as well as other researchers, by identifying research areas that are particularly important to an understanding of the nation's future energy consumption. Attempting to use analyses in forecasting applications affords valuable insight as to the reasonableness of results, gaps that need to be filled, appropriate levels of detail, and other important information in ensuring that the highest-priority research areas are identified.

It is clear that the demand for electricity, as measured by national annual sales of kilowatthours, is by no means the only demand information needed for R&D planning decisions. Information on the future demand for capacity--as determined by hourly, weekly, and seasonal characterizations of typical utility load shapes--is also of critical importance, as is regionalization of forecasts. These latter two aspects are currently being investigated by EPRI and corresponding forecasts will be produced in the future.* This document, however, concentrates on annual national energy consumption.

*Current work in these areas include RP1007, a study design for regional electricity consumption forecasting, and RP1008, the development of a regional load curve model.

Section 2

FORECASTS USING DEMAND 77

Many sets of conditional forecasts have been and will be run with the Demand 77 forecasting model. Most, if not all, will be variants of three basic scenarios. Each of these scenarios is being run against national economic growth assumptions as forecast by the annual model by Wharton Econometric Forecasting Associates (1). Also, each of these scenarios has been run both with and without assumed restrictions on natural gas supply.

The first scenario is baseline. The primary influences here, aside from national economic growth, are energy prices derived from analyses by EPRI's Supply Program. Although it must be recognized that the complexities of forecasting fuel prices are of the same order of magnitude as forecasting energy consumption and therefore involve a great deal of uncertainty, it is nonetheless reasonable to regard these prices as being neither extremely high nor extremely low.

The second scenario is high electricity consumption, derived from the Federal Energy Administration (FEA) 1976 scenario for high electrification, $8 (per barrel) oil. This scenario is one that we regard as approaching the limits of plausibility in stimulating energy consumption, with respect to both electricity and total energy consumption.

The third scenario is energy conservation. This scenario is based primarily on the objectives and policies described in President Carter's National Energy Plan (2). The Demand and Conservation Program staff, and most other observers of energy analysis and policy, would not regard this as being as much an "outside" representation of conservation as the high electricity consumption scenario is of high consumption. Certainly it is conceivable and plausible (and some would even say inevitable) that a more stringent conservation policy would have to be adopted in the next 25 years. However, this scenario was selected to represent the low side because of the interest in the consumption implications of President Carter's policy, should it be enacted as originally presented.

Finally, we ran an extreme price scenario to investigate the effects of an extraordinary increase in energy prices. In this scenario, assuming no additional conservation measures, all real energy prices quintupled by the year 2000.

One of the reasons for running a number of different sets of assumptions is to determine the range of uncertainty of future energy consumption. Obviously, uncertainty is not being measured with the elegance of theoretical classical statistics. Given the number of equations involved in the forecasting effort, the different mathematical and statistical properties of the various forecasting equations, and the uncertainty surrounding the exogenous variables, it is our judgment that an analytically elegant attempt at determining the error distribution about the forecasts would be extremely costly, of doubtful value, and perhaps impossible. Efforts will be undertaken, however, to see if there are reasonable compromises between the collection of deterministic forecasts (as represented in this paper) and the strict application of classical statistics.

The Wharton forecasts of personal income, wage rates, industrial output, and other variables enter into the energy demand models in a number of different and often complicated ways. A summary measure of the movement of these numerous variables is the growth rate of real gross national product (GNP) for the forecast period. These growth rates are shown in Table 2-1. Also shown in Table 2-1 are the prices developed from the Supply Program estimates. In the actual forecasts, these prices have been adjusted to delivered prices, reflecting the cost of distribution and other factors.

THE BASELINE CASE

The results of the baseline forecasts are given in tables 2-2 and 2-3. Both these tables show energy consumption for each of the sectors in Btu and in physical units. They also summarize electricity growth, the growth of direct consumption of each fossil fuel, and the growth of the consumption of total energy in absolute and percentage terms. They differ in that Table 2-2 assumes shortfalls in natural gas supply and Table 2-3 assumes that the supply and demand for natural gas will be in balance at the assumed prices. Table 2-2 and all other scenarios involving natural gas supply restrictions assume that electric utility use of natural gas drops from 3.4×10^{15} Btu in 1974 to 0 in 2000. This natural gas is then made available to the end-use sectors. When there is excessive demand for natural gas (that is, the supply of natural gas is not sufficient to meet the amount demanded at the forecast price), 10% of the shortfall is allocated to the residential-commercial sector and 90% to the industrial sector. It is assumed, on the basis

Table 2–1

AVERAGE GROWTH RATES OF IMPORTANT EXOGENOUS VARIABLES
(%/yr)

	1975-1980	*1980-1985*	*1985-1990*	*1990-1995*	*1995-2000*
GNP	4.0	3.1	3.3	3.2	3.3
Manufacturing output (constant U.S. dollars)	5.7	3.0	3.3	3.2	3.2
GNP deflator	5.7	4.0	5.2	4.8	4.8
Wage rate (constant U.S. dollars)	5.3	6.9	5.5	6.0	6.0
Population 16 and over	1.5	1.1	1.0	0.9	0.9
Petroleum (refinery and acquisition costs + user taxes in constant U.S. dollars)					
Conservation	7.8	2.6	1.1	1.7	1.9
Base	2.9	2.4	2.4	2.0	2.3
High consumption	−0.9	−0.9	−1.0	−1.0	−1.1
Quintupled prices	6.5	6.5	6.5	6.5	6.5
Natural gas (field price in constant U.S. dollars)					
Conservation	19.1	10.4	0.9	1.3	1.6
Base	9.7	9.7	2.5	2.2	2.0
High consumption	7.0	5.2	4.1	3.4	2.9
Quintupled prices	6.5	6.5	6.5	6.5	6.5
Coal (minemouth cost in constant U.S. dollars)					
Conservation	1.0	0.9	0.9	0.9	0.8
Base	1.0	0.9	0.9	0.9	0.8
High consumption	1.4	1.3	1.2	1.2	1.1
Quintupled prices	6.6	6.6	6.6	6.6	6.6
Electricity (busbar cost in constant U.S. dollars)					
Conservation	4.3	3.5	3.0	2.6	2.3
Base	4.3	3.5	3.0	2.6	2.3
High consumption	2.2	2.0	1.8	1.7	1.6
Quintupled prices	6.5	6.5	6.5	6.5	6.5

Table 2–2

BASELINE WITH NATURAL GAS SUPPLY RESTRICTIONS

Consumption and Percentages, by Sector

Consumption Levels (10^{15} Btu)

Year	Residential–Commercial: Coal	Natural Gas	Petro-leum	Elec-tricity	Solar	Industrial: Coal	Natural Gas	Petro-leum	Elec-tricity	Transportation: Natural Gas	Petro-leum	Elec-tricity
1975	0.25	7.6	5.7	4.0	0.0	3.8	8.6	5.5	2.6	0.6	17.9	0.00
1980	0.17	7.0	6.6	5.8	0.1	4.2	9.8	6.5	3.3	0.6	19.2	0.00
1985	0.15	6.4	7.6	8.0	0.1	4.8	11.3	8.2	4.3	0.7	20.6	0.00
1990	0.18	5.6	8.9	10.4	0.2	5.4	12.2	10.3	5.4	0.7	22.3	0.00
1995	0.22	4.8	10.4	13.0	0.3	6.0	14.0	12.3	7.1	0.8	24.4	0.01
2000	0.27	4.0	12.1	15.8	0.4	6.7	16.5	14.8	9.4	0.8	27.1	0.03

Percentage of Total U.S. Consumption

Year	Residential–Commercial: Coal	Natural Gas	Petro-leum	Elec-tricity	Solar	Industrial: Coal	Natural Gas	Petro-leum	Elec-tricity	Transportation: Natural Gas	Petro-leum	Elec-tricity
1975	6.0	45.3	19.7	60.6	0.0	94.0	51.1	19.0	39.4	3.6	61.4	0.0
1980	3.9	40.1	20.3	63.7	100.0	96.1	56.2	20.2	36.3	3.7	59.4	0.0
1985	3.0	34.6	20.9	65.2	100.0	97.0	61.7	22.6	34.8	3.8	56.5	0.0
1990	3.2	30.1	21.5	65.8	100.0	96.6	66.0	24.8	34.1	3.9	53.7	0.0
1995	3.5	24.5	22.0	64.7	100.0	96.5	71.6	26.2	35.3	3.9	51.8	0.1
2000	3.9	18.7	22.4	62.7	100.0	96.1	77.5	27.4	37.2	3.8	50.3	0.1

Consumption Levels*

Year	Residential–Commercial: Coal	Natural Gas	Petro-leum	Elec-tricity	Solar	Industrial: Coal	Natural Gas	Petro-leum	Elec-tricity	Transportation: Natural Gas	Petro-leum	Elec-tricity
1975	10.9	7.4	1.0	1.2	0.0	169.8	8.3	1.0	0.8	0.6	3.1	0.00
1980	7.7	6.8	1.1	1.7	62.3	187.6	9.5	1.1	1.0	0.6	3.3	0.00
1985	6.5	6.2	1.3	2.3	128.7	212.5	11.0	1.4	1.3	0.7	3.6	0.00
1990	7.8	5.4	1.5	3.1	205.1	239.0	11.8	1.8	1.6	0.7	3.8	0.00
1995	9.6	4.6	1.8	3.8	289.9	265.4	13.5	2.1	2.1	0.7	4.2	0.00
2000	12.1	3.8	2.1	4.6	389.7	295.8	16.0	2.5	2.7	0.8	4.7	0.00

*Units: Coal, 10^6 tons; natural gas, 10^{12} ft^3; petroleum, 10^9 bbl; electricity, 10^{12} kWh; solar, 10^{12} Btu.

Table 2–2 (continued)

Consumption Levels (10^{15} Btu)

Year	Coal	Natural Gas	Petroleum	Electricity	Solar	All Fuels	Energy*	Electricity Share (%)
1975	4.1	16.7	29.2	6.6	0.0	50.0	70.0	28.5
1980	4.4	17.5	32.4	9.2	0.1	54.3	82.2	34.0
1985	4.9	18.4	36.5	12.3	0.1	59.9	97.3	38.4
1990	5.6	18.5	41.5	15.8	0.2	65.8	114.0	42.3
1995	6.2	19.5	47.1	20.1	0.3	73.1	134.2	45.5
2000	6.9	21.2	54.0	25.2	0.4	82.5	159.0	48.1

Growth Rates of Energy Consumption

	Residential–Commercial						Industrial					
Year	Electricity (10^{12} kWh)	Growth Rate (%)	Fuels (10^{15} Btu)	Growth Rate (%)	Energy (10^{15} Btu)	Growth Rate (%)	Electricity (10^{12} kWh)	Growth Rate (%)	Fuels (10^{15} Btu)	Growth Rate (%)	Energy (10^{15} Btu)	Growth Rate (%)
1975	1.2	–	13.6	–	25.7	–	0.8	–	17.9	–	25.8	–
1980	1.7	8.00	13.9	0.39	31.6	4.25	1.0	5.20	20.6	2.84	30.7	3.58
1985	2.3	6.52	14.3	0.60	38.8	4.09	1.3	5.11	24.3	3.39	37.3	3.97
1990	3.1	5.44	14.9	0.83	46.6	3.83	1.6	4.88	27.9	2.73	44.3	3.49
1995	3.8	4.48	15.7	1.08	55.1	3.42	2.1	5.52	32.3	2.99	53.8	3.96
2000	4.6	3.98	16.6	1.27	64.7	3.24	2.7	5.74	36.9	3.27	66.4	4.29

	Transportation						All Sectors					
Year	Electricity (10^{12} kWh)	Growth Rate (%)	Fuels (10^{15} Btu)	Growth Rate (%)	Energy (10^{15} Btu)	Growth Rate (%)	Electricity (10^{12} kWh)	Growth Rate (%)	Fuels (10^{15} Btu)	Growth Rate (%)	Energy (10^{15} Btu)	Growth Rate (%)
1975	0.000	–	18.5	–	18.5	–	1.9	–	50.0	–	70.0	–
1980	0.000	18.88	19.9	1.41	19.9	1.41	2.9	6.94	54.3	1.66	82.2	3.23
1985	0.001	18.88	21.3	1.42	21.3	1.42	3.6	6.02	59.9	1.98	97.3	3.42
1990	0.002	18.88	23.0	1.56	23.1	1.57	4.6	5.25	65.8	1.87	114.0	3.22
1995	0.004	18.88	25.2	1.80	25.2	1.82	5.9	4.83	73.1	2.15	134.2	3.32
2000	0.009	18.88	27.9	2.08	28.0	2.12	7.4	4.83	82.5	2.45	159.0	3.46

*Heat rate = 10,383 Btu/kWh.

Table 2—3

BASELINE WITHOUT NATURAL GAS SUPPLY RESTRICTIONS
Consumption and Percentages, by Sector

Consumption Levels (10^{15} Btu)

	Residential—Commercial					*Industrial*				*Transportation*		
Year	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Solar*	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Natural Gas*	*Petro-leum*	*Elec-tricity*
1975	0.25	7.6	5.7	4.0	0.0	3.8	8.6	5.5	2.6	0.6	17.9	0.00
1980	0.17	7.0	6.6	5.8	0.1	4.2	9.8	6.5	3.3	0.6	19.2	0.00
1985	0.12	6.5	7.5	8.0	0.1	4.6	12.8	7.3	4.1	0.7	20.6	0.00
1990	0.10	6.0	8.6	10.4	0.2	4.7	16.5	7.5	5.0	0.7	22.3	0.00
1995	0.09	5.6	9.9	12.9	0.3	4.9	21.3	7.6	5.3	0.8	24.4	0.01
2000	0.09	5.2	11.3	15.6	0.4	5.0	27.4	7.7	8.3	0.8	27.1	0.03

Percentage of Total U.S. Consumption (%)

	Residential—Commercial					*Industrial*				*Transportation*		
Year	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Solar*	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Natural Gas*	*Petro-leum*	*Elec-tricity*
1975	6.0	45.3	19.7	60.6	–	94.0	51.1	19.0	39.4	3.6	61.4	0.0
1980	3.9	40.1	20.3	63.7	100.0	96.1	56.2	20.2	36.3	3.7	59.4	0.0
1985	2.6	32.6	21.3	66.0	100.0	97.4	64.0	20.5	34.0	3.5	58.2	0.0
1990	2.2	26.0	22.4	67.5	100.0	97.8	70.9	19.5	32.4	3.1	58.0	0.0
1995	1.9	20.3	23.5	67.0	100.0	98.1	77.0	18.1	33.0	2.8	58.3	0.1
2000	1.7	15.5	24.5	65.4	100.0	98.3	82.1	16.6	34.5	2.4	58.9	0.1

Consumption Levels*

	Residential—Commercial					*Industrial*				*Transportation*		
Year	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Solar*	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Natural Gas*	*Petro-leum*	*Elec-tricity*
1975	10.9	7.4	1.0	1.2	0.0	189.8	8.3	1.0	0.8	0.6	3.1	0.00
1980	7.7	6.8	1.1	1.7	52.3	187.8	9.5	1.1	1.0	0.6	3.3	0.00
1985	5.4	6.3	1.3	2.3	128.7	202.7	12.4	1.3	1.2	0.7	3.6	0.00
1990	4.6	5.9	1.5	3.0	205.1	210.5	15.9	1.3	1.5	0.7	3.8	0.00
1995	4.2	5.4	1.7	3.8	289.9	218.8	20.6	1.3	1.9	0.7	4.2	0.00
2000	3.9	5.0	1.9	4.6	389.7	222.7	26.6	1.3	2.4	0.8	4.7	0.00

*Units: Coal, 10^6 tons; natural gas, 10^{12} ft^3; petroleum, 10^9 bbl; electricity, 10^{12} kWh; solar, 10^{12} Btu.

Table 2–3 (continued)

Consumption Levels (10^{15} Btu)

Year	*Coal*	*Natural Gas*	*Petro- leum*	*Elec- tricity*	*Solar*	*All Fuels*	*Energy**	*Electricity Share (%)*
1975	4.1	16.7	29.2	6.6	0.0	50.0	69.9	28.5
1980	4.4	17.5	32.4	9.2	0.1	54.3	82.2	34.0
1985	4.9	20.0	35.4	12.1	0.1	60.3	97.1	38.0
1990	4.8	23.2	38.4	15.4	0.2	66.7	113.5	41.2
1995	5.0	27.6	41.9	19.3	0.3	74.8	133.3	43.9
2000	5.1	33.4	46.1	23.9	0.4	85.0	157.8	46.2

Growth Rates of Energy Consumption

	Residential–Commercial						*Industrial*					
Year	*Electricity (10^{12}kWh)*	*Growth Rate (%)*	*Fuels (10^{15}Btu)*	*Growth Rate (%)*	*Energy (10^{15}Btu)*	*Growth Rate (%)*	*Electricity (10^{12}kWh)*	*Growth Rate (%)*	*Fuels (10^{15}Btu)*	*Growth Rate (%)*	*Energy (10^{15}Btu)*	*Growth Rate (%)*
1975	1.2	–	13.6	–	25.7	–	0.8	–	17.9	–	25.8	–
1980	1.7	8.00	13.9	0.39	31.6	4.25	1.0	5.20	20.6	2.84	30.7	3.58
1985	2.3	6.48	14.3	0.64	38.6	4.08	1.2	4.38	24.6	3.64	37.2	3.88
1990	3.0	5.39	15.0	0.91	46.5	3.82	1.5	3.88	28.7	3.10	43.9	3.37
1995	3.8	4.43	15.8	1.14	55.1	3.41	1.9	4.96	33.7	3.28	53.0	3.87
2000	4.6	3.95	16.9	1.35	64.5	3.23	2.4	5.41	40.1	3.52	65.2	4.22

	Transportation						*All Sectors*					
Year	*Electricity (10^{12}kWh)*	*Growth Rate (%)*	*Fuels (10^{15}Btu)*	*Growth Rate (%)*	*Energy (10^{15}Btu)*	*Growth Rate (%)*	*Electricity (10^{12}kWh)*	*Growth Rate (%)*	*Fuels (10^{15}Btu)*	*Growth Rate (%)*	*Energy (10^{15}Btu)*	*Growth Rate (%)*
1975	0.000	–	18.5	–	18.5	–	1.9	–	50.0	–	69.9	–
1980	0.000	18.88	19.9	1.41	19.9	1.41	2.7	6.94	54.3	1.66	82.2	3.28
1985	0.001	18.88	21.3	1.42	21.3	1.42	3.5	5.74	60.3	2.09	97.1	3.39
1990	0.002	18.88	23.0	1.56	23.1	1.57	4.5	4.89	66.7	2.06	113.5	3.17
1995	0.004	18.88	25.2	1.80	25.2	1.82	5.6	4.61	74.8	2.30	133.3	3.28
2000	0.009	18.88	27.9	2.08	28.0	2.12	7.0	4.45	85.0	2.59	157.8	3.43

*Heat rate = 10,383 Btu/kWh.

of existing information, that 65% of the shortfall will be taken up by petroleum, 15% by coal, and 20% by electricity. In the case of electricity, it is assumed that 1 Btu of electricity at the point of final consumption substitutes for 2 Btu of natural gas, allowing for generally greater efficiency at the point of use.

In reviewing the results of Table 2-2, a number of features are of interest. At the most general level, total energy growth is forecast to be somewhat under 3.5% for each of the five-year periods. This leads to total energy consumption of 159×10^{15} Btu by the year 2000.

It appears that the growth rate in kilowatthours of electricity can be expected to be relatively high over the next few years and to decline gradually thereafter. Much of this is due to the long period of time necessary for consumption to fully respond to the recent rapid increases of electricity prices. As discussed in Section 4, the residential and commercial models of electricity consumption reflect the phenomenon of long-run dynamic adjustment to any given period's changes in prices, income, or other variables. (The rate of growth of electricity in transportation is simply the recent historical rate. The same assumption is used in the high electricity consumption scenario.)

Also, even if fossil fuel consumption were to remain constant, it would be mathematically necessary for the growth rate of electricity to eventually converge on the growth rate of total energy. If the growth rate of electricity did not approach that of total energy, sooner or later the part would exceed the whole. By the same token, the electricity shares of total energy cannot forever grow at a constant, much less accelerated, rate lest the share eventually exceed 100%. Figure 2-1 shows that Demand 77 forecasts the electricity share growing at a declining rate, as it eventually must. Although the figure shows only the baseline case with restricted natural gas supply, results for the other scenarios are similar.

It is also interesting to note that the growth rate of nonelectric consumption, while small in the first years of the forecast, gradually increases in the later years. This is apparently due to the general slackening in the rates of price increases after 1985, as shown in Table 2-1. Clearly, this result is highly undesirable in the prevailing view of energy policy, which is geared largely to reducing this growth rate rather than accelerating it. Furthermore, as can be seen in the results on Btu by form of energy, coal is not taking up a major part of this market. Natural gas, even though restricted, nonetheless grows by about

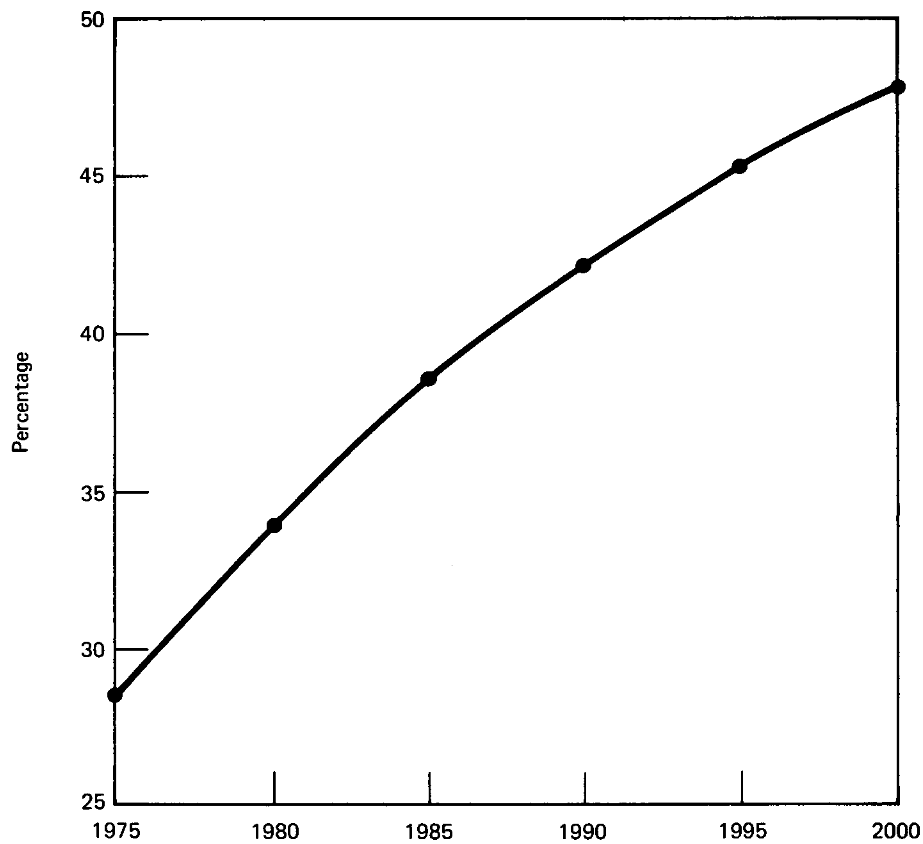

Figure 2-1 Electricity as a percentage of total energy consumption (baseline case with restricted natural gas supply only)

27% between 1975 and 2000, with 21.2 x 10^{15} Btu being the limit estimated under the price and availability analyses of the Supply Program. The major rate of growth, however, occurs in petroleum consumption, approximately 85% between 1975 and 2000.

In summary, the baseline case with natural gas supply restrictions implies a robust, but gradually declining, growth rate for electricity and a relatively high growth rate for fossil fuels and total energy. In examining this case by sectors it appears that the most robust growth for fossil fuels is to occur in the industrial sector, despite the shortage of natural gas. Of some concern in these forecasts is the decline in natural gas consumption in the residential-commercial sector, with or without supply restrictions. These results appear counterintuitive and are not suggested by recent history.

Table 2-3 (baseline without natural gas supply restrictions) shows predictable results: less robust growth in electricity and petroleum and very rapid growth in the consumption of natural gas, where it is assumed that adequate supplies would be available to meet the demand at the specified price. The exception is residential-commercial natural gas consumption, which is forecast to decline regardless of availability. About 0.5 x 10^{12} kWh are "returned" to natural gas from electricity in this scenario.

THE HIGH ELECTRICITY CONSUMPTION CASE

This set of forecasts is based on the FEA case for high electrification and $8/bbl oil, in the National Energy Outlook (3). Table 2-1 details the price assumptions consistent with that scenario, which is based on the promotion of electrification of end uses throughout the economy. Also assumed is a decrease in petroleum prices. We regard this scenario to be on the extreme edge of high feasible assumptions, since it involves not only the cheap oil but a major push to coal and nuclear energy.

The forecasts of energy consumption with assumed natural gas supply restrictions are shown in Table 2-4. In this scenario the growth rate in total energy consumption is never less than 4%/yr for any period after 1980. The resulting 196 x 10^{15} Btu is definitely in the high range of energy consumption forecasts.

Electricity consumption in this scenario repeats the pattern of a very high growth rate in the initial years, with a gradual decline throughout the entire period; but even the 1995-2000 growth rate of 5.7% is quite definitely on the robust side.

Table 2–4

HIGH ELECTRICITY CONSUMPTION WITH NATURAL GAS SUPPLY RESTRICTIONS

Consumption and Percentages, by Sector

Consumption Levels (10^{15} Btu)

	Residential–Commercial					*Industrial*				*Transportation*		
Year	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Solar*	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Natural Gas*	*Petro-leum*	*Elec-tricity*
1975	0.25	7.6	5.7	4.0	0.0	3.8	8.6	5.5	2.6	0.6	17.9	0.00
1980	0.17	7.2	7.2	5.9	0.0	4.1	9.6	6.6	3.6	0.7	19.7	0.00
1985	0.15	6.6	9.2	8.4	0.0	4.6	11.1	8.4	4.9	0.7	23.1	0.00
1990	0.18	5.9	11.7	11.5	0.0	5.1	11.8	10.7	6.4	0.8	27.2	0.00
1995	0.22	5.2	14.7	15.3	0.0	5.6	13.5	13.1	8.5	0.8	32.1	0.01
2000	0.28	4.4	18.6	19.9	0.0	6.3	15.9	16.0	11.4	0.9	38.2	0.03

Shares of Total U.S. Consumption (%)

	Residential–Commercial					*Industrial*				*Transportation*		
Year	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Solar*	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Natural Gas*	*Petro-leum*	*Elec-tricity*
1975	6.0	45.3	19.7	60.6	0.0	94.0	51.1	19.0	39.4	3.6	61.4	0.0
1980	4.1	40.9	21.5	62.0	0.0	95.9	55.4	19.6	38.0	3.8	58.9	0.0
1985	3.2	35.7	22.5	63.4	0.0	96.8	60.3	20.6	36.8	4.0	56.8	0.0
1990	3.4	31.7	23.5	64.2	0.0	96.6	64.1	21.6	35.7	4.3	54.9	0.0
1995	3.8	26.5	24.6	64.1	0.0	96.2	69.2	21.8	35.9	4.3	53.6	0.1
2000	4.2	20.7	25.6	63.5	0.0	95.8	75.0	22.0	36.4	4.3	52.5	0.1

Consumption Levels*

	Residential–Commercial					*Industrial*				*Transportation*		
Year	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Solar*	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Natural Gas*	*Petro-leum*	*Elec-tricity*
1975	10.9	7.4	1.0	1.2	0.0	169.8	8.3	1.0	0.8	0.6	3.1	0.00
1980	7.7	6.9	1.2	1.7	0.0	182.9	9.4	1.1	1.1	0.6	3.4	0.00
1985	6.7	6.4	1.6	2.5	0.0	202.3	10.7	1.4	1.4	0.7	4.0	0.00
1990	8.0	5.7	2.0	3.4	0.0	225.2	11.5	1.8	1.9	0.8	4.7	0.00
1995	9.7	5.0	2.5	4.5	0.0	249.1	13.1	2.3	2.5	0.8	5.5	0.00
2000	12.3	4.3	3.2	5.8	0.0	278.6	15.4	2.8	3.4	0.9	6.6	0.01

*Units: Coal, 10^6 tons; natural gas, 10^{12} ft^3; petroleum, 10^9 bbl; electricity, 10^{12} kWh; solar, 10^{12} Btu.

Table 2–4 (continued)

Consumption Levels (10^{15} Btu)

Year	*Coal*	*Natural Gas*	*Petroleum*	*Electricity*	*Solar*	*All Fuels*	*Energy**	*Electricity Share (%)*
1975	4.1	16.7	29.2	6.6	0.0	50.0	70.0	28.5
1980	4.3	17.5	33.5	9.6	0.0	55.3	84.5	34.6
1985	4.7	18.9	40.6	13.4	0.0	63.7	104.3	38.9
1990	5.2	18.5	49.5	18.0	0.0	73.2	127.9	42.8
1995	5.8	19.5	59.9	23.8	0.0	85.3	157.7	46.0
2000	6.5	21.2	72.8	31.4	0.0	100.6	196.1	48.7

Growth Rates of Energy Consumption

	Residential–Commercial						*Industrial*					
Year	*Electricity (10^{12}kWh)*	*Growth Rate (%)*	*Fuels (10^{15}Btu)*	*Growth Rate (%)*	*Energy (10^{15}Btu)*	*Growth Rate (%)*	*Electricity (10^{12}kWh)*	*Growth Rate (%)*	*Fuels (10^{15}Btu)*	*Growth Rate (%)*	*Energy (10^{15}Btu)*	*Growth Rate (%)*
1975	1.9	–	13.6	–	25.7	–	0.8	–	17.9	–	25.6	–
1980	1.7	8.42	14.5	1.36	32.6	4.92	1.1	7.18	20.4	2.60	31.5	4.06
1985	2.5	7.25	15.9	1.77	41.5	4.95	1.4	6.13	24.0	3.36	39.0	4.37
1990	3.4	6.45	17.7	2.20	52.8	4.91	1.9	5.48	27.6	2.81	47.1	3.87
1995	4.5	5.76	20.1	2.61	66.6	4.75	2.5	5.90	32.2	3.13	58.2	4.31
2000	5.8	5.48	23.3	2.97	83.9	4.75	3.4	6.00	38.2	3.49	73.0	4.64

	Transportation						*All Sectors*					
Year	*Electricity (10^{12}kWh)*	*Growth Rate (%)*	*Fuels (10^{15}Btu)*	*Growth Rate (%)*	*Energy (10^{15}Btu)*	*Growth Rate (%)*	*Electricity (10^{12}kWh)*	*Growth Rate (%)*	*Fuels (10^{15}Btu)*	*Growth Rate (%)*	*Energy (10^{15}Btu)*	*Growth Rate (%)*
1975	0.000	–	18.5	–	18.5	–	1.9	–	50.03	–	70.0	–
1980	0.000	18.88	20.4	1.91	20.4	1.91	2.8	7.94	55.26	2.01	84.5	3.84
1985	0.001	18.88	23.8	3.17	23.8	3.17	3.9	6.88	63.69	2.88	104.3	4.31
1990	0.002	18.88	28.0	3.27	28.0	3.27	5.3	6.10	73.23	2.83	127.9	4.15
1995	0.004	18.88	32.9	3.34	33.0	3.35	7.0	5.81	85.26	3.09	157.7	4.29
2000	0.009	18.88	39.1	3.50	39.2	3.52	9.2	5.67	100.63	3.37	196.1	4.46

*Heat rate = 10,383 Btu/kWh.

To appreciate the implication of this growth, note that electricity goes from 1.9×10^{12} kWh in 1975 to 9.2×10^{12} kWh in the year 2000, almost a fivefold increase. In comparison, the direct consumption of fossil fuels in this period is forecast to approximately double under the scenario's cheap energy assumption. Most of this growth, of course, is accounted for by petroleum, since natural gas is restricted and will grow only about 27% over the period. Petroleum, on the other hand, is forecast to increase to approximately two and a half times its 1975 consumption rate by the year 2000. The direct consumption of coal in this period is forecast to grow by more than 50%, and by the year 2000 it will account for approximately 3% of the total direct energy consumption.

The pattern of consumption by sector is similar to that of the baseline scenario, except that the growth of petroleum and electricity is considerably more exaggerated. Of continued interest (and some suspicion) is the decline in residential-commercial natural gas consumption.

As is true of the baseline case, this pattern is true with or without natural gas supply restrictions, as may be seen in Table 2-5, in which natural gas is not restricted at the given set of supply prices. Under this assumption, the total consumption of natural gas almost doubles while the consumption of other fuels falls, compared with the restriction case. As in the baseline case, total energy consumption is somewhat less without restrictions than with them. This is due primarily to conversion losses in substituting electricity for natural gas, even though electricity is assumed to have a two-to-one advantage in efficiency at the point of application. Without natural gas restriction there is a slight decline in the rate of growth of electricity consumption, and total electricity consumption declines to about 8.7×10^{12} kWh in 2000, compared with 9.2×10^{12} kWh with natural gas restriction.

THE ENERGY CONSERVATION CASE

As stated above, this scenario is based on the energy conservation aspects described in the National Energy Plan (2). In our analysis of this plan, however, it was necessary to make many assumptions concerning how it would affect prices and consumption. These assumptions might well have been somewhat different from those used in the administration's analysis, since that analysis has not yet been fully documented. Had these assumptions been identical, our results from the model would have been more or less similar to the administration's conclusions about the ability of the energy plan to meet its objectives.

Table 2–5

HIGH ELECTRICITY CONSUMPTION WITHOUT NATURAL GAS SUPPLY RESTRICTIONS
Consumption and Percentages, by Sector

Consumption Levels (10^{15} Btu)

	Residential–Commercial					*Industrial*				*Transportation*		
Year	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Solar*	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Natural Gas*	*Petro-leum*	*Elec-tricity*
1975	0.25	7.6	5.7	4.0	0.0	3.6	8.6	5.5	2.6	0.6	17.9	0.00
1980	0.17	7.2	7.2	5.9	0.0	4.1	9.7	6.6	3.6	0.7	19.7	0.00
1985	0.12	6.7	9.0	8.4	0.0	4.3	12.7	7.3	4.7	0.7	23.1	0.00
1990	0.11	6.4	11.3	11.5	0.0	4.4	16.3	7.8	6.0	0.8	27.2	0.00
1995	0.10	6.0	14.2	15.2	0.0	4.5	20.9	8.3	7.8	0.8	32.1	0.01
2000	0.09	5.6	17.8	19.8	0.0	4.6	27.1	8.8	10.3	0.9	38.2	0.03

Shares of Total U.S. Consumption (%)

	Residential–Commercial					*Industrial*				*Transportation*		
Year	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Solar*	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Natural Gas*	*Petro-leum*	*Elec-tricity*
1975	6.0	45.3	19.7	60.6	0.0	94.0	51.1	19.0	39.4	3.6	61.4	0.0
1980	4.1	40.9	21.5	62.0	0.0	95.9	55.4	19.6	38.0	3.8	58.9	0.0
1985	2.8	33.4	22.9	63.9	0.0	97.2	63.0	18.6	36.1	3.6	58.5	0.0
1990	2.3	27.1	24.5	65.8	0.0	97.7	69.5	16.8	34.2	3.4	58.7	0.0
1995	2.1	21.6	26.0	66.0	0.0	97.9	75.4	15.2	33.9	3.1	58.8	0.1
2000	1.9	16.8	27.5	65.7	0.0	98.1	80.5	13.5	34.2	2.7	59.0	0.1

Consumption Levels*

	Residential–Commercial					*Industrial*				*Transportation*		
Year	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Solar*	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Natural Gas*	*Petro-leum*	*Elec-tricity*
1975	10.9	7.4	1.0	1.2	0.0	169.8	8.3	1.0	0.8	0.6	3.1	0.00
1980	7.7	6.9	1.2	1.7	0.0	182.9	9.4	1.1	1.1	0.6	3.4	0.00
1985	5.5	6.5	1.6	2.5	0.0	191.6	12.3	1.3	1.4	0.7	4.0	0.00
1990	4.7	6.2	2.0	3.4	0.0	195.6	15.8	1.3	1.8	0.8	4.7	0.00
1995	4.2	5.8	2.4	4.4	0.0	199.9	20.2	1.4	2.3	0.8	5.5	0.00
2000	4.0	5.5	3.1	5.8	0.0	204.2	26.2	1.5	3.0	0.9	6.6	0.01

*Units: Coal, 10^6 tons; natural gas, 10^{12} ft^3; petroleum, 10^9 bbl; electricity, 10^{12} kWh; solar, 10^{12} Btu.

Table 2–5 (continued)

Consumption Levels (10^{15} Btu)

Year	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Solar*	*All Fuels*	*Energy**	*Electricity Share (%)*
1975	4.1	16.7	29.2	6.6	0.0	50.0	70.0	28.5
1980	4.3	17.5	33.5	9.6	0.0	55.3	84.5	34.7
1985	4.4	20.2	39.4	13.2	0.0	64.0	104.1	38.5
1990	4.5	23.4	46.3	17.5	0.0	74.2	127.4	41.8
1995	4.6	27.7	54.6	23.0	0.0	86.9	156.9	44.6
2000	4.7	33.6	64.8	30.2	0.0	103.1	194.9	47.1

Growth Rates of Energy Consumption

Residential–Commercial

Year	*Electricity (10^{12}kWh)*	*Growth Rate (%)*	*Fuels (10^{15}Btu)*	*Growth Rate (%)*	*Energy (10^{15}Btu)*	*Growth Rate (%)*
1975	1.2	–	13.6	–	25.7	–
1980	1.7	8.42	14.5	1.36	32.6	4.92
1985	2.5	7.20	15.9	1.81	41.5	4.94
1990	3.4	6.40	17.8	2.27	52.7	4.90
1995	4.5	5.74	20.3	2.67	66.5	4.74
2000	5.8	5.46	23.5	3.02	83.8	4.74

Industrial

Year	*Electricity (10^{12}kWh)*	*Growth Rate (%)*	*Fuels (10^{15}Btu)*	*Growth Rate (%)*	*Energy (10^{15}Btu)*	*Growth Rate (%)*
1975	0.8	–	17.9	–	25.8	–
1980	1.1	7.16	20.4	2.60	31.5	4.08
1985	1.4	5.43	24.3	3.63	38.8	4.28
1990	1.8	4.68	28.5	3.18	46.9	3.75
1995	2.3	5.50	33.7	3.41	57.4	4.24
2000	3.0	5.74	40.4	3.73	71.8	4.58

Transportation

Year	*Electricity (10^{12}kWh)*	*Growth Rate (%)*	*Fuels (10^{15}Btu)*	*Growth Rate (%)*	*Energy (10^{15}Btu)*	*Growth Rate (%)*
1975	0.000	–	18.5	–	18.5	–
1980	0.000	18.88	20.4	1.91	20.4	1.91
1985	0.001	18.88	23.8	3.17	23.8	3.17
1990	0.002	18.88	28.0	3.27	28.0	3.27
1995	0.004	18.88	32.9	3.34	33.0	3.35
2000	0.009	18.88	39.1	3.50	39.2	3.52

All Sectors

Year	*Electricity (10^{12}kWh)*	*Growth Rate (%)*	*Fuels (10^{15}Btu)*	*Growth Rate (%)*	*Energy (10^{15}Btu)*	*Growth Rate (%)*
1975	1.9	–	50.03	–	70.0	–
1980	2.8	7.94	55.25	2.01	84.5	3.84
1985	3.9	6.54	64.05	2.99	104.1	4.28
1990	5.1	5.60	74.21	2.99	127.4	4.11
1995	6.7	5.66	86.90	3.21	156.9	4.26
2000	8.8	5.56	103.11	3.48	194.9	4.43

*Heat rate = 10,383 Btu/kWh.

Two principal difficulties in translating President Carter's proposals into quantitative terms are the difficulty of making quantitative assessments of the effects of standards and that of assessing the effects of incentives to invest in new capital equipment, weatherproofing, and other conservation measures. Since interpretation of the effects of the standards and incentives is especially vital in this case, we will dwell at some length on the assumptions made in translating them into the quantitative data embodied in our forecasting model. Essentially two types of information are used: estimates, from engineering studies, of the improvements of efficiency to be expected; and judgment about how much of the conservation goal would be achieved by implementation of President Carter's program and how much by normal market forces.

In the residential-commercial sector, the Carter administration's policy calls for 90% of residential dwelling units to be insulated by 1985. We estimate that approximately 65% of the energy use in noninsulated housing is for heating. The problem in dealing with the incentives for insulation and the effect that they will have on our forecasts is that energy prices already have provided a considerable incentive for increased insulation in new homes and for retrofitting existing ones. Response to this is implicitly already built into the model. Thus, the problem is estimating how much of the 90% target is an increment over what would have taken place in the market without any further incentive other than that provided by increased energy prices.

We have estimated that even without retrofit, by 1985 approximately 70% of the housing stock will be insulated as a result of existing standards in new construction. In order to achieve the 90% standard, approximately two-thirds of the remaining units (about 20% of the 1985 housing stock) would have to be retrofitted. Of this 20% we have arbitrarily assumed that 8% will be insulated because of normal market forces and 12% as a result of federal policy. In addition to basic ceiling insulation, the program calls for tax breaks to encourage undertaking a variety of approved residential energy-conserving measures. These include wall and floor insulation, weather stripping, improved treatment of windows, and upgrading of existing ceiling insulation. Based on engineering calculations of the impacts of these measures on space-conditioning requirements, our expectation is that all of these energy-saving initiatives will reduce residential petroleum and natural gas consumption by approximately 3% by 1985 and an additional 2.5% by 2000. We do not expect these initiatives to have a significant impact on the consumption of electricity before 1985. Between 1985 and 2000, however, 0.5% of the reductions in residential Btu consumption due to insulation and related standards are attributed to electricity.

A second major objective is to expand solar heating to 2.5 million homes by 1985. Although the plan itself is not clear on whether this applies to space heating or water heating or both, we have interpreted it to mean both, but we exclude solar air conditioning since this technology does not appear to be commercially attractive within the time of our forecasts. The savings calculated are based on heating requirements after adequate insulation is in place. This expansion would account for approximately 10% of expected new construction in this period, which implies that by the end of the period the proportion of new construction of buildings with solar water and space heating will be very high, even allowing for the possibility that many of the 2.5 million units will be retrofitted. Thus, we assume that between 1985 and 2000, 20% of new housing will have solar space heating and water heating. Assuming that 70% of the energy used for water heating and 50% of the energy used for space heating could be supplied by solar heating, it appears that approximately 1% of the total residential energy use could be displaced by solar energy by 1985. Given the rapid acceleration implied, this would increase to 5% by 2000. Again, it is not known how much of this saving might be realized through the operation of normal market forces without the stimulus of the administration's program. We have arbitrarily set this at about 50-50, implying that 0.5% of the savings achieved by 1985 and 2.5% of the savings achieved in the year 2000 would be due to legislation enacting the administration's policy. It is expected that 10% of these savings will come at the expense of electricity and 90% will be allocated proportionately between residential natural gas and petroleum consumption.

Additional savings are expected to be realized through the imposition of performance standards on major electrical appliances. Considering what we regard to be reasonable assumptions about the rates of retirement of existing appliances and the rates of replacement and augmentation of the appliance stock, together with engineering estimates about what efficiency standards could accomplish, we estimate that improved efficiency would account for savings of 2.6% of residential electricity use by 1985 and 8.5% by 2000. In each case, however, projected increases in electricity prices already provide a stimulus to increased efficiency in appliances. We assume that price increases alone would prompt approximately 50% of the savings resulting from increased efficiency. Thus, we attribute 1.3% by 1985 and 4.3% by 2000 to the imposition of standards.

In the commercial sector, we assume that Standard 90-75 of the American Society of Heating, Refrigeration, and Air Conditioning Engineers, or something similar, will become the standard for new commercial buildings. Making what we regard to be reasonable assumptions about the rate of construction of such new buildings, we estimate that projected reductions in commercial gas and petroleum consumption, in addition to what could be expected from normal market forces, will amount to 4% of commercial sector energy consumption by 1985 and 7.5% by 2000. It is assumed that electricity consumption could be reduced by 1% by 1985 and 2.8% by 2000 as a result of the administration's energy conservation plan. It is further assumed that solar energy will have the same impact on the commercial sector as on the residential sector.

In the industrial sector, major proposals deal with industrial cogeneration, fuel taxes, and a restriction on burning natural gas or petroleum in new boilers. In the case of cogeneration, neither the degree of stimulus nor the expected results are specified. We arbitrarily assume that cogeneration will take up increments of 1%/yr of purchased industrial electricity until 2000. This implies a major change in industrial self-generation, which has not grown for a number of years. Since industry tends to prefer natural gas and petroleum as cogeneration fuels, it is assumed that cogeneration will cause some increases in consumption of those fuels. In the area of taxes, the administration's proposals for taxes on industrial fuels are added to the prices in the baseline scenario. Investment tax credits to encourage the shift from petroleum to natural gas to coal are assumed to result in increments of 0.5% of the petroleum and natural gas Btu per year into coal--that is, 0.5% will be shifted in 1978, 1.0% in 1979, 1.5% in 1980, and so on. Starting in 1990, as a result of tax incentives, 1% of petroleum and natural gas is replaced by solar energy.

In the transportation sector, analysis by James Sweeney (4) suggests that the tax and rebate proposals on automobiles of varying fuel efficiencies may be swallowed by existing efficiency standards and thus have relatively little impact. The imposition of gasoline taxes, however, would appear to be important. The rebate status on the purchase price of electric vehicles is estimated to increase their importance to the point that they are expected to account for 1% of the petroleum Btu by 1985, 2% by 1990, 4% by 1995, and 6% by 2000.

The implication of the energy conservation scenario presented in Table 2-6 is to drop the growth rate of all energy consumption to approximately 3%/yr between 1975 and 2000. This results in total energy consumption of 146 x 10^{15} Btu. The growth

Table 2–6

CONSERVATION WITH NATURAL GAS SUPPLY RESTRICTIONS UNNECESSARY

Consumption and Percentages, by Sector

Consumption Levels (10^{15} Btu)

	Residential–Commercial					*Industrial*					*Transportation*		
Year	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Solar*	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Solar*	*Natural Gas*	*Petro-leum*	*Elec-tricity*
1975	0.25	7.6	5.7	4.0	0.0	3.9	8.5	5.5	2.6	0.0	0.6	17.9	0.00
1980	0.17	6.9	6.2	5.8	0.1	5.5	8.9	6.1	3.4	0.0	0.6	18.4	0.00
1985	0.12	6.2	6.7	7.8	0.2	7.9	9.7	6.7	4.1	0.0	0.7	18.5	0.02
1990	0.10	5.7	7.2	10.0	0.4	10.5	10.9	6.8	4.8	0.2	0.7	19.6	0.04
1995	0.09	5.2	7.7	12.3	0.5	13.9	12.9	6.9	6.0	0.2	0.8	20.7	0.09
2000	0.08	4.7	8.3	14.8	0.6	18.2	14.9	7.0	7.5	0.2	0.8	22.3	0.14

Shares of Total U.S. Consumption (%)

	Residential–Commercial					*Industrial*					*Transportation*		
Year	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Solar*	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Solar*	*Natural Gas*	*Petro-leum*	*Elec-tricity*
1975	6.0	45.4	19.7	60.6	0.0	94.0	51.1	18.9	39.4	0.0	3.6	61.4	0.0
1980	3.0	41.9	20.2	63.1	100.0	97.0	54.2	19.9	36.9	0.0	3.9	59.9	0.0
1985	1.5	37.3	20.9	65.2	100.0	98.5	58.5	21.0	34.6	0.0	4.1	58.1	0.2
1990	0.9	32.7	21.4	67.3	67.0	99.1	63.1	20.4	32.4	33.0	4.2	58.2	0.3
1995	0.6	27.7	21.9	67.1	71.5	99.4	68.2	19.6	32.4	28.5	4.1	58.6	0.5
2000	0.4	23.0	22.1	65.9	74.2	99.6	73.1	18.6	33.5	25.8	3.9	59.2	0.6

Consumption Levels*

	Residential–Commercial					*Industrial*					*Transportation*		
Year	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Solar*	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Solar*	*Natural Gas*	*Petro-leum*	*Elec-tricity*
1975	10.9	7.4	1.0	1.2	0.0	171.3	8.3	1.0	0.8	0.0	0.6	3.1	0.00
1980	7.5	6.7	1.1	1.7	120.3	242.8	8.6	1.1	1.0	0.0	0.6	3.2	0.00
1985	5.2	6.0	1.1	2.3	238.8	350.4	9.4	1.2	1.2	0.0	0.7	3.2	0.00
1990	4.4	5.5	1.2	2.9	364.7	468.7	10.6	1.2	1.4	179.4	0.7	3.4	0.01
1995	3.8	5.0	1.3	3.6	497.4	617.2	12.3	1.2	1.7	197.9	0.7	3.6	0.03
2000	3.6	4.5	1.4	4.3	636.6	808.5	14.5	1.2	2.2	221.7	0.8	3.8	0.04

*Units: Coal, 10^6 tons; natural gas, 10^{12} ft^3; petroleum, 10^9 bbl; electricity, 10^{12} kWh; solar, 10^{12} Btu.

Table 2–6 (continued)

All Sectors – Consumption Levels (10^{15} Btu)

Year	Coal	Natural Gas	Petro-leum	Elec-tricity	Solar	All Fuels	Energy*	Electricity Share (%)
1975	4.1	16.7	29.2	6.6	0.0	50.0	70.0	28.5
1980	5.6	16.4	30.7	9.1	0.1	52.9	80.6	34.4
1985	8.0	16.7	31.9	11.9	0.2	56.7	93.1	39.1
1990	10.6	17.3	33.6	14.9	0.5	62.1	107.4	42.2
1995	14.0	18.6	35.4	16.4	0.7	68.6	124.6	45.0
2000	18.3	20.4	37.6	22.5	0.9	77.2	145.7	47.0

Growth Rates of Energy Consumption

Residential–Commercial

Year	Electricity (10^{12}kWh)	Growth Rate (%)	Fuels (10^{15}Btu)	Growth Rate (%)	Energy (10^{15}Btu)	Growth Rate (%)
1975	1.2	–	13.6	–	25.7	–
1980	1.7	7.74	13.4	–0.33	30.9	3.76
1985	2.3	6.22	13.2	–0.19	36.9	3.64
1990	2.9	5.16	13.3	0.11	43.8	3.48
1995	3.8	4.22	13.5	0.25	51.0	3.08
2000	4.3	3.74	13.7	0.38	58.8	2.89

Industrial

Year	Electricity (10^{12}kWh)	Growth Rate (%)	Fuels (10^{15}Btu)	Growth Rate (%)	Energy (10^{15}Btu)	Growth Rate (%)
1975	0.8	–	17.9	–	25.8	–
1980	1.0	5.46	20.5	2.70	30.7	3.57
1985	1.2	4.17	24.3	3.49	36.9	3.72
1990	1.4	3.21	28.5	3.23	43.2	3.22
1995	1.7	4.28	33.7	3.41	51.8	3.71
2000	2.2	4.77	40.4	3.69	63.3	4.07

Transportation

Year	Electricity (10^{12}kWh)	Growth Rate (%)	Fuels (10^{15}Btu)	Growth Rate (%)	Energy (10^{15}Btu)	Growth Rate (%)
1975	0.000	–	18.5	–	18.5	–
1980	0.000	18.88	19.0	0.55	19.0	0.55
1985	0.007	47.60	19.2	0.17	19.3	0.24
1990	0.013	15.17	20.3	1.09	20.4	1.16
1995	0.027	15.03	21.5	1.15	21.7	1.27
2000	0.041	8.45	23.1	1.47	23.5	1.57

All Sectors

Year	Electricity (10^{12}kWh)	Growth Rate (%)	Fuels (10^{15}Btu)	Growth Rate (%)	Energy (10^{15}Btu)	Growth Rate (%)
1975	1.9	–	50.0	–	70.0	–
1980	2.7	6.87	52.9	1.11	80.7	2.89
1985	3.5	5.52	56.8	1.42	93.1	2.91
1990	4.4	4.54	62.1	1.81	107.4	2.91
1995	5.4	4.28	68.6	2.03	124.6	3.00
2000	6.6	4.10	77.2	2.38	145.6	3.17

*Heat rate = 10,383 Btu/kWh.

in electricity consumption follows a pattern of relatively rapid growth of almost 7%/yr in the first part of the forecast period, with a decline to approximately 4% toward the end of the period. The result is approximately 6.6 x 10^{12} kWh by 2000. Throughout the period the growth rate in direct fuel consumption is considerably less than that of electricity. However, the rate increases throughout the period.

Comparing these results with the baseline case incorporating natural gas supply restrictions, it may be seen that the energy conservation scenario implies that coal consumption will be approximately 4.5 times its 1975 level by the year 2000, whereas in the baseline case the level of coal consumption in 2000 is approximately 1.7 times the 1975 level. It is also interesting to note that in the energy conservation scenario natural gas never has to be restricted, assuming the same wellhead prices as those used in the baseline case.

As would be expected, petroleum consumption grows much less rapidly under the energy conservation scenario, reaching a level of approximately 1.3 times its 1975 level, compared with approximately 1.85 times the 1975 level in the baseline case. The contrast in electricity consumption is considerably less dramatic. Electricity consumption in the baseline case almost quadruples its 1975 level. In the energy conservation scenario, it is still almost 3.5 times the 1975 level.

The contrasts are also interesting in the various sectors. In the residential-commercial sector, consumption of all forms of energy is less than baseline in the year 2000, with the exception of solar, as would be expected with the tax incentives. Natural gas consumption is expected to be higher in the energy conservation case than in the baseline case as a result of no restrictions.

In the industrial sector, as noted above, the increase in coal consumption is dramatic, and there is a sharp drop in the rate of growth of petroleum consumption. Petroleum consumption in transportation is considerably less under the conservation scenario, primarily due to the effect of a prospective gasoline tax.

THE QUINTUPLED ENERGY PRICES CASE

In order to test the effect that a truly extreme assumption would have on energy prices, and to get some idea of what would be necessary to reach a goal of 2% annual growth, a scenario was run on quintupled real energy prices by the year 2000. Quintupling between 1975 and 2000 implies a compounded growth rate of

6.65%/yr. Thus, these results should be treated more as an exercise than as a serious conditional forecast.

Also in this realm, the problem of feedback to the national economy is impossible to ignore. There is little doubt that both the composition and the rate of growth would be affected by such price increases. Both economic theory and common sense suggest that economic growth would be slowed and that the composition of output would shift to goods and services less energy-intensive than would otherwise be the case. Both the slackened economic growth and compositional changes would result in lower energy growth than would be the case if growth and composition were not affected, which is the assumption implicit in ignoring feedback. Thus, a reasonable interpretation of this case is that the energy consumption results are biased upward, compared with the situation in a fully integrated model.

Table 2-7 summarizes the results with natural gas supply restrictions. Flawed as they are, these results are nonetheless instructive. First, it should be noted that the natural gas supply restrictions are operative. Without restrictions, natural gas consumption is much higher, according to simulation runs. Also note that the pattern of growth of electricity is markedly lower in the price-quintupling case. Total energy growth is slower at the beginning of the period, varying between 2.1% and 3.1%. Fuels continue their familiar pattern of slower growth in the beginning of the period and acceleration later on. Also, their growth rates are about the same as those in the conservation case.

The reason for the drastic difference in growth rates in electricity is clear from examination of Table 2-1. While natural gas prices are projected to quadruple by 1985 in the energy conservation case and to increase by 250% in the baseline case, electricity prices grow much more slowly in the more conventional cases than in the price-quintupling case.

With respect to total energy, it is interesting to note that even this extreme case, in the absence of feedback to national economic growth, will not consistently push the increase of total consumption below 2%/yr. This suggests that if such a target is to be achieved, it must be either through increased employment of nonprice measures or be purchased at the expense of economic growth and changed composition of output. While this rate of real price increase is sometimes matched or exceeded in the energy conservation and baseline cases--particularly for natural gas between 1975 and 1985--a general quintupling of energy prices seems highly unlikely.

Table 2–7

QUINTUPLED REAL ENERGY PRICES

Consumption Levels (10^{15} Btu)

Year	*Coal*	*Natural Gas*	*Petro-leum*	*Elec-tricity*	*Solar*	*All Fuels*	*Energy*	*Electricity Share (%)*
1975	4.1	16.7	29.2	6.6	–	50.0	70.0	28.5
1980	4.7	18.0	30.4	7.3	0.06	53.1	75.3	29.4
1985	5.5	18.4	33.8	8.1	0.13	57.8	82.4	29.9
1990	6.4	18.5	38.0	9.0	0.21	63.0	90.3	30.2
1995	7.2	19.5	42.8	10.2	0.29	69.8	100.6	30.7
2000	8.1	21.2	48.9	11.8	0.39	78.4	114.3	31.4

Growth Rates

Year	*Electricity (10^{12}kWh)*	*Growth Rate (%)*	*Fuels (10^{15}Btu)*	*Growth Rate (%)*	*Energy (10^{15}Btu)*	*Growth Rate (%)*
1975	1.9	–	50.0	–	70.0	–
1980	2.1	2.14	53.1	1.21	75.3	1.47
1985	2.4	2.14	57.8	1.71	82.4	1.84
1990	2.6	2.08	63.0	1.74	90.3	1.83
1995	3.0	2.52	69.8	2.05	100.6	2.19
2000	3.5	3.06	78.4	2.36	114.3	2.58

SECTORAL SHARES OF ENERGY CONSUMPTION

The baseline shares of electricity used by the residential-commercial and industrial sectors fluctuate, without any discernible trend, between 60% and 66% for residential-commercial and from 34% to 40% for industrial. Transportation is projected to use a miniscule amount. In both the high electricity consumption and energy conservation scenarios the sectoral shares of electricity consumption follow roughly the same pattern as in the baseline case.

The baseline residential-commercial share of petroleum consumption is projected to rise slowly, while that of the industrial sector is rising more rapidly. The transportation share of petroleum consumption, on the other hand, declines. It is interesting to note that transportation has a higher share of petroleum in the energy conservation case than in either the baseline or the high electricity consumption case--a larger share of a smaller pie still results in a smaller piece.

The most striking change is in the sectoral shares of natural gas. There is a precipitous decline in the residential-commercial sector, from roughly 32% in 1975 to 19% in 2000. The industrial share climbs from 51% to over 77%. The results for natural gas in the high electricity consumption and energy conservation cases are similar to the baseline case. All of them indicate that industry will obtain the lion's share of natural gas as market forces dictate an absolute as well as relative decline in the residential-commercial sectors.

As might be expected under all three scenarios, the end use of coal is overwhelmingly an industrial market. This is more pronounced in the energy conservation case because of the increased use of coal by industry as a result of the incentive to shift from petroleum and gas included in President Carter's energy program.

The most important general results of the three different scenarios are summarized in figures 2-2 and 2-3. These figures show the results of the conditional forecast based on the scenarios with natural gas restrictions. The asymmetry between the high consumption and conservation cases is shown quite vividly here. As stated above, we regard the high consumption scenario as much less likely than the energy conservation scenario.

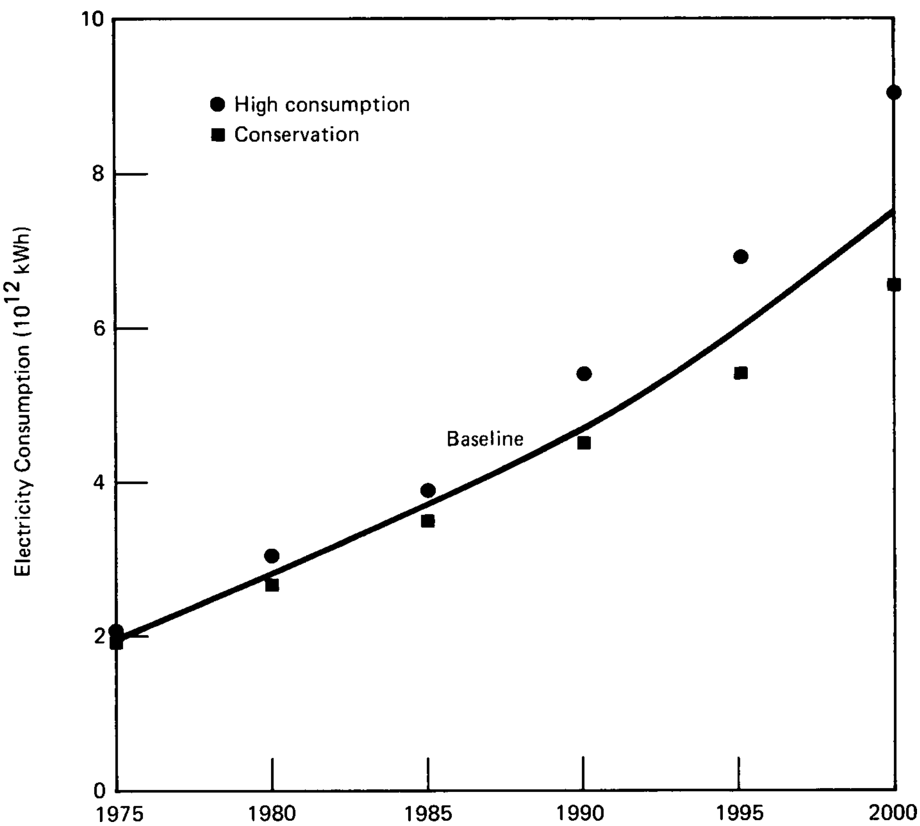

Figure 2-2 Electricity consumption, 1975-2000

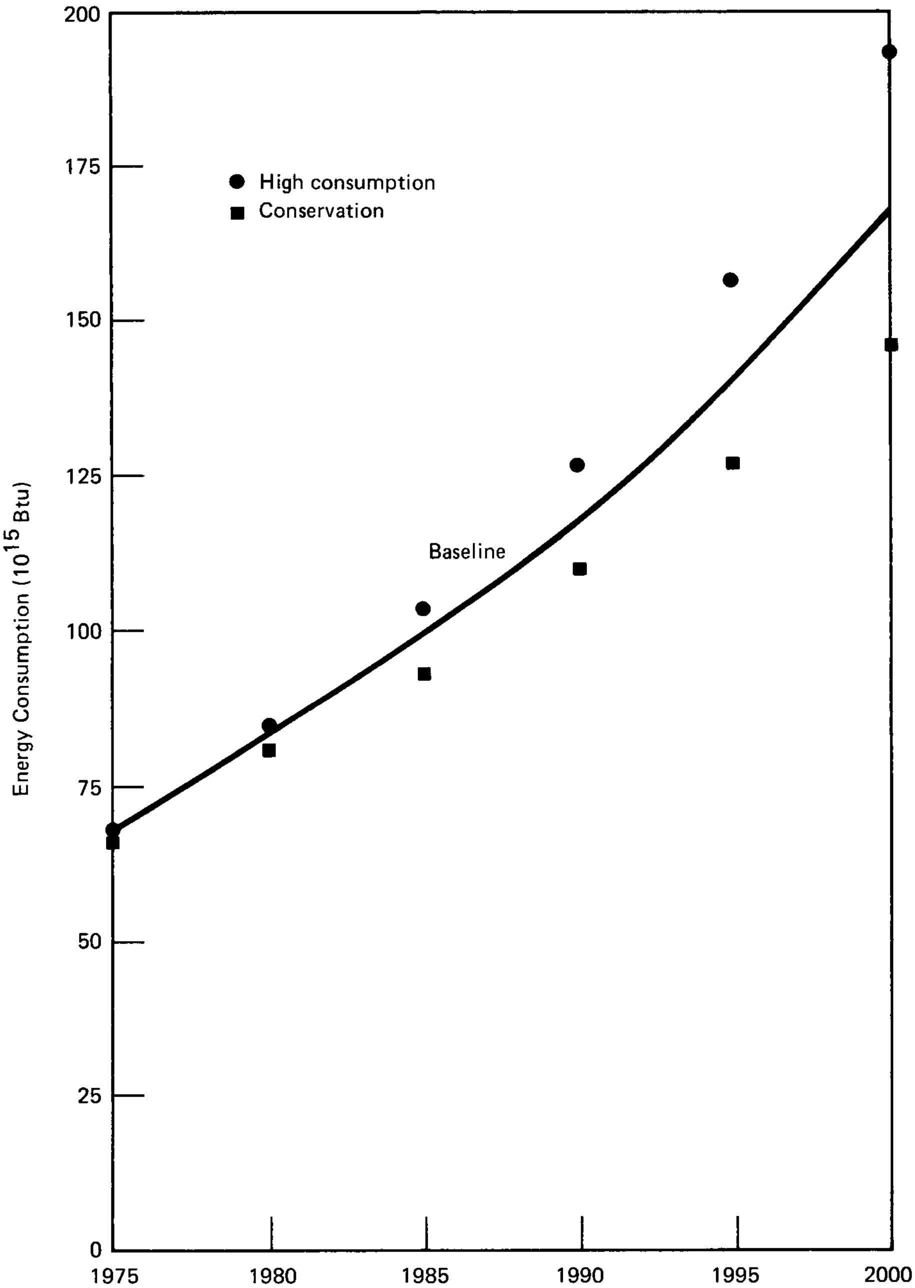

Figure 2-3 Total energy consumption, 1975-2000

COMPARISONS WITH OTHER FORECASTS

In order to assess the reasonableness of the Demand 77 forecasts, it is useful to compare them with forecasts by others. For this purpose we have selected a variety of forecasts made in the period after the Arab oil embargo. The forecasts selected for comparison were chosen because they are well known and also because they embody a wide range of approaches and assumptions. The inclusion or omission of sets of forecasts should not be interpreted as an implicit qualitative judgment by EPRI staff.

The differences in forecasts can be traced to differences in the theory and methods of determining the underlying forecasting structure and in the assumptions about the values of the variables used in the forecasts. The major variables considered are the rates of economic growth and population change and the future of energy prices. Most of the forecasts compared have been produced with econometric models of various sophistication, complexity, and detail. Exceptions are the work of Dr. Chauncey Starr and the Market-Oriented Program Planning Study (MOPPS), which are based on trend extrapolation of ratios involving energy and the economy and engineering analysis; and the work of the National Electricity Reliability Council (NERC), which is a compendium of forecasts of individual electric utilities and thus embodies the entire range of techniques used by those utilities.

In the case of Dr. Starr's work, the assumptions of economic growth and unemployment rates were somewhat more optimistic than those of Demand 77, factors which alone push energy consumption higher. Engineering judgment was used to make estimates of energy conservation through improved conversion and end-use efficiency, and the share of total energy growth that would be attributed to electricity. The analysis did not take explicit account of compositional shifts in the economy, such as more rapid growth of less energy-intensive industries, or of the effects of energy prices on consumption. Exclusion of these factors would also tend to push energy consumption upward. The conservation and efficiency estimates largely compensate for the exclusion of the price and compositional factors included in Demand 77, since Dr. Starr's estimated 7.5×10^{12} kWh and his total energy consumption of 170×10^{15} Btu are relatively close to the baseline estimates of 7.4×10^{12} kWh and 159×10^{15} Btu. It is also interesting to note that in Dr. Starr's projections electricity shares grow at an accelerated rate, contrasted to growth at a decelerated rate in Demand 77.

Table 2-8 provides comparisons of forecasts of kilowatthour growth rates. Table 2-9 provides comparisons of forecasts of total energy consumption. The distributions of forecasts are shown graphically in figures 2-4 and 2-5. In each of the forecasts selected there was an attempt to compare some sort of medium forecast (analogous to baseline in Demand 77) and a high and a low forecast. In some cases things did not work out in exactly this fashion. For example, the forecasts produced by Data Resources, Inc., sometimes report higher growth rates for the medium case (their control case) than for the high (their optimistic) case. This should not be interpreted as an anomaly; rather, it is an indication of the difficulties of associating optimism with high energy consumption.

In looking at electricity, it appears that for the high, medium, and low cases the Demand 77 forecasts produce generally higher rates of growth for 1975-1985 than the others. After 1985, however, the Demand 77 growth rates fall into the pack. It is interesting to note that the rate of growth is predicted to diminish in all forecasts except that of the Federal Energy Administration. A particularly interesting comparison can be made between Demand 77 and the low case of Data Resources, Inc.; similar results may be seen for total energy. Both the Demand 77 and the Data Resources results are based on interpretations of the impact of President Carter's energy policy, although the interpretations are somewhat different. Demand 77 forecasts that successful enactment of the administration's policy would have somewhat more impact than Data Resources indicates. However, because our baseline forecasts are higher to begin with, with the exception of total energy in 1975-1980, Data Resources is somewhat more optimistic about approaching President Carter's desired 20% growth rate of energy consumption. Essentially, Demand 77 forecasts the growth of total energy consumption to be more or less constant throughout the period for each of its scenarios. Data Resources, on the other hand, foresees a definite slackening in the growth rate of total energy consumption.

In general, the comparisons find our results for total energy consumption to be toward the high side after 1980. In part this is due to the extremeness of our high-side scenario and the conservatism of our low-side scenario. However, it is also true of the medium forecasts and the comparison with the 1980-1990 Data Resources low results, which should be roughly comparable to the energy conservation case of Demand 77.

Table 2–8

COMPARISON OF ANNUAL GROWTH RATES IN U.S. ELECTRICITY CONSUMPTION (%/yr)

Forecast	*Demand 77*	*Starr**	*SR-37*	*EEI**	*NFP**	*DRI*	*FEA**	*IEA**	*EPP**	*MOPPS**	*NERC-FPC**
1975-1980											
High	7.9	6.7	8.4	6.1	6.2	6.3	6.3	5.4	6.8	4.1	–
Medium	6.9	5.5	7.4	6.1	5.5	6.6	5.4	–	3.3	–	6.7
Low	6.9	4.7	6.1	5.5	4.5	6.1	5.2	4.4	3.0	3.2	–
1980-1985											
High	6.8	6.7	7.2	6.6	6.2	5.6	6.3	5.4	6.8	4.1	–
Medium	6.0	5.5	5.3	5.4	5.5	5.6	5.4	–	3.3	–	6.2
Low	5.5	4.7	3.2	4.3	4.5	5.6	5.2	4.4	3.0	3.2	–
1985-1990											
High	6.1	6.7	–	5.6	5.5	4.9	6.4	4.3	5.0	4.1	–
Medium	5.3	5.5	–	5.0	4.6	4.7	5.7	–	2.4	–	5.5
Low	4.5	4.7	–	2.8	3.5	4.9	5.3	2.9	1.7	3.2	–
1990-1995											
High	5.8	6.7	–	5.6	5.5	–	6.4	4.3	5.0	4.1	–
Medium	4.8	5.5	–	5.0	4.6	–	5.7	–	2.4	–	5.5
Low	4.3	4.7	–	2.8	3.5	–	5.3	2.9	1.7	3.2	–
1995-2000											
High	5.7	6.7	–	5.6	–	–	–	4.3	5.0	4.1	–
Medium	4.6	5.5	–	5.0	–	–	–	–	2.4	–	–
Low	4.1	4.7	–	2.8	–	–	–	2.9	1.7	3.2	–

Sources:

Starr = Chauncey Starr, "Electricity Needs to the Year 2000," presented to the Subcommittee on Energy Research, Development, and Demonstration; House of Representatives Committee on Science and Technology; Washington, D.C., 1976.

SR-37 = Larry J. Williams, *A Preliminary Forecast of Energy Consumption Through 1985*, SR-37 (Palo Alto, Calif.: Electric Power Research Institute, 1976).

EEI = Edison Electric Institute, *Economic Growth in the Future* (New York: McGraw-Hill, 1976).

NFP = Mitre Corporation, *Need for Power (NFP) Study*, Interim Report, prepared for U.S. Energy Research and Development Administration, Washington, D.C., 1977.

DRI = Data Resources, Inc., *Energy Review, Summer 1977* (Lexington, Mass.: Data Resources, Inc., 1977).

FEA = Federal Energy Administration, *National Energy Outlook* (Washington, D.C.: U.S. Government Printing Office, February 1976).

IEA = Institute for Energy Analysis, *Economic and Environmental Impacts of a Nuclear Moratorium, 1985-2010* (Oak Ridge Associated Universities, September 1976).

EPP = Energy Policy Project of the Ford Foundation, *A Time to Choose* (Cambridge, Mass.: Ballinger, 1974).

MOPPS = Energy Research and Development Administration, *Market Oriented Program Planning Study*, Review Draft (Washington, D.C., 1977).

NERC-FPC = Projections of the National Electric Reliability Council and the Federal Power Commission, as reported in NFP (see above).

*Growth rates are repeated from one five-year period to another where they have only been reported for longer periods.

Table 2–9

COMPARISON OF ANNUAL GROWTH RATES IN TOTAL U.S. ENERGY CONSUMPTION (%/yr)

Forecast	*Demand 77*	*Starr**	*SR-37*	*EEI**	*DRI*	*FEA**	*IEA**	*EPP**	*MOPPS**
1975-1980									
High	3.8	–	4.2	3.8	3.7	3.1	2.2	4.0	1.8
Medium	3.3	3.1	3.3	3.8	4.2	2.8	–	2.1	–
Low	2.9	–	2.3	3.3	3.8	2.2	1.5	1.8	–
1980-1985									
High	4.3	–	4.7	3.0	2.8	3.1	2.2	4.0	1.8
Medium	3.4	3.1	2.8	2.9	2.8	2.8	–	2.1	–
Low	2.9	–	0.8	2.3	2.5	2.2	1.5	1.8	–
1985-1990									
High	4.2	–	–	2.8	2.4	–	2.4	3.2	1.8
Medium	3.2	3.1	–	2.8	2.5	3.3	–	1.2	–
Low	2.9	–	–	0.5	2.4	–	1.4	0.5	–
1990-1995									
High	4.3	–	–	2.8	–	–	2.4	3.2	1.8
Medium	3.3	3.1	–	2.8	–	–	–	1.2	–
Low	3.0	–	–	0.5	–	–	1.4	0.5	–
1995-2000									
High	4.5	–	–	2.8	–	–	2.4	3.2	1.8
Medium	3.5	3.1	–	2.8	–	–	–	1.2	–
Low	3.2	–	–	0.5	–	–	1.4	0.5	–

Note: See Table 2-8 for sources.

*Growth rates are repeated from one five-year period to another where they have only been reported for longer periods.

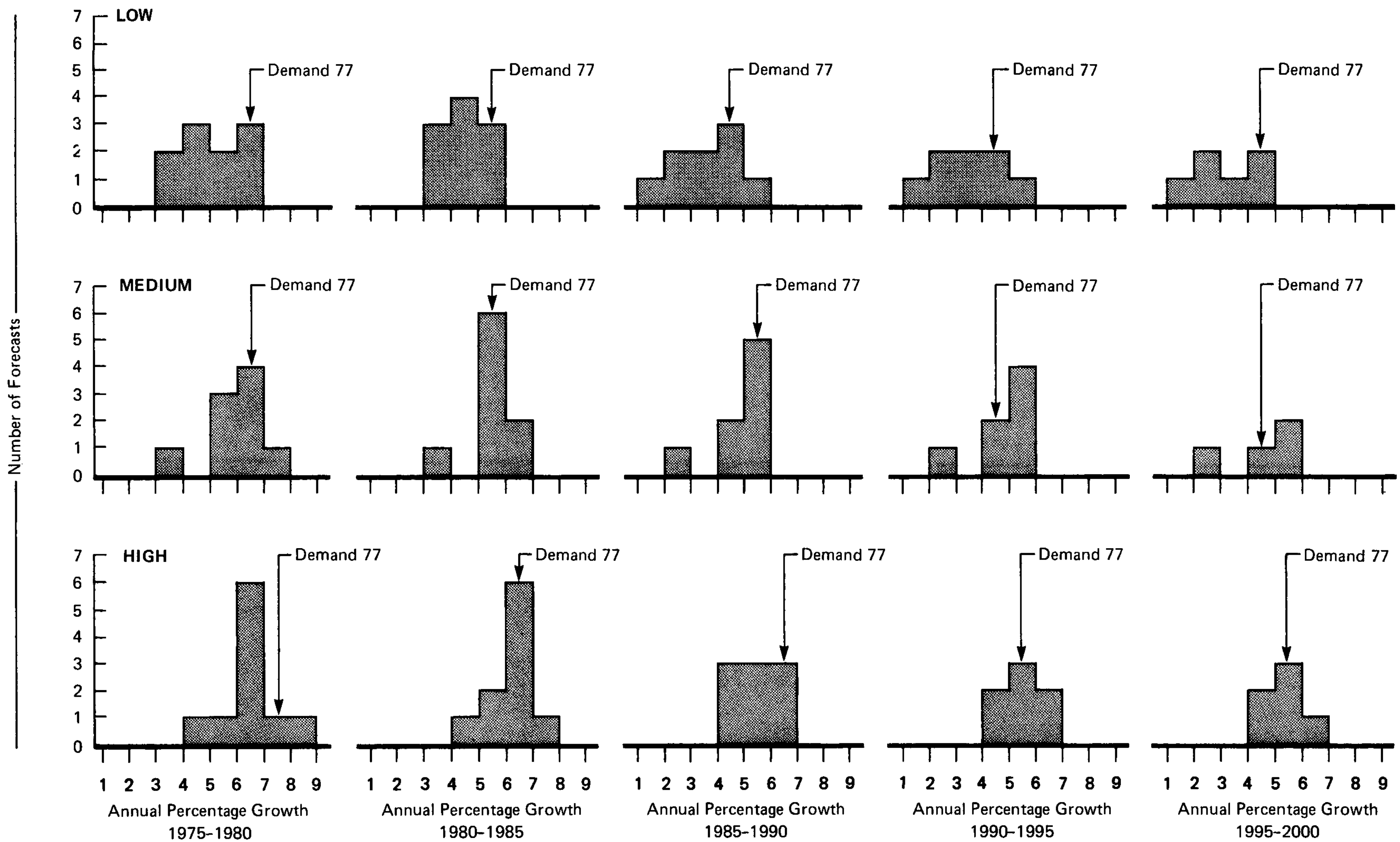

Figure 2-4 Distribution of forecast growth rates of electricity consumption

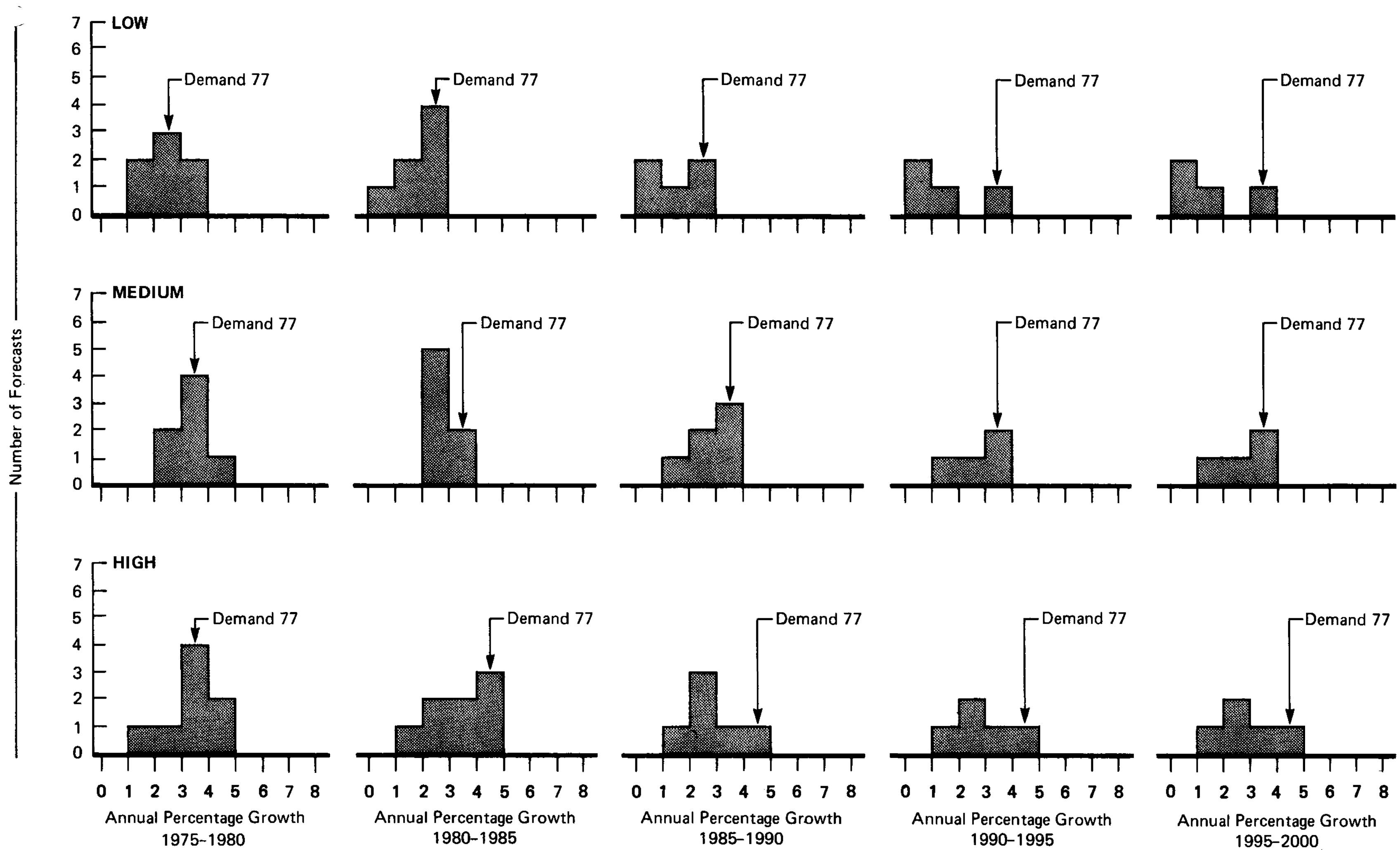

Figure 2-5 Distribution of forecast growth rates of total energy consumption

Section 3
MODEL DEVELOPMENT STRATEGY

Demand 77 is one step in an annual effort to update and improve long-run energy consumption forecasts. These forecasts will embody a wide range of assumptions concerning energy prices, availability, and government policies. The forecasting process itself is built on four basic principles: (1) behaviorism, (2) eclecticism, (3) incrementalism, and (4) generality. Demand 77 assumes one-way causation between the general economy and the energy sector. But this assumption is theoretically unrealistic in that changes in energy prices have an impact on the composition and growth of the economy, which in turn have an impact on energy consumption, which will have its own impact on industrial composition, and so forth. There is little information on the magnitude of such feedback effects, but they could be quite important. The exploration of interdependency among supply, demand, and economic growth is a major joint undertaking currently under way in EPRI's Demand and Conservation, Supply, and Systems programs.

BEHAVIORISM

The forecasts of Demand 77 are based on an econometric model of energy consumption behavior. It consists of a series of equations relating the energy consumption of various classes of users to variables that are postulated to have a major influence on consumption. The relationships hypothesized in these equations are based on economic theory. The principle of behaviorism manifests itself by the fact that tests of hypotheses and estimates of the equations' parameters are developed from data on how households and organizations have actually used energy rather than how they could or should use it.

One critical assumption behind the development of such forecasting models is that the primary motivating influences on energy consumption are measurable variables such as income, prices and weather. That is, the behavior of households and organizations is determined primarily by self-interest, competing wants, relative prices, and limited resources. A second critical assumption is that even though the variables governing behavior may change drastically, the underlying structure of behavior governing the intensity of the response remains constant. Alternatively, drastic changes in consumption are due to changes in what people respond to--not in how they respond. Allowances are not made for possible attitudinal shifts, such as the emergence of a conservation ethic. Evidence to date does not support the contention that such an attitudinal shift has emerged or is emerging, but forecasters should be aware that such a shift *might* take place and should be prepared to take it into account in forecasting.

This approach does not imply that energy consumption is postulated to follow a smooth growth path. Changes in the level and composition of economic activity and in absolute and relative prices (i.e., general energy price levels and ratios between prices of different energy forms) will cause many deviations from a smooth and steady growth path.

An implication of the behaviorist approach reflected in the forecast is that *actual* energy consumption may have little relationship to *feasible* energy consumption. That is, it is not assumed that energy-conserving technology will necessarily be adopted, even though it is apparently superior on a life-cycle cost or other "objective" basis. Clearly, technology exists for major energy savings to be realized, but whether households or organizations adopt such technologies depends on complex balancing of the value of energy conservation against other objectives, such as comfort and convenience, and trade-offs between energy costs, capital costs, and other operating costs. Thus we want to emphasize that our focus is on what past behavior indicates is *likely* to happen rather than on what *could* or *should* happen.

ELECTICISM

The principle of eclecticism is of fundamental importance to the forecasting approach in the Demand and Conservation Program. In constructing the forecasting model, we selected what appeared to be the best approaches from among our own research projects and from the research of others not necessarily connected with EPRI. Even within our own research there are usually several different projects investigating a particular problem at different levels of detail, using different methodologies and different data sources.

The drawback of this approach is that it does not produce a model developed from a single coherent body of doctrine, implying that if the workings of one sector are understood, so are the others. In giving up the coherence and simplicity of a unified model, the eclectic model attempts to address each problem in its own terms. Thus, the demand for electricity in the residential sector is not modeled with the same basic theoretical structure as the demand for electricity in manufacturing. This is no more profound than the assertion that the plant manager takes different things into account at work than he does at home. It is our judgment that the increase in complexity is a price well worth paying in order to take the special problems of each sector into account rather than subjecting them to the Procrustean bed of a uniform model structure.

Proceeding in this way, the Demand and Conservation Program is able to take the best analysis from its own contractors' work and the work of other researchers and incorporate it into the forecasting model. Furthermore, an eclectic approach enables us to replace existing research results with superior ones as they come along. Thus, we regard each equation of the Demand 77 model to be a module that can be pulled out and replaced when a better one is available.

In Demand 77, the forecasting equations are based on models estimated from national time-series data or from data on states. However, the general direction of research within the Demand and Conservation Program is to move away from the analysis of aggregate time series to more detailed data on the specific functions and activities for which energy is used. Also, there is a trend toward the use of data based on individual energy users rather than aggregates of many users. The use of such micro data makes it possible for analytic models to be estimated using the type of data for which economic and other behavioral theory is based. Also, it permits analysis of variables that change very slowly with time and whose influence is not captured by aggregate time-series analysis. One example would be the implications of a generally aging population. Microlevel data that include households whose heads are different ages would enable us to analyze the influence of the age structure of the population on energy consumption, a point that could be very important for long-run energy consumption forecasting.

A problem that must be addressed in the application of an electric approach is to make sure that the combined energy equations represent neither more nor less than the total amount of end-use energy consumption of each fuel by each sector. Special care must be taken that some sectors or fuels are neither forgotten nor double-counted.

INCREMENTALISM

The flexibility of an eclectic approach, in which superior equations can replace inferior ones, implies incrementalism, the third of our basic principles. It is a plan of the Demand and Conservation Program to make its forecast part of a process rather than a one-time operation. As research projects are completed and their results evaluated, and as results come to light from sources other than projects sponsored by EPRI, superior forecasting equations will replace the ones that had served earlier. Thus, one may regard the individual forecasting equations as modules that can be replaced as improvements are made. Once each year, data files will be updated, new modules put in place, and a forecast produced. Each year's effort will result in a report which documents the changes that have been made in the model--changes in the assumptions driving the forecasts and in the forecasts themselves. The goal is to attempt to incorporate improvements in two sectors per year. For example, in Demand 78 it is expected that major improvements will be available for incorporation in both the commercial and transportation sectors. Also, annual forecasts can provide at least some information as to whether there is systematic forecasting error by comparing predicted versus actual values.

GENERALITY

An important goal of the demand forecasting process is to increase its generality in successive years. Generality in this context is the ability to assess the implications of a variety of changes that may or may not happen in the future, such as drastically different public policies, breakthroughs in technology, a renewed oil embargo, and so forth. This implies that the forecast must be made in a great deal of detail in order to handle the effects of different growth rates of prices, potential nonprice policies (such as government-imposed standards of one sort or another), different assumptions about the rate of economic growth, and possible paths of technologic change. For example, in the residential sector it would be highly desirable to separate consumption by appliances from consumption by heating, ventilating, and air conditioning systems. This would enable us to develop more precise estimates of the impact of policies such as the encouragement of improved insulation and the potential effects of technologic change (such as solar space heating and cooling systems, improved heat pumps, and other innovations). The possible effects of technologies and policies designed to foster cogeneration in manufacturing are another example of where detailed analysis by function as well as by sector is desirable. It is important, however, to keep in mind that for forecasting to be successful, it must embody realistic evidence as to how people actually behave. Thus, the behavioral content of the models and forecasts should not be sacrificed for additional detail. Rather, improvement of behavioral analysis and increased detail in analyzing energy use should be viewed as complements rather than substitutes.

The four basic principles--behaviorism, eclecticism, incrementalism, and generality--imply a forecasting model that is large, detailed, and complex. However, once the equations and data files of the model have been entered into a computer system and debugged, running simulations on alternative scenarios concerning energy prices, incomes, and other variables is a relatively simple, quick, and inexpensive operation. By improving the model incrementally--that is, by exchanging modules rather than by complete periodic overhauls--a forecasting model is always ready and available for simulations on various alternative sets of assumptions.

Section 4
THE <u>DEMAND 1977</u> FORECASTING MODEL

The Demand and Conservation Program has taken the position that the best way of constructing long-run conditional forecasts of energy consumption is to develop them from models estimated from annual data. There are several main reasons for doing this. The first is that the evolution of a long-run phenomenon is the culmination of many short-run processes. Thus, in order to fully understand the long run, one must also understand what happens in the short run. This is less important in models designed to illustrate and highlight particular important principles than it is for models designed to produce results upon which decisions will be based.

One-time impacts often take many years to fully work themselves out and thereby influence the future. For example, the rapid increase in energy prices over the past few years has spawned an increased awareness of energy consumption in the heating and cooling of buildings. However, since heating and cooling involve the way buildings are constructed and equipped, and since buildings are typically long-lived and capable of only limited modifications through retrofitting, it will be impossible for energy consumption in heating and cooling to fully adjust to the new prices until much of the existing energy-inefficient building stock has been replaced by structures whose construction characteristics and heating, ventilating, and air conditioning equipment fully reflect the energy prices of the 1970s. Of course energy prices will have changed in the meantime, and they will continue to change. Thus, full adjustment of plant and equipment to energy prices (and other variables) is never complete. The consequence, of course, is that the same is true for energy consumption. Since all uses of energy involve the use of some kind of equipment, lagged adjustment is pervasive in energy demand analysis.

Also, for conditional forecasting purposes it may be desirable to "shock" the model sometime during the forecast period by introducing possible events, such as a major increase in the price of petroleum by 1985, or, conversely, the collapse of OPEC in, say, 1985 or 1990. In the former case, the path of adjustment to long-run equilibrium between consumption levels and explanatory variables would be such that for many years energy consumption would be higher than a long-run equilibrium solution would suggest (because of the time lag in introducing energy-efficient buildings and equipment), and in the latter case it would be lower (because of the time lag in introducing buildings and equipment appropriate for low energy prices). Either of these instances would have a measurable impact on energy consumption in the year 2000.

Another major consideration in deriving long-run forecasts through annual steps is that the path to the long-run forecasts is itself of some importance in policymaking. In particular, a policy that might appear to be advantageous in the long run might be so disadvantageous in the short run that it would never be feasible.

OUR PREVIOUS EFFORT: EPRI'S 1976 APPLICATION OF THE DRI ENERGY POLICY MODEL

The Demand and Conservation Program began its series of annual forecasts in 1976 with an application of the Data Resources, Inc. (DRI) Energy Policy Model developed by Philip Verleger, Jr., in 1974. The work on adoption of this model began during the fall of 1975, before results were available from research initiated by the Demand and Conservation Program. The resulting work led to the publication of Larry J. Williams' report A Preliminary Forecast of Energy Consumption Through 1985 (EPRI SR-37). Relatively minor modifications were made in the original DRI specifications. Williams ran simulations with this model on 12 different scenarios comprising combinations of two economic growth assumptions, three sets of energy price assumptions, and two restricted natural gas assumptions. The original publication made conditional forecasts to the year 1985. These were later extrapolated, in unpublished work, to the year 2000.

THE DEMAND 77 MODEL

The Demand and Conservation Program's current national forecasting model embodies a great deal of research that has not previously been incorporated into a forecasting framework. Two major aspects of this work, the demand for electricity in the residential sector and the demand for all forms of energy in manufacturing, result from research sponsored by EPRI or conducted in-house. The model also incorporates James Sweeney's work (4) on the demand for gasoline and work used elsewhere in forecasting applications, including the demand for electricity in the commercial sector, the demand for petroleum and natural gas in the combined residential-commercial sector, and the demand for fuels other than gasoline in the transportation sector. Allowances were made for the introduction of solar energy in the residential, commercial, and industrial sectors and of electricity in transportation.

Electricity in the Residential Sector

The articulation of the residential energy demand forecasting model began with the assembling of existing empirical and theoretical knowledge of the subject. Starting with the set of exogenous variables, or variables that are determined independently of energy consumption, one would ideally like to have detailed engineering data concerning the operating characteristics of new and existing energy-consuming devices, meteorologic information, and an accurate description of the population of consumers. Strictly speaking, only the second of the above examples should be viewed as independent of the economic processes being modeled, but one frequently assumes that some variables have only one-way causation in order to keep the modeling effort within manageable proportions. In Demand 77, prices and measures of economic activity (such as personal income or industrial output) are assumed to be exogenous.

Recognizing that the demand for electricity is a derived demand for the services of electricity-consuming devices, it would be desirable to characterize existing stocks and new investments in appliances and housing. In a fully developed energy model, one would also forecast the prices of electricity and substitute fuels and would introduce these prices into the energy forecasting model in a theoretically meaningful manner. Since the basic consuming unit of electricity in the residential sector is the household, it would be desirable to also have a model of the growth in the number of households. This type of effort requires a great deal of regional detail, including regional movements of the population, changes in its age composition, changes in the rates and locations of household formation, and changes in the nature of the family structure. These elements of the residential demand for energy would be integrated with a model of the U.S. economy through variables, such as price indices, and measures of economic activity, such as per capita income.

The ideal residential consumption model would have other features as well, but the above discussion should help the reader to understand the general thrust of the model's development. In fact, however, the state-of-the-art models do not have as much detail as we would like. Even if such models were available they would be very cumbersome to use in an overall forecasting framework. Progress in this direction will be made in subsequent forecasts of national energy consumption, but

Demand 77 embraces a more aggregative approach in which appliance stock and demographic information are included implicitly.

The residential model used in Demand 77 was developed by Taylor, Blattenberger, and Verleger (TBV) (5). The mathematical form of the model is a single-equation, geometrically distributed lag structure generically known as the Koyck model. (A discussion of this type of model may be found in standard econometrics texts, such as Chapter 10 of J. Johnston, Econometric Methods, 2d ed. [New York: McGraw-Hill, 1972].) The estimated form of the model is presented below in Eq. 4-1. It was estimated in double logarithmic form using data on states for the years 1956 through 1972.

$$\begin{aligned}
\ln q_{it} = a_i &+ \underset{(82.47)}{0.91} \ln q_{it-1} + \underset{(4.64)}{0.091} \ln y_{it} - \underset{(-2.31)}{0.04} \ln c^{*}_{it} \\
&- \underset{(-2.96)}{0.04} \ln R_{it} + \underset{(-0.27)}{0.03} \ln g_{it} + \underset{(4.88)}{0.07} \ln hd_{it} \\
&+ \underset{(4.97)}{0.03} \ln cd_{it}
\end{aligned} \qquad (4\text{-}1)$$

$$R^2 = 0.991$$

where:

a_{it} = state-specific constant for state i

q_{it} = kWh consumption per customer in state i for year t

y_{it} = state personal income per capita

c^{*}_{it} = cost of purchasing initial 1500 kWh

R_{it} = marginal price per kWh (price per kWh of block containing observed average monthly consumption)

g_{it} = average residential natural gas price

hd_{it}, cd_{it} = heating degree-days; cooling degree-days

In the equation above, the numbers in parentheses are values of the Student's t-distribution, and R^2 is the coefficient of determination adjusted for degrees of freedom. (For those not familiar with these measures, the former is a measure of whether the estimated parameter is statistically significant; the latter measures the amount of variation of $\ln q_{it}$ accounted for by the explanatory variables. Absolute values of t exceeding 2.0 indicate that the parameter is highly significant; between 1.0 and 2.0 implies reasonable significance; less than 1.0 implies negligible significance. R^2 varies between 0 and 1.0, with 1.0 indicating a perfect fit and 0 indicating no relationship whatsoever.)

The Koyck behavioral specification is dynamic and is derived from the assumption that desired energy consumption is dependent on the variables specified above. However, because of the persistence of tastes and the difficulty of rapid adjustments in the characteristics and quantities of buildings and equipment, actual consumption is continually adjusting to desired consumption, with only partial adjustment being realized in any given year. This dynamic specification implies that adjustments of consumption to changes in income, energy prices, and other variables will be much more complete over the long run than in the short run. The magnitude of the coefficient of the lagged dependent variable (0.91) suggests that approximately half of the long-run response would require 7.5 years to work itself out in reaction to a one-time change in an explanatory variable.

The basic structure of the equation is a familiar one in the econometric literature, having been applied to many different problems with a considerable amount of empirical success. The principal advancements of the TBV model over previous specifications involve (1) the estimation technique, (2) an improved electricity price data set, and (3) an improved treatment of declining block rate structures for electricity. The estimation technique is a variance-components method, which allows the intercept to vary randomly across states. (See Balestra and Nerlove [6] for a presentation of this method.)

The model incorporates several advances in the treatment of consumer response to declining block rate structures. State rate structures for electricity were rigorously derived by TBV directly from the individual declining block rates of the utilities. The procedure accounted for the number of customers on particular blocks of a utility's rate structure and aggregated across utilities within states, using the number of customers as weights. The model uses a conventional marginal electricity price taken from the marginal block of the typical household facing the rate structure and a variable to represent intramarginal expenditure, which is approximated by the area below the rate schedule up to 1500 kWh. Intramarginal expenditure is intended to capture the aggregate income effect. Strict interpretation of microeconomic theory implies that the coefficients of y_{it} and c^*_{it} should be equal and opposite in sign, since c^*_{it} has the same effect as a reduction in income. However, it did not seem reasonable to impose the equality restriction, given the aggregate nature of the data and approximation inherent in any modeling effort.

In essence, this approach allows us to interpret the combined effect of the two price variables as corresponding to a situation in which the consumer paid a single price for each kilowatthour consumed. The marginal price coefficient is interpreted primarily as a measure of the substitution effect, and the combination of the two price variables therefore represents the sum of income and substitution effects for the consumer. (The coefficient for marginal price will also represent some income effect, so total price elasticity obtained by summing the fixed charge and marginal price elasticities are likely to be biased upward due to this double counting.) This has significant effects on both price and income elasticities, as may be seen from Table 4-1, which compares the TBV results with several other well-known models.

A number of unresolved issues remain to be addressed in future research on residential energy demand. The state level of aggregation of the TBV model is superior to alternative models based on higher levels of aggregation, such as census regions, but it may still be criticized as an overly aggregated representation of household behavior. An important extension of the TBV model will be the separate modeling of the household demand for space heating and cooling energy. This would allow us to address the competition among fuels for space heating in various regions of the country. Research in this area is currently under way, and related data development is being conducted in conjunction with the U.S. Department of Energy (RP1005, an analysis of household appliance choice, and RP1099-1, the development of household energy consumption survey data).

Table 4-1

COMPARISON OF RESIDENTIAL DEMAND ELASTICITIES

	TBV	Houthakker, Verleger, Sheehan	Anderson	Mount Chapman, Tyrrell
Marginal price				
Short run	-0.04	-0.09	____	____
Long run	-0.48	-1.02	____	____
Average price				
Short run	____	____	____	-0.14
Long run	____	____	-1.12	-1.20
Fixed charge				
Short run	-0.04	____	____	____
Long run	-0.45	____	____	____
Income				
Short run	0.09	0.14	____	0.02
Long run	1.03	1.64	0.8	0.20

Note: For results other than TBV, see Ref. 7.

Another area that deserves further attention is the development of data concerning the price of substitute heating fuels. Because of the lack of data, TBV represented the price of natural gas using average revenue. This assumes that the price of natural gas enters the electricity demand relationship differently from the price of electricity, since both fuel types are generally sold under block rate structures. Also, the existing model does not account for natural gas supply restrictions on the competitiveness of fuel oil. (These problems will be addressed in RP1098, a study concerning residential energy forecasting models: further development.) Also, since the relevant consuming unit is the household, and the correct unit of electricity consumption is kilowatthours per household, another area of needed research in the residential sector is the development or adoption of models to predict household formation.

Electricity Use in the Commercial Sector

The forecasting analysis conducted by Charles River Associates (7) provided the basis for the 1977 EPRI forecast for the commercial sector. On the basis of that project, the model developed by Mount, Chapman, and Tyrrell (MCT) and reestimated in RP333 was selected. The chosen MCT model is a double-logarithmic, constant-elasticity, flow-adjustment model. The underlying behavioral assumption is that actual current demand relative to demand in the previous year is proportional to the ratio of the desired demand in the current year to the actual demand in the previous year. Actual and desired demand are not identical because of lags in adjustment. This is an explicitly dynamic model of energy-consuming behavior and, as such, is quite similar to the model employed for the residential sector. With desired demand depending on the exogenous variables, it can be shown that this adjustment hypothesis results in the following logarithmic form:

$$\ln q_{it} = a_r + \underset{(61.48)}{0.88} \ln q_{it-1} - \underset{(-6.09)}{0.147} \ln PE_{it} - \underset{(-0.27)}{0.003} \ln PG_{it}$$

$$+ \underset{(4.83)}{0.12} \ln y_{it} + \underset{(8.29)}{0.12} \ln P_{it} \qquad (4\text{-}2)$$

$$R^2 = 0.99$$

where:

- a_r = regional constant for region r
- q_{it} = kWh consumption in state i for period t
- PE_{it} = average price (mills/kWh) for electricity in state i for year t
- PG_{it} = average price per thousand therms of natural gas
- y_{it} = personal income per capita in constant dollars
- P_{it} = population in the state i for year t

The dependent variable is aggregate commercial kilowatthours, as opposed to the per-customer definition used in the residential model. This approach was chosen because consuming units are considerably more heterogeneous and therefore are correspondingly vague in the commercial sector. The version of the model used in these forecasts was estimated using data for the 48 conterminous states from 1947 to 1970, and the model was estimated using ordinary least-squares techniques. (Electricity prices were falling in this period. In future applications, it would be useful and instructive to include postembargo data to see if the results changed.) Regional variation across states was treated by incorporating estimated constants for each of the nine census regions. It is interesting to note that electricity price elasticities were 0.15 and -1.26 for the short and long runs, respectively. Income elasticities were 0.12 and 0.99.

The signs and magnitudes of the coefficients are generally reasonable except for the price of natural gas, which carries a questionable negative sign but is insignificantly different from zero. The model suggests that 50% of the long-run response to a change of exogenous variables will occur in 5.6 years.

Although the MCT model has provided a useful step in the analysis of the commercial sector, many questions remain. Perhaps the most basic problem hindering research in this sector is that consuming units falling under the commercial definition are much more diverse than is the case in the residential sector. An equally important problem is the highly aggregated nature of existing data. The space-conditioning load is particularly important in this sector, but existing data do not contain detail on end-use heating and cooling devices or on building characteristics. Progress on a number of these issues is expected from current research (RP662, Data Resources, Inc.). However, research will continue to be hampered by the basic difficulties in the definition of a commercial customer and by the paucity and dubious quality of existing data.

Petroleum and Natural Gas in the Combined Residential-Commercial Sector

The EPRI forecast of residential-commercial consumption of petroleum and natural gas is taken from the FEA's National Energy Outlook (3). Although the FEA PIES model was not directly linked with our model, care was exercised to ensure that prices assumed for the FEA forecast were compatible with the assumptions in place for the other sectors of the EPRI forecast.

The demand portion of PIES forecasts fuel usage for each of nine census regions with a two-stage modeling framework. The first stage forecasts total energy requirements for a region as a function of per capita income, a fuel price index, and the previous year's fuel consumption. The second stage forecasts fuel shares as a function of the ratio of the fuel price to the total energy price index in that region and a lagged value of the fuel share.

Both sets of equations were estimated with pooled time-series cross-section data from 1960 to 1972, using a minimum distance estimator. The set of estimated relationships was then used to numerically generate price and income elasticities that were used in the PIES model to generate the forecasts.

Our use of the FEA estimates involved the calculation of petroleum and natural gas usage growth rates for the relevant scenario and then applying these growth rates to our data.

Energy Use in the Industrial Sector

Industrial energy use is estimated as a derived demand for factors of production. The manufacturing sector is disaggregated into 9 industries that are modeled separately. The industries are listed in Table 4-2, along with two ways of measuring the level of output in each of the 9 industries. Both measures play important roles in forecasting energy usage in the 9 industries. The selection criteria for choice of industry depend on rank orderings based on quantity of purchased electricity as well as purchased fossil fuels. Table 4-3 shows the most recent Annual Survey of Manufacturers' data on electricity and fossil fuel consumption. In 1974, the first 8 two-digit SIC industries account for 77% of electricity and 87% of fossil fuel usage. The remaining 12 two-digit industries have been aggregated into a single residual industry.

A flow chart of the industrial energy modeling procedure is shown in Figure 4-1. In present form the energy models are "slave satellites" of the Wharton Annual and Industry Forecasting Model. The Wharton annual model was designed to provide long-term macroeconometric forecasts with detailed structural analysis and ties the national income accounts to the interindustry accounts within the framework of a macro model.

Table 4-2

OUTPUT LEVELS OF SELECTED INDUSTRIES IN 1973

(millions of current dollars)

Industry	SIC	Value of Product	Share of Total (%)	Value Added	Share of Total (%)
Primary metal industries	33	59,012	7.9	22,907	6.7
Chemicals and allied products	28	58,117	7.8	32,913	9.6
Paper and allied products	26	29,565	4.0	13,153	3.8
Food and kindred products	20	113,576	15.2	35,190	10.2
Stone, clay, and glass products	32	20,707	2.8	12,037	3.5
Transportation equipment	37	106,327	14.3	44,182	12.8
Petroleum and coal products	29	28,300	3.8	6,074	1.8
Textile mill products	22	27,426	3.7	11,236	3.3
Remainder of manufacturing		302,238	40.6	166,183	48.3
Total	20-39	745,258	100.0	343,875	100.0

Table 4-3

ENERGY USAGE OF SELECTED INDUSTRIES IN 1974

SIC	Purchased Electricity (10^6 kWh)	Share of Total (%)	Purchased Fossil Fuel (10^9 kWh-Equiv.)	Share of Total (%)
33	163,319	26.48	610.7	18.46
28	124,168	20.13	733.9	22.19
26	40,870	6.63	349.1	10.55
20	36,875	5.98	243.3	7.36
32	28,858	4.68	362.6	10.96
37	28,375	4.60	81.5	2.46
29	27,240	4.42	432.2	13.07
22	26,908	4.36	67.6	2.04
Remainder	139,521	22.62	427.0	12.91
Total	616,803	100.00	3307.6	100.00

The Wharton structure subdivides along eight interdependent analytic components: (1) the final demand component, (2) the input-output component, (3) the labor requirements component, (4) the wage component, (5) the industrial price component, (6) the final expenditure price component, (7) the income payments component, and (8) the monetary component. Final spending by category is detailed in the final demand sector. The input-output sector uses activity levels for each industrial sector. Labor requirements are predicted with Cobb-Douglas production functions and capacity utilization estimates. Wage rate determination, industrial price determination, and conversion to final expenditure prices take place in the wage and price sectors. The calculation of nonwage payments, interest income, rental income, transfer payments, and employee compensation take place jointly in the labor requirements sector and the wage rate sector. Interest rate determination and money demand are included in the monetary sector.

The specific variables from the Wharton model that were input to the energy models are value of output, the price of output, the user cost of capital, and wage rates. Since there are 20 two-digit industries, this results in over 80 pieces of

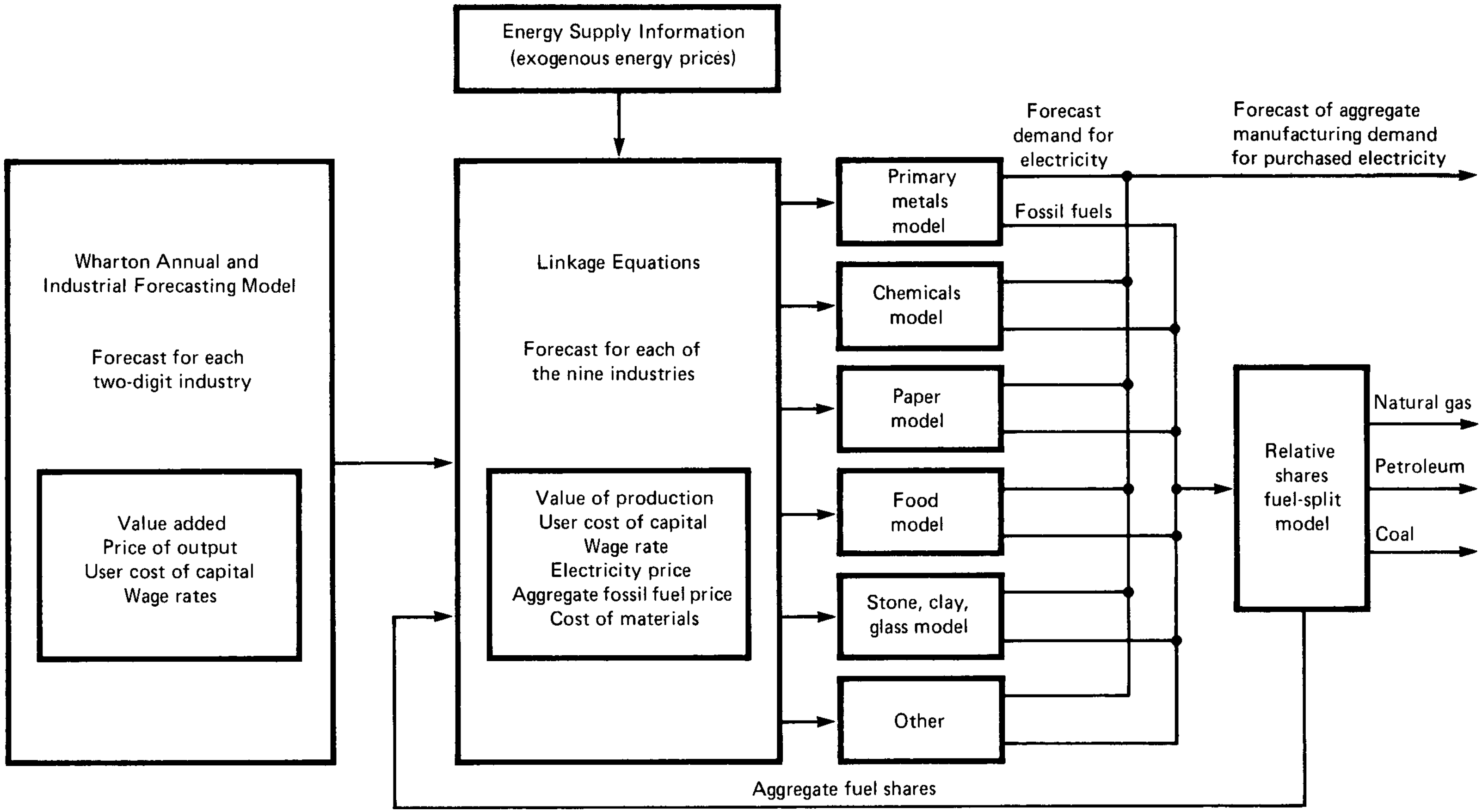

Figure 4-1 Industry energy model schematic

information fed from the Wharton model to the linkage section for each year of the forecast.

Other information feeding the linkage section included the previous years' aggregate fuel share result, an exogenous estimate of capacity utilization rates in each two-digit industry, and exogenous estimates of primary fuel prices and electricity prices. The energy supply price information was provided by the Supply Program of EPRI. These data, along with the Wharton macro information, are transformed by the linkage equations into the precise form required by the nine industry models.

The basic structure of the industrial energy demand models is developed from the assumption that a manufacturing company will produce a certain level of output at the least cost, given certain constraints imposed by the technical and managerial options available to it. These options can be represented mathematically as a production function:

$$q = f(x_1, x_2, \ldots, x_i, \ldots, x_n)$$

where q represents a physical measure of the level of (homogeneous) output and x_i represents the level of each factor input required to produce q. From a technical point of view the number of input combinations that could be chosen to produce a given level of output is infinite. However, when the producer is confronted with an array of input prices $(p_1, p_2, \ldots, p_i, \ldots, p_n)$ the cost minimization hypothesis results in a unique selection of the levels of the input factors. Using historical observations of the past behavior of collections of firms, we use statistical techniques to estimate the structure of production technology in each industry. Then, given the level of output required and the vector of factor prices, at any future time we could forecast the demand for each factor of production.

In practice it is more feasible to estimate a cost function dual to the production function (8). Duality theory demonstrates that a cost function uniquely represents the technical options and determines the exact form of the production function. For a discussion of the many possible specifications of cost functions the reader is referred to the work of Russell and Norman (8). As a result of their research and additional work performed in-house at EPRI, the Generalized Leontief form was selected for the marginal cost function. The complete cost function is

$$C(q,p) = \sum_{i=1}^{5} a_i \ln p_i + q \sum_{i=1}^{5} \sum_{j=1}^{5} b_{ij} (p_i p_j)^{\frac{1}{2}} \tag{4-3}$$

where:

- q is a measure of output (value of product)
- p_i is the price of the i^{th} factor input (e.g., user cost of capital, wage rates, average kWh electricity price, average Btu fossil fuel price, and cost of other material inputs)
- a_i, b_{ij} are parameters to be estimated from historical behavior

The first term represents a committed expenditure that must be paid out even if output q is 0. The five input factors are composed of the two primary factors, capital and labor, and three intermediate factors: electricity, fossil fuels, and other materials.

The cost function can be used to generate a series of five factor demand equations by using a result of duality theory known as Shephard's Lemma. The demand equation for the i^{th} factor has the form:

$$x_i = \frac{a_i}{p_i} + q \sum_{j=1}^{5} b_{ij} \left(\frac{p_i}{p_j}\right)^{\frac{1}{2}}, \; i = 1,5 \tag{4-4}$$

The parameters a_i, b_{ij}, in these five equations were estimated statistically from historical observations on the prices, output levels, and factor input levels. The data covered the period 1947-1971 and were taken primarily from the <u>Census of Manufacturers</u> and the <u>Annual Survey of Manufacturers</u>. The estimation technique was the iterative three-stage least-squares procedure for simultaneous estimation of all five equations.

With numerical estimates of the parameters and the information from the linkage section, it is possible to forecast electricity and fossil fuel demands for each of the nine industries. These are added to obtain total manufacturing purchases of electricity and fossil fuels. The latter number is used by the fuel-split model to calculate the amount of natural gas, petroleum, and coal required to make up the aggregate manufacturing fossil fuel demands.

The first step in the fuel split model converts the aggregate fossil fuel demands from a Census of Manufacturers concept into a Bureau of Mines figure. The Bureau of Mines data are necessary for the fuel-split model since the Annual Survey of Manufacturers data report only electricity and fossil fuel consumption. The census data report fossil fuel splits, but only at four- or five-year intervals. A problem is the lack of agreement between data from the Census and the Survey and that from the Bureau of Mines. For example, in 1971 the Census reported that all industry used 3.3 x 10^{12} kWh-equivalent, or 11.37 x 10^{15} Btu of fossil fuels, while the Bureau of Mines reported the industrial sector consumption level at 15 x 10^{15} Btu. Table 4-4 shows the same comparative numbers for each fuel type. Although the numbers do not agree in absolute level, there is a very high correlation in the year-to-year changes of total fossil fuel consumption. A simple linear regression equation accurately predicts the Bureau of Mines fossil fuel consumption number from the Census of Manufacturers value. Once this conversion takes place, the remaining equations of the fuel-split model operate with Bureau of Mines data, which report industrial fuel-splits annually.

Table 4-4

INDUSTRIAL SECTOR COMPARISON OF DATA FOR 1971

Source	Petroleum (10^6 bbl)	Coal (10^6 tons)	Natural Gas (10^9 ft^3)	Electricity (10^9 kWh)
Bureau of Mines	537.7	154.6	9604	672.0
Census	245.7	75.1	6454	517.8

The underlying justification for the structure of the fuel-split model results from the notion that the substitution possibilities and choices of specific fuel types reflect much the same mathematical structure represented by the production function. In this case we need an aggregating function to relate specific fuel types to an aggregate fossil fuel output, which in turn is a factor input to the production process. Duality theory again allows us to represent the aggregating function with the dual form, which is essentially an aggregate price index. We have again used the Generalized Leontief function to represent this price index. In addition, dynamics have been added to this portion of the model by viewing the resulting fuel demand as a desired level of coal, oil, or natural gas. The actual level is specified as a function of last year's actual level and the desired level for this year. This procedure attempts to capture the time lags introduced by the existence of capital stock that cannot adjust instantaneously to desired levels.

The fuel shares calculated are used in a relative-shares model that calculates the fossil fuel splits for each of the nine industry models. The following equation shows how this is accomplished:

$$\frac{S_{ikt}}{S_{jkt}} = \left(\frac{M_{it}}{M_{jt}}\right)\left(\frac{S_{ik71}}{S_{jk71}}\right)\Big/\left(\frac{M_{i71}}{M_{j71}}\right) \qquad (4\text{-}5)$$

where S_{ikt} is the fraction of fuel i used by industry k in year t, and M_{it} is the fraction of fuel i used by the entire industrial sector in year t. 1971 is the most recent year for which comprehensive fuel-split data are available on a two-digit SIC level. This information is displayed in Table 4-5. The basic assumption of the model is that each two-digit industry follows aggregate trends in its fuel choices. The only use made of the industry-level fuel-split information is to weigh the prices of coal, natural gas, and petroleum to produce a fossil fuel price for each of the nine industries. This price is used in the forecast for the following years.

Table 4-5

FUEL SHARES OF SELECTED INDUSTRIES IN 1971

SIC	Coal (%)	Petroleum (%)	Natural Gas (%)
33	26.4	12.2	61.5
28	19.8	9.8	70.3
26	19.3	36.1	44.7
20	14.3	17.4	68.3
32	21.1	11.0	67.9
37	23.9	16.7	59.4
29	0.6	5.9	93.5
22	16.8	33.0	50.2
Remainder	7.0	51.2	41.8
Total	15.8	21.7	62.4

Energy Use in the Transportation Sector

Transportation energy consumption is composed primarily of auto and nonauto gasoline, highway and rail distillate (diesel) fuel, and jet fuel. Our forecast derives from several different models of fuel demand by end use.

Gasoline demands are predicted primarily with a vintage capital model of gasoline use developed by J. Sweeney (4) for use by FEA in PIES. A forecast of total vehicle miles is developed in one portion of the model and the fleet average miles per gallon is forecast in another section. Vehicle miles are assumed to depend on per capita income, the cost of vehicle operation (both time and fuel cost), and the unemployment rate. Automobile use of gasoline is obtained by dividing vehicle miles by the average fleet efficiency. Efficiency (i.e., miles per gallon) of the existing stock of automobiles is determined as a weighted average of efficiencies of automobiles of various vintages. The weights in the averaging correspond to the product of the number of autos in existence from each vintage and an index of miles driven by automobiles of various ages. Exponential scrapping of the existing fleet occurs over time. The number of new cars purchased each year is determined within the model from the desired vehicle miles and the capital stock of automobiles from earlier vintages, less those scrapped. The efficiency of new cars is specified as a function of gasoline price in the current year and a measure of average technical efficiency of new cars when standardized for curb weights. The price dependency represents a shifting of the weight mix of automobiles, while the technical efficiency represents changes in miles per gallon when the weight mix is held constant. The technical efficiency is assumed to increase by 31% between 1975 and 1985. However, for the energy conservation scenario solutions, the legislated efficiency standards are imposed on newly purchased cars.

Other transportation petroleum end uses are modeled along the lines followed by the DRI Energy Policy Model. Jet fuel usage is composed of military usage (which is projected exogenously) and commercial jet usage. The latter is estimated as a function of air passenger miles adjusted for the load factor to account for excess capacity and an exogenous time trend that represents technologic change in aircraft designs.

Diesel fuel usage is specified as a function of the relative price of distillate and a measure of economic activity in railroad and motor freight transportation. Transportation use of residual fuel is estimated along similar lines, with the relevant economic activity variable being real gross product originating in water transportation.

The remaining transportation fuel demands (liquefied gas and natural gas) are projected as trends, with a price correction included in the liquefied gas equation.

Section 5
WHAT HAS BEEN LEARNED FROM DEMAND 77?

While it is clear that Demand 77 has made major strides in embodying recent research, it is also clear that substantial modification is desirable for addressing many forecasting problems. Three major lessons learned from Demand 77 are the need for functional disaggregation, the importance of sectoral disaggregation, and the need for additional work on natural gas and petroleum consumption.

In assessing the energy conservation scenario, in particular, the need for functional disaggregation became painfully clear. Many of the actual and potential policy proposals concerning energy conservation are addressed to specific activities of a sector, such as heating or cooling, rather than to the sector as a whole. This applies, in particular, to imposing standards and fostering the development of new technologies. In assessing the implications of appliance efficiency standards as one example among many, it was necessary to make arbitrary assumptions as to the extent to which efficient appliances would be sold through normal market mechanisms implied by the baseline price series and how much of an effect would be realized through the imposition of the standards themselves. Clearly, higher electricity prices will encourage the sale of devices of increased efficiency with or without the existence of government mandates or standards; but at present there is no way to separate the effects of the marketplace from the effects of standards. If one were to take the total amount of energy that would be saved by efficient appliances and attribute it to the imposition of standards, the result would be an exaggeration of the effects of the standards, since some of those effects would have taken place through the market in any case. In order to handle this problem, it was necessary to make judgmental estimates of the extent to which the imposition of standards would result in energy conservation above and beyond what would be implied by increased energy prices alone. Such estimates could be made with much more precision if functional disaggregation (say, disaggregation by appliance types and comfort conditioning systems) were available.

A second major lesson learned from Demand 77 was the importance of disaggregation within broad sectors. In the industrial sector, many forecasts of electricity consumption have been surprisingly low, considering the problems of availability and cost of petroleum and natural gas. Looking at aggregate figures alone, one would expect to see a much more pronounced effect of substitution for fossil fuels. However, when the disaggregated results are examined by two-digit SIC codes, the reason for the relatively low growth is clear, namely that those industries which have traditionally consumed the most electricity (primary metals, chemicals, and others) are projected to grow rather slowly compared with other manufacturing industries. Such disaggregation is desirable for all of the major sectors. For example, it is desirable to analyze residential consumption by demographic classes rather than treating all households as though they were homogeneous. Also, a two-digit (or more) breakdown would be highly desirable for the commercial sector, which comprises an extremely heterogeneous group of industries.

It is clear that the whole area of natural gas and petroleum consumption and the impacts of supply restrictions on electricity consumption need careful exploration. In the manufacturing sector, many firms are in the position in which they cannot rely on their gas supply, and in all sectors there exist some prohibitions on natural gas hookups. A difficult aspect of this problem is that the situation differs among regions. Thus, even in our national forecasting efforts we are forced to pay close attention to regional phenomena. A somewhat similar problem is encountered in petroleum products, which have never been significant factors in the heating fuel market in many parts of the country. Increased attention must be paid to restrictions on natural gas supply and unavailability of petroleum in model development efforts, especially regional aspects.

Another problem linked with natural gas and petroleum is that we feel uncomfortable with the PIES model results for residential and commercial consumption of petroleum and natural gas. It is counterintuitive that the residential-commercial use of natural gas should decline absolutely, even without restriction. Part of our unease with this model stems from the aggregation of the commercial and residential sectors. More understanding of these sectors is necessary before we can be comfortable with the results of either the PIES models or alternative models that might be used.

Work on functional disaggregation, sectoral disaggregation, and natural gas and petroleum are problems that are of immediate importance in assessing the impacts of alternative price, economic growth, policy, and technologic change assumptions in end-use energy consumption. Research is currently proceeding that will enable us to make assessments of the impacts on energy consumption of such emerging and prospective technologies as heat pumps, electrified transportation, and cogeneration. In addition to the functional disaggregation mentioned above (which is necessary for even ad hoc adjustments) for technological change, there are major conceptual problems in assessing the market acceptability of new technologies. Behavioral models of the adoption of new technology currently comprise a major part of the Demand and Conservation Program's research efforts.

Also, in looking at the results of Demand 77, we are somewhat uncomfortable with not having any assessment at all of possible changes in personal values concerning energy consumption. On the one hand, the post-1974 experience does not indicate anything like the emergence of a conservation ethic. On the other hand, it is possible that values are not transmitted so rapidly as to cause a turnaround within three years. It is possible that changes in values, to the extent that they have occurred at all, will show up most significantly in the post-Earth Day population--people whose incomes and family sizes are just now arriving at the point that attitudinal shifts would be manifesting themselves in the aggregate consumption statistics.

In short, what has been learned from Demand 77 is that we still know relatively little about possible future paths of energy consumption. We do, however, know more than was known a year ago; and significant improvements in the state of knowledge, from both EPRI-sponsored research and other research, can be expected to contribute greatly to understanding and forecasting energy consumption over the next few years.

Section 6

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