U.S. Energy and Economic Growth, 1975-2010

AUTHORS

Edward L. Allen
Chester L. Cooper
Frances C. Edmonds
James A. Edmonds
David B. Reister
Alvin M. Weinberg
Charles E. Whittle
Leon W. Zelby

Institute for Energy Analysis

Oak Ridge Associated Universities

ORAU/IEA 76-7
September 1976

DISCLAIMER

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Oak Ridge Associated Universities
Institute for Energy Analysis
Oak Ridge, Tennessee 37830

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: 6.50
Paper Copy $~~5.50~~
Microfiche $2.25 (domestic)
$~~3.75~~ (foreign)
12.10

Contents

Preface

The study was conducted by the Institute for Energy Analysis (IEA) of Oak Ridge Associated Universities (ORAU) under the sponsorship of the Energy Research and Development Administration (ERDA).

IEA wishes to thank the many experts consulted while it prepared the study. These include Peter L. Auer, Hans A. Bethe, Calvin C. Burwell, Monte Canfield, Jr., Roger S. Carlsmith, Thomas B. Cochran, Floyd L. Culler, George Daly, Edward F. Denison, William Fulkerson, Howard H. Fuller, Campbell Gibson, Walter R. Hibbard, Jr., L. John Hoover, Kenneth A. Hub, Philip L. Johnson, Michael Kennedy, George B. Kistiakowsky, Ronald Kutschi, Hans H. Landsberg, Dennis L. Meadows, Celia Evans Miller, Philip F. Palmedo, Robert G. Sachs, Sam H. Schurr, John H. Vanston, Jr., David R. Weinberg, and Larry J. Williams. Of course, none of them are in any way responsible for our findings—this responsibility is borne solely by IEA.

Alvin M. Weinberg, Director
Institute for Energy Analysis

Summary

This study projects economic growth (GNP) and energy demand for the United States to the year 2010. Our main finding is that both GNP and total energy demand are likely to grow significantly more slowly than has been assumed in most analyses of energy policy. Our projections of energy, GNP, and electricity (total and per capita) are summarized in Table 1. Note that electricity demand is expected to grow more rapidly than total energy demand.

Two scenarios designated "high" and "low" were developed in this study. However, even the "high" scenario, 126 quads (q; 1 q equals 10^{15} Btu) in 2000, is much lower than most previous estimates. We believe this raises serious questions about fundamental energy and energy R&D policies which, generally, have been based on perceptions of more lavish energy futures. Although the aggregate demands and GNP are projected to increase rather modestly, the energy demands per capita and GNP per capita increase at rates comparable to or even higher than historic rates.

We recognize that it is impossible to predict the long-term future. However, it is our belief that the projections we have developed in this study represent a logical culmination of many trends toward lower growth. These trends have not yet been factored into the older energy projections upon which so much energy policy is based.

Our projections result from a detailed analysis of historic trends for the many

TABLE 1. GNP, Energy, and Electricity Demand

(total and per capita)

	Total					
	GNP (10^9 1975 $)		Energy and electricity (quads)		Population (10^6)	
Year	Low	High	Low	High	Low	High
1975	1,499	1,499	71.1 (20.1)	71.1 (20.1)	213	213
1985	2,135	2,135	82.1 (30.8)	88.0 (34.1)	228	231
2000	3,184	3,326	101.4 (47.3)	125.9 (64.0)	245	254
2010	4,076	4,470	118.3 (55.5)	158.8 (82.4)	250	264

	Per capita					
	GNP (1975 $)		Energy demand (10^6 Btu)		Electricity (10^6 Btu and percent)	
Year	Low	High	Low	High	Low	High
1975	7,038	7,038	334	334	94 (28)	94 (28)
1985	9,364	9,242	360	381	134 (38)	147 (39)
2000	12,996	13,094	414	496	193 (47)	252 (51)
2010	16,304	16,932	473	602	222 (47)	312 (52)

factors that determine GNP and energy demand. The main factors that imply lower GNP are a fertility rate that has fallen to 1.8 and is likely to continue at approximately this level, a somewhat slower rise in labor force, and a rate of growth of labor productivity of between 1.7 and 2.4 percent per year. The lower energy demand derives primarily from our extrapolation of historic trends that show greater efficiency (i.e., E-to-GNP ratio), the effect of higher energy prices, and the introduction of energy-saving technologies. The shift toward electricity stems primarily from our expectation that oil and gas prices will rise sharply compared to coal and nuclear prices.

We realize in putting forward future energy scenarios in such contrast to those customarily used to guide energy policy that the Institute for Energy Analysis assumes a heavy responsibility. Throughout our study, therefore, we have made an effort to indicate precisely what methods were used and what assumptions were made in arriving at our projections. Each reader can then decide for himself how seriously to take these projections of an unknowable future, and to what extent energy R&D policy ought to be based on our analysis.

Methodology

We arrive at estimates of energy demand in four steps.

(1) First we estimate GNP (the first two sections of this report). This is done by using a usual formulation: GNP ≡ Labor Force x Labor Productivity. The labor force is estimated from projections of population and of labor participation rates. The adult population is already determined, for much of the period (up to the early 1990s), and the labor participation rate is assumed close to the present one. Labor productivity is estimated by extrapolation of historic trends and productivity is not expected to grow at rates significantly higher than historic rates. In general, we have tried to bias our results toward the high side. For example, we have used optimistic assumptions about future labor productivity

and have been conservative in our judgments regarding future energy conservation.

(2) From projections of GNP and population, we derive energy demands (the third section). We divide the energy demand into two parts—one directly related to GNP, the other directly related to population. The part related directly to GNP consists of two "intermediate factors": industrial activities and transport of goods and services. The part related directly to population is comprised of three intermediate factors: households, commercial space, and automobiles. The relations among intermediate factors, GNP, and population are depicted in Figure 5 (see the second section). The magnitude of the intermediate factors directly related to GNP—for example, the size and composition of industry in, say, 1990—is estimated from past relations between these factors and GNP. The magnitude of intermediate factors directly related to population—for example, the number of households in 1990—is estimated directly from the demographic projections. Magnitudes of some of the intermediate factors are rather dependent on assumptions about life style. For example, the number of automobiles and annual mileage per vehicle in 1990 and the size and composition of future households are important assumptions. Thus, in estimating intermediate factors we had to make assumptions regarding life styles.

(3) From the magnitudes of each intermediate factor, we estimate its corresponding end-use energy demand; the total energy demand is then the sum of the energy demands in each end-use category. Two parameters enter into these estimates: the rate of introduction of new technologies (e.g., lightweight automobiles) and degree of energy conservation (so-called efficiency improvement index). These relations are shown in Figure 6.

(4) In these estimates we have not introduced prices of energy explicitly; instead, we have given independent estimates of energy prices, based generally on extrapolation and judgment. Our estimated prices are given in Table 2. Implicit in our projections are price elasticities, and it is necessary to determine whether these elasticities are plausible. An analysis of future energy prices and elasticities produces the values shown in Table 3. We find these elasticities to be well within the range of elasticities obtained in other studies.

As another check to determine whether the assumed prices are consistent with the estimates for energy demand and GNP, a simple one-sector economic growth model that relates energy, capital, labor, GNP, and energy prices has been developed. A short description of this model is given in the fourth section; full

TABLE 2. Estimated Prices of Different Energy Modalities

(relative to 1975 in constant dollars)

	1975	1985	2000	2010
Coal	1.0	1.22	1.65	2.00
Oil	1.0	1.54	2.40	3.23
Gas	1.0	6.42	10.00	13.40
Electricity	1.0	1.22	1.65	2.00

Note: The 1975 average prices were as follows: Coal, $17.50 per ton, delivered to utilities; Oil, $10.40 per barrel, composite cost to refiners; Natural Gas, $0.43 per thousand cubic feet at the wellhead; Electricity, 27 mills per kilowatt-hour (kWhr) to consumer.

TABLE 3. Price Elasticities*

(relative to reference scenario)

	Low scenario				High scenario			
	Elect.	Gas	Oil	Coal	Elect.	Gas	Oil	Coal
Residential	−1.08	−1.21	−0.97	0.0	−0.60	−1.43	−1.03	0.0
Commercial	−1.19	−1.21	−0.97	0.0	−0.61	−1.43	−1.03	0.0
Transportation	0.0	0.0	−0.57	0.0	0.0	0.0	−0.26	0.0
Industrial (Total)		−0.37				−0.28		

*Any elasticity value of magnitude less than 0.1 has been rounded to 0.0.

details are presented in Appendix A. The model suggests that our projections of GNP are achievable with the price schedule for energy that we have assumed; and that lower energy demands can be reached without serious economic effects if energy price increases are gradual and anticipated.

Assumptions

Given the unknowability of the future, we chose to estimate energy demand according to two scenarios—a "high" and a "low." The assumptions underlying the two scenarios for each of the elements that determine energy demand are summarized in Tables 4, 5, and 6. Table 4 lists the assumptions made for the key factors that contribute to growth and composition of the population, the labor

TABLE 4. Summary of Key Input Assumptions for Population, Labor Force, and GNP Growth

Year or period	Total fertility rate (children/woman)		Labor participation rate (worker per person 16 and over)	Percent annual growth rate of full-time employment	
	Low	High	Low and high*	Low*	High*
1975	1.8	1.8	0.61		
1975–1985				1.9	1.9
1985	1.7	1.8	0.625		
1985–2000				0.7	0.8
2000	1.7	1.9	0.63		
2000–2010				0.45	0.6
2010	1.7	1.9	0.63		

Year or period	Percent annual growth rate of average labor productivity		Percent annual growth in GNP	
	Low	High	Low	High
1975–1985	1.7	1.7	3.6	3.6
1985–2000	2.0	2.2	2.7	3.0
2000–2010	2.05	2.4	2.5	3.0

*Immigration in each case is assumed to be the same (400,000 per year) as recent Bureau of the Census population projections. The unemployment rate is assumed to fall to 4–5 percent.

force, and GNP. (The specific assumptions underlying Table 4 are discussed in detail in the first section of this report.) Table 5 lists the assumptions made for the key factors determining growth in the intermediate factors of households, commercial (service) space, and automobile inventory. Table 6 lists the assumptions made for changes in the end-use efficiencies for different energy-use categories. Each of the assumptions is represented by values for selected years between 1975 and 2010.

TABLE 5. Intermediate Factors for Households, Services, and Automobiles

Year or period	Household formation rate (No. per adult)	Commercial space per household (ft^2)		Autos per person over 16 years	
	Low and high	Low	High	Low	High
1975	0.53	350	350	0.67	0.67
1985	0.55	350	387	0.65	0.71
2000	0.57	350	449	0.65	0.77
2010	0.56	350	496	0.64	0.79

Note: Households are assumed to shift to smaller average size housing units, commercial composition is assumed to shift from education-type units toward health care and recreation units, and automobiles are assumed to shift toward lighter-weight vehicles.

Findings

Two projections for population, labor force, and GNP are given in Table 7. These projections are based on the analysis in the first section of this report and the assumptions listed earlier for future fertility rates, labor participation rates, and labor productivity. It is important to note that the higher projections developed here for population, labor force, and GNP are lower than other recent growth estimates now being used as a basis for energy projections. Both our high and low scenarios for long-term GNP growth are optimistic in the sense that we have used optimistic assumptions concerning future productivity gains.

Projections of number of households, commercial space, and inventory of automobiles are listed in Table 8. These results are based on the analysis in the second section of this report and the assumptions for future household formation

TABLE 6. Average Efficiencies and Improvement Factors

Year	Household (10^6 Btu/unit)		Commercial (10^5 Btu/ft^2)		Autos and service trucks		Truck/bus/rail freight (10^3 Btu/ton-mile)	Industrial index to 1975	
	Low	High	Low	High	Low	High	Low and high	Low	High
1975	219	219	3.69	3.69	54.4	54.4	7.1	1.0	1.0
1985	198	222	3.40	3.40	35.2	37.9	6.8	1.10	1.10
2000	178	241	3.08	3.08	22.8	26.6	6.5	1.16	1.14
2010	170	258	2.97	2.97	19.4	22.7	6.3	1.18	1.22

TABLE 7. Population, Labor Force, and GNP Growth

Year or period	Population (10^6)		Labor force (10^6)		GNP (10^9 1975 $)		Percent annual growth in GNP	
	Low	High	Low	High	Low	High	Low	High
1975	213	213	95	95	1,499	1,499		
1975–1985							3.6	3.6
1985	228	231	110	110	2,135	2,135		
1985–2000							2.7	3.0
2000	245	254	123	124	3,184	3,326		
2000–2010							2.5	3.0
2010	250	264	128	132	4,076	4,470		

rates, commercial space and type, and automobile ownership and use listed earlier.

The key finding is that energy demand over the next 25 years is likely to grow much slower than most other studies indicate. We also find that the demand for electricity is likely to rise faster than the total demand for energy. Table 9 presents our energy demands by sector estimates to the year 2010. These estimates range from 101 to 126 q by the year 2000.

In summary:

(1) Future long-term average U.S. economic growth, in terms of real GNP, is not likely to exceed 2.5–3.0 percent annually, even with optimistic assumptions about future growth in labor productivity. This compares to an average annual rate of growth of 3.4 percent for GNP during the past 35 years.

(2) Future long-term growth in U.S. energy demands, even with moderate assumptions about conservation, is not likely to exceed the 101–126 q range by the year 2000 if net average energy prices increase at an annual rate of 2.3–4.3 percent, and the price increases are gradual and anticipated.

(3) The projected growth in GNP implies that per capita GNP growth will range from 2.4 to 2.6 percent annually, compared to a growth rate of 1.8 percent over the past 35 years. Projected annual growth in per capita energy use will range from 1.0 to 1.7 percent compared to 1.4 percent for the past 35 years.

(4) Energy-demand scenarios developed here imply a shift in electricity use from a current 28 percent of the total to approximately 50 percent by the year 2000.

Concluding Remarks

The low estimates that emerge from our analysis are in no sense "normative";

TABLE 8. Households, Commercial Space, and Automobiles

Year	Households (10^6)		Commercial space (10^9 ft^2)		Automobiles (10^6)		Annual mileage (10^{12})	
	Low	High	Low	High	Low	High	Low	High
1975	72	72	25.2	25.2	105	105	1.05	1.05
1985	87	87	30.5	33.7	115	126	1.15	1.39
2000	101	101	35.4	45.3	127	152	1.27	1.82
2010	104	107	36.4	53.1	130	166	1.30	1.99

TABLE 9. Energy Demand by Sector
(10^{15} Btu)

Year	Total		Household		Commercial		Transportation		Industrial	
	Low	High	Low	High	Low	High	Low	High	Low	High
1975	71.1	71.1	15.8	15.8	9.3	9.3	18.6	18.6	27.4	27.4
1985	82.1	88.0	17.2	19.3	10.2	11.8	19.2	21.4	35.5	35.5
2000	101.4	125.9	18.0	24.3	10.9	15.4	22.2	28.1	50.3	58.1
2010	118.3	158.8	17.7	26.8	10.8	17.9	25.3	33.9	64.5	80.2

we have avoided suggesting what *ought* to be the U.S. energy future. Rather, our estimates flow from an analysis of what we believe is *likely* to happen in a surprise-free world. Recognizing the risks and hazards of forecasting, we believe that a surprise-free future is likely to be a lower energy future than official policy has thus far contemplated. We believe that this should be taken into account in choosing the nation's energy options and developing its R&D policy.

The Future Course of Economic Growth

Several basic factors affecting America's economic future have recently become evident which could signal a marked change in the future course of economic growth and energy consumption (the next few decades may differ significantly from the recent past). If the trends we have identified continue, the actual future U.S. energy growth rates will be well below those of the recent past. An examination of the factors influencing economic growth and energy scenarios follows. This examination leads the Institute for Energy Analysis (IEA) to conclude that future energy consumption is likely to be significantly lower than has been projected in other published studies.[1]

The gross national product (GNP) is determined by a complicated process using inputs of labor, capital, raw materials, and energy. Historically, the primary sources of economic growth have been increases in the factor inputs of labor and capital, and in productivity or output per unit of input. In a series of studies over the past 15 years,[2] Edward F. Denison has estimated the importance of each source of growth for the U.S. economy. His results are summarized in Table 10.

For the period 1929–1969, the average growth rate for national income was 3.33 percent. Denison estimates that increases in factor inputs contributed 1.81 percent to the economic growth and that increases in productivity contributed 1.52 percent. The increase in the quality and quantity of the labor force has been the most important source in determining the growth of GNP. In the past, the

TABLE 10. Sources of Growth of Total National Income

(contributions to growth rate in percentage points)

	Total actual national income*	
	1929–1969	1948–1969
National income	3.33	3.85
I. Total factor input	1.81	2.10
A. Labor	1.31	1.30
Employment	1.08	1.17
Hours	–0.22	–0.21
Average hours	–0.50	–0.37
Efficiency offset	0.19	0.06
Intergroup shift offset	0.09	0.10
Age-sex composition	–0.05	–0.10
Education	0.41	0.41
Unallocated	0.09	0.03
B. Capital	0.50	0.80
Inventories	0.09	0.12
Nonresidential structures and equipment	0.20	0.36
Dwellings	0.19	0.29
International assets	0.02	0.03
C. Energy and raw materials	0.00	0.00
II. Productivity† (technical and managerial)	1.52	1.75
A. Advances in knowledge	0.92	1.19
B. Reallocation of resources from farming	0.29	0.30
C. Economies of scale	0.36	0.42
D. Other	–0.05	–0.16

*National income differs from gross national product by indirect business taxes and depreciation.

†Average labor productivity in the text includes all factors in this table except employment.

availability of raw materials and energy has not been a significant source of growth; in the future, however, shortages of raw materials and energy may slow the rate of economic growth.

This chapter will address each of the major sources of economic growth. We will examine the implications for growth of population, labor force, and education and the upward trend in capital investment needed to produce a given level of output. In combination, these trends signal decreasing economic growth rates over the next few decades.

One of our two estimates is that the GNP growth rate will be 3.6 percent per year in 1975–1985, 2.7 percent per year in 1985–2000, and 2.5 percent per year in 2000–2010. When this course of economic growth is combined with other measures governing energy demands, the result is our "low"-energy projection or scenario. We will refer to this low scenario from time to time as we discuss the individual factors governing both economic and energy growth. The detailed construction of the energy projections based on our analysis of future economic growth is described in the third major section of this report.

In the last part of this section we examine a number of considerations which could lead to more rapid rates of economic growth. If all or most of these factors actually came into play, a sustained 3 percent rate of increase in GNP for the periods 1985–2000 and 2000–2010 would occur rather than the drop to 2.7 percent and 2.5 percent, respectively, used in the lower case. When this higher rate of economic growth is combined with slower market penetration of energy-saving measures and other energy-sensitive factors, the "high"-energy projection or scenario is obtained. Although this high scenario is developed in detail in the third section of this study, it will be convenient to refer to it from time to time as the "high case" in this and subsequent sections.

Even with the latitude in economic growth trends represented by the low- and high-growth cases, the GNP projections developed here are well below those used in most other published energy-related studies.[3] If, as we believe to be the case, future GNP growth rates (based largely on projecting past trends) are overstated in these models, then the related energy demands also are overstated. Our lower projections stem mainly from our estimate of demographic factors, since estimation of future factor productivity has been optimistic. As we shall demonstrate later, the absolute magnitude of GNP will vary somewhat with differing population projections. However, the GNP per worker and hence the rate of improvement of the material "quality" of life are largely insensitive to future population trends. The chief difference between our analysis and other projections is the effort made here to foresee future trends in population, labor force, and average labor productivity without reliance only on historic performance over the past 35 years.

Population Trends

Population growth basically determines the size of the future labor force (a key input to economic development), and serves as a useful guide to energy demand, since everyone consumes energy either directly or indirectly. Population growth and the closely related educational quality improvements have been the most important factors contributing to the economic expansion of the nation. In 1870 the U.S. population was 39.9 million; by 1970 it had grown to 204.8 million. During this time there was also a steady rise in that proportion of the population old enough to work. This population and labor force growth was made possible by the high rate of immigration of working-age adults and by high fertility rates among married women.[4]

Immigration has now been largely closed off, although there are a significant number of illegal entrants—mostly farm laborers from Mexico. More important to total population projections than immigration curtailment has been the sharp decline in the birth rate. At the turn of the century the average female bore over four children; now the average number is less than two—below the level needed to sustain the population over the long run without immigration. This decline in population expansion was halted briefly during and after world War II, but the downward trend continued after 1960 and now closely approximates the long-term trend. Obviously, important social factors are at work which account for the continuation of the long-term declining pattern of population increases. The abrupt curtailment of the postwar "baby boom" is shown in Table 11, which represents annual births expressed in terms of the implied completed pregnancies per woman.

The hundred-year downward trend in fertility rates (see Figure 1) cannot continue for many more decades; if it did, the birth rate would soon approach zero. Rather, fertility is likely to move toward an asymptotic positive value. In order to bracket a broad range of possibilities the Census Bureau now uses three population projections. The Series I projection is based on an early return to the experience of the mid-1960s and is calculated on the basis of a fertility rate of

TABLE 11. U.S. Total Fertility Rates, 1957–1975

Year	Fertility rate
1957	3.76
1961	3.63
1968	2.48
1971	2.28
1974	1.86
1975	1.80*

*Preliminary Census Bureau estimates.

2.7. Series II is based on a moderate increase to a total fertility rate of 2.1. Series III is based on a continuation and leveling of present trends to a total fertility rate of 1.7. A rate of 2.1 represented by the Series II projection is roughly what is needed to keep the population stable in the long term. These Census Bureau projections[5] are shown in Table 12, giving population in millions of people.

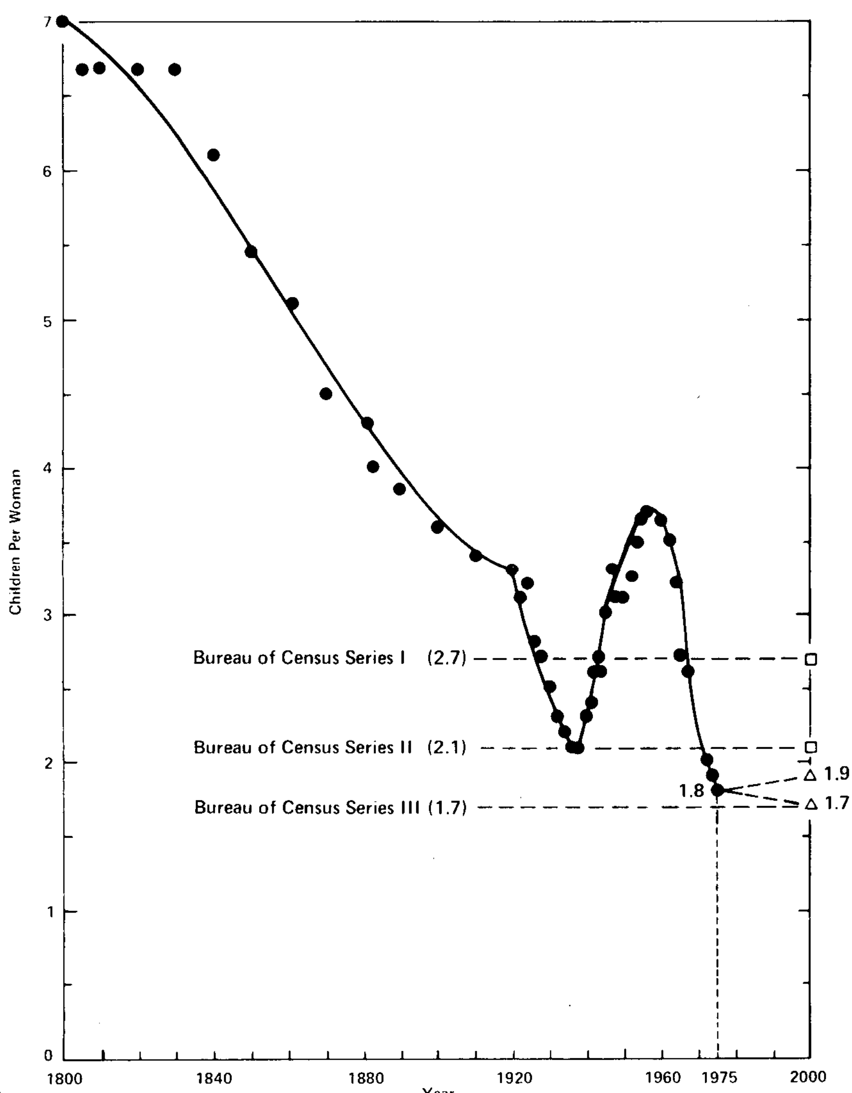


TABLE 12. Bureau of the Census Population Projections (10^6 People)

(each series is based on different fertility rate assumptions)

Year	Series I	Series II	Series III
1975	213	213	213
1980	226	223	220
1990	258	245	236
2000	287	262	245
2010	322	279	250
2020	362	294	252

For the purpose of this study we have based our low case on the Census Bureau's Series III projection, which assumes a decline in the fertility rate from 1.8 to 1.7 by the year 2000; this is a modest decline in the current level. Our high case, which is a modification of this projection, assumes a reversal in the current fertility rate from 1.8 to 1.9 by the year 2000, or sufficient planned immigration to hold the population to an equivalent level. This results in a projection which is intermediate between the U.S. Census Bureau Series II and Series III projections and gives a range of ±0.1 around the current 1.8 level.

The compositions of the population for these two cases are shown in Tables 13 and 14.

Some demographers believe that there has been a postponement in child-bearing in the early 1970s which will be made up in the future. Since surveys show that married women intend to have more children than the current fertility rate would support, the fertility rate could move back to 2.0. However, some believe that postponement will be a permanent process and that, as women move out of their twenties, the chance of a "catch up" in births diminishes.

Changes in life styles, rapidly escalating costs of college education, and changing moral and ethical standards undoubtedly all play a role today in determining family size. Perhaps more important has been the growing (but not yet universal) availability of birth control devices and information, and the legalization of abortion. However, unwanted pregnancies among low-income, unmarried teenagers are high and constitute a significant percentage of total births. This reflects ignorance about birth control methods, not conscious choice.

TABLE 13. Assumed Population for IEA Low Case (10^6 People)

(based on a fertility rate decline from current 1.8 to 1.7)

Year	Total	Under 16	16 to 64	65 and over	21 and over	16 and over
1975	213	58	133	22	135	156
1980	220	53	143	25	147	168
1985	228	52	150	27	158	177
1990	236	52	155	29	166	184
1995	241	52	158	30	173	189
2000	245	50	164	31	177	195
2005	248	48	169	31	181	200
2010	250	48	171	33	186	204

Note: These numbers have been individually rounded and may or may not appear to be correctly summed.

Professor Charles F. Westoff has concluded that 95 percent of the decline in fertility rates during the 1960s among married women was caused by a decline in unplanned births, although 39 percent of the births in 1970 were still unplanned.[6] Virtually all population experts expect substantial early progress in control of unwanted births among teenagers. If unwanted births in this category were cut in half, the overall fertility rate would fall to between 1.5 and 1.6 and would cause a substantial population decline early in the 2000s. If either of these projections (1.5 or 1.6) becomes the path of population growth for the balance of this century, the U.S. population would approach a maximum in the early decades of the next century, a level which could be sustained only through controlled immigration.

It is important to note that none of the commonly accepted economic growth models used for projecting energy requirements (including the Hudson-Jorgenson model[7]) assumes a fertility rate lower than 2.1; some use higher fertility projections. To date, there is no evidence of a reversal in fertility rates; in the early months of 1976, the rate fell below 1.8.

If the effect of lower fertility rates in the future carries no other implications for energy consumption, it is clear that (per capita consumption being equal) a smaller total projected population will result in a smaller projected total demand. In addition, energy consumption is likely to decline below that projected on the basis of higher fertility rates because of the effect of lower fertility rates on the growth of the labor force. The key here is the relationship of population growth to economic growth. To get a sense of the implications of a low fertility rate on economic growth, it is useful to contrast future trends with those of the 1950s and 1960s. In those decades population grew by 1.7 and 1.3 percent per year, respectively.

TABLE 14. Assumed Population for IEA High Case (10^6 People)

(based on a fertility rate climb from current 1.8 to 1.9 or equivalent immigration)

Year	Total	Under 16	16 to 64	65 and over	21 and over	16 and over
1975	213	58	133	22	135	156
1980	222	54	143	25	147	168
1985	231	55	150	27	158	177
1990	240	57	155	29	166	184
1995	248	58	159	30	173	190
2000	254	57	167	31	178	197
2005	259	55	173	31	184	204
2010	264	54	177	33	191	210

Note: These numbers have been individually rounded and may or may not appear to be correctly summed.

Labor Force and Participation Rates

More important than overall population numbers, from the standpoint of economic growth, is the impact of declining fertility on the size of the labor force. The high economic growth of the 1960s was based on an annual labor force growth of 1.7 percent, a rate that persisted in the early 1970s. Even under the high-case assumption that the fertility rate will recover to 1.9 per female, and that a higher percentage of women will enter the labor force, the growth of the labor force will still fall to 0.96 percent during the 1980s, and to less than 0.8 percent in the 1990s. The decline of population growth means that, with about a 16-year delay, a roughly parallel decline in the growth of the labor force will occur. Under the projection of the low case, the labor force would expand at an even lower rate after 1990, as shown in Table 15.

The labor force participation rate sets the size of the labor force; it is the percentage of persons 16 years of age and over who are either employed or actively seeking employment. We have used this standard convention even though basing the potential labor force on this age group is not altogether appropriate in terms of today's economic and social patterns. First, nearly all persons between 16 and 18 years of age are in school, and while their participation in the labor force is high, it is limited to part-time work. Furthermore, most persons 65 years of age and over are now out of the labor market (80 percent of men and over 90 percent of women), and an increasing percentage of those between 60 and 65 years also have withdrawn.

TABLE 15. Percent Growth in the Labor Force

Year	Low case	High case
1975–1980	1.8	1.8
1980–1985	1.2	1.2
1985–1990	0.96	0.96
1990–1995	0.53	0.63
1995–2000	0.63	0.78
2000–2005	0.54	0.71
2005–2010	0.37	0.54

There is little information about labor force participation rates one hundred years ago, but by 1890 the labor force included 51.7 percent of the population over 14 years of age. By 1970, normal labor force participation grew beyond 60 percent. In 1974 about 61 percent of the 16-year-and-over population fell into these categories; that is, employed or seeking work. This rate is projected by some experts to rise to about 63 percent by 1990, largely because of the continuing increase in the rate of participation by women. The following table shows the details of labor force projections based on the low- and high-case projections. Since persons born in 1975 will not enter the labor force for 16 years, there is no difference in labor force size between the two cases until after 1990.

A 63 percent overall participation rate by 1990, based on present trends, would mean a slight decrease in male participation rates from current experience, but a significant increase (from 45 percent in 1975 to 50 percent by 1990) in the female participation rate.

One of the consequences of a slowing population growth rate is a decrease in the proportion of persons in the dependent category. These differences are very significant if one defines the dependent population as the under-16 group. In the low case, this under-16 group would fall from 27 percent of the population in 1975 to about 21 percent in the year 2000. However, if one adds the 65-year-and-older group to the under-16-year group, the decline in the total is much more modest—from 37 percent in 1975 to about 34 percent by 2000.

There is a good possibility that even this more moderate reduction in the size of the non-labor-force group (resulting from the addition of those over 65 years of age) is still too large, since it may understate the decline by 2000 in labor participation rates by the 60–65 years of age category. People in large numbers are beginning to retire and leave the labor force earlier than 65. In 1950, 85 percent of all men in the age group 55–64 were active in the labor force; by

TABLE 16. Labor Force Projections

	Low-case projection			High-case projection		
Year	Population 16 and over	Participation rate	Labor force	Population 16 and over	Participation rate	Labor force
1975	156	0.61	95	156	0.61	95
1980	168	0.62	104	168	0.62	104
1985	177	0.625	110	177	0.625	110
1990	184	0.63	116	184	0.63	116
1995	189	0.63	119	190	0.63	119
2000	195	0.63	123	197	0.63	124
2005	200	0.63	126	204	0.63	129
2010	204	0.63	128	210	0.63	132

Note: These numbers are rounded individually and hence rates of growth do not correspond exactly to those obtained in Table 15.

1974, their participation fell to 78 percent. For women in the 55–65 age group, the percent increased between 1950 and 1970, but has been declining over the past five years.

The increase in early retirement is primarily a consequence of near-universal coverage of the work force by social security and/or supplemental retirement benefits. Sharp increases in benefit amounts in recent years have led to a growing trend in retirement after age 60 by both men and women. One study, contained in the 1976 annual Economic Report of the President,[8] concludes that for every 10 percent increase in social security benefits relative to average wages, the number of male beneficiaries increases by 6 percent after five quarters.

The labor participation rate for younger women seems likely to increase in the future. This impact on labor force size will, in part, be offset if post-1956 trends in participation rates for older men and women continue, or may be magnified if these trends are reversed.

Quality of the Labor Force

On the basis of Denison's analysis of the sources of growth of national income between 1948 and 1969, labor factors were estimated to have contributed 1.30 percent of the total annual growth in national incomes of 3.85 percent per year.[9] The two major labor force contributions (there were some small offsets) were increases in employment (1.17 percent) and in educational attainment (0.41 percent) as shown in Table 10. With the slowing growth in numbers of workers and a continued downward trend in the length of the workweek (the average annual decline in hours is estimated at 0.34 percent per year), the annual contribution of an increased labor force to economic growth by 2000 will be unlikely to reach 0.5 percent, even though it was 1.17 percent for the 1948–1969 period.

The investment in human capital resulting from more years of education has accounted for a significant share of past total economic growth. However, there is considerable question whether the present quality of the labor force is as high as it once was. Thus results from Scholastic Aptitude Test scores (SATs), administered by the Educational Testing Service to college-bound high school students, show a gradual decline over the past twelve years.[10] This may signal a diminishing contribution of formal education to the quality of the U.S. labor force, although on-the-job training programs may become more significant in the future.

Approximately 70 percent of the almost 95 million workers in the labor force today have completed four years of high school; about 15 percent have completed four or more years of college. Gains may continue as educated younger workers replace uneducated older workers, but at a much reduced rate. Further gains will come as the proportion of high school graduates completing college increases (estimated at 24 percent by 1990), but the rate will slow.

Investment Trends

The availability of capital for new investment is a key variable for economic growth, since the rate of introduction of new technology is an important determinant as the rate of productivity increases. In the United States, the annual sum expended on fixed business investment over the past five years has averaged 10.4 percent of GNP. According to the recent annual report of the Council of Economic Advisers (CEA),[11] this ratio needs to increase to 12 percent of GNP in order to meet the goal of full employment, to reduce energy dependence, and to conform to environmental standards. This percentage is much higher in some of the European countries. The CEA states that the U.S. rate in 1976 will be, at best, 9.4 percent of GNP. Studies such as the one made by Paul W. McCracken, former Chairman of the Council of Economic Advisers,[12] suggest that the pace of capital investment may be slower in the future. Table 17 shows the historic trend for the gross investment in the commercial and industrial sectors for each new worker added to the labor force.

Theoretically, the supply of investment funds will match the demand for capital. In practice, however, this outcome may not be achieved. Interest rates may not always be free to perform their incentive and rationing functions, and markets may not always clear, as the periodic shortage of funds for housing frequently demonstrates. Studies by the Brookings Institution[13] and the New York Stock Exchange,[14] for example, suggest future capital shortages. Note that in the energy sector in 1974 and 1975 construction plans for 106 nuclear power plants and 129 coal-fired plants were canceled or deferred, partly because of financial difficulties and partly because of diminishing demand for energy. Regulatory commissions under political pressure have been unwilling to grant rate increases large enough to make utilities attractive to investors. An attractive interest rate in extended periods of inflation must reflect an adequate return to investors as well as the deterioration of purchasing power.

We note the following important trends affecting growth in investment as a share of GNP:

(1) A continuing trend in investment toward the consumption-oriented service industries, many of which have a lower rate of energy use per worker than manufacturing industries.[15]

TABLE 17. Gross Nonresidential Fixed Investment per Worker Added to the Labor Force

(1968 dollars)

Period	Annual amount
1961–1965	55,300
1966–1970	46,400
1971–1974	41,000*

*Data for 1974 estimated.

(2) A growing share of investment going into replacement outlays as opposed to new investment.

(3) An upward trend of capital investment needed to produce a given level of output due to new environmental standards.

(4) A spectacular growth in transfer expenditures by the federal government for which it receives no offsetting goods or services. (These are consumption-oriented programs that decrease savings at certain phases of the business cycle and reduce economic growth.)

(5) Unprecedented federal, state, and local deficits which contribute to inflation and, in periods of high private-sector demand, compete for financial resources with the private sector.

(6) Future energy costs higher than those assumed in most current projections as more marginal sources of conventional fossil fuels are tapped. Current estimates of capital requirements for a given output from new energy sources are at least two to three times higher than estimates made only five years ago.

(7) A continued reduction of depreciation allowances and of the supply of investment funds as a consequence of continued inflation.

Capital Coefficients

The trend of capital coefficients (dollars required to put in place a given plant capacity) in the future will be upward—in part because of increasing costs to meet energy needs, and in part because of additional sums required by legislated environmental standards. The Council of Economic Advisers' annual report[16] refers to a Department of Commerce study which puts new capital needs at $986.6 billion in the 1976–1980 period compared to $486.8 billion invested during the previous five years. The report notes that in order to raise this sum, greater reliance would have to be placed on private-sector investment (as opposed to consumption stimulation), and new tax concessions for the private business sector would be needed.

A study by Dr. Anne Carter[17] estimates that the impact of meeting currently specified environmental pollution goals could reduce the expected near-term (to 1985) future annual economic growth rate (GNP) from 3.5 to 3.0 percent. Changes in electric power generation—distribution technology and the introduction of coal gasification—could lead, in her view, to a further 0.4 percent cut with long-run annual growth potential reduced to 2.6 percent. This consequence, she argues, need not follow if savings rates are boosted sharply.

Total costs for meeting the targets of the 1970 air pollution legislation and the interim standards of the 1972 water quality legislation are unknown. A recent Brookings Institution study[18] estimated the definable costs through 1983 at about $375 billion. The report of the National Commission on Water Quality[19] added $199 billion (current dollars) to control storm runoff in urban areas. Most of these costs are for the erection of publicly owned treatment facilities to be paid for by federal grants and taxes. Direct industry costs for the water cleanup alone, as computed by the National Commission on Water Quality, would be about $80 billion for capital outlays through 1983 and annual operating costs of over $12 billion. Indirect costs to pay industry's share of the added taxes were not calculated. For air pollution, part of the costs are borne by consumers who pay for the installation of devices on new automobiles. Cumulative air abatement costs are estimated to be substantially larger than water cleanup costs; the costs for the disposal of solid wastes are currently unknown. In 1974 new plant and equipment requirements to control air and water pollution accounted for about 5 percent of total expenditures.[20]

A minimum estimate for industry expenditures needed to meet the new standards, exclusive of tax contributions supporting municipal water treatment facilities, would be $300 billion.[21] This amount equals about two years' gross private (nonresidential) investment at 1974 expenditure rates.

Transfer Expenditures and the Federal Deficit

Probably the most spectacular shift in federal spending over the past two decades has been the large increase in transfer expenditures. These outlays include social security, unemployment assistance, veterans' benefits, Medicare and related health programs, housing payments, public assistance, and similar payments. These expenditures do not contribute to national income, but rather are payments for which the government receives no offsetting goods or services. Unless these expenditures are financed by Treasury borrowing, they must be paid for by larger taxes levied on the more productive businesses and individuals. Since fiscal year 1955, these expenditures have been increasing at about twice the rate of GNP growth (see Table 18).[22]

Transfer expenditures are essentially consumption-oriented programs which can raise GNP through the multiplier effect in terms of unemployed resources. As economic recovery progresses, however, there is an increased need for private capital formation. If the government continues to run large deficits to finance transfer outlays in years when economic activity is high, then the government will be actively competing with the private sector to finance capital spending. The very large deficit for fiscal year 1977, for example, now forecast from $43 billion to $60 billion, will probably have some negative effects on the private sector (as would a similar size deficit in FY 1978).

The rapid increase in federal deficits during the 1970s is without peacetime precedent and has occurred in periods of prosperity as well as depression. The use of massive deficits stimulated by the growth of transfer expenditures may have become a way of life rather than a countercyclical tool of fiscal policy.

Heavy borrowing by the federal government has increased its share of demand on the capital markets. In 1970, federal borrowing accounted for 38 percent of the new dollar issue volume; by 1975, its share reached 61 percent. In the private sector there has been a major decrease in new equity financing. As a consequence, there has been a sharp increase in the debt-to-equity ratio. In 1965, 75 percent of corporate capital was in the form of equity; by 1974, this percentage had dropped to 53 percent. In a recent review of capital markets,[23] an Assistant Secretary of the Treasury concluded that less funds are now being committed to the private sector and that such investments are being concentrated in fewer firms.

TABLE 18. Growth in Federal Expenditures on Payments for Individuals

(billions of current dollars)

Year	Payments to individuals	Total budget outlays	Percent
1955	13.3	68.5	19.4
1975	147.6	324.6	45.5
1980*	232.5	482.8	48.2
2000†	1,132.0	1,404.0	81.0

*Office of Management and Budget Mid-Session Budget Review, May 30, 1975.

†Computation to show what would happen if transfer expenditures continue to grow at the average annual 1955–1974 rate, which would require new federal programs to be enacted by Congress.

Capital Costs for Energy

No one really knows what the capital costs of meeting future energy needs will be. Studies by the Federal Energy Administration,[24] National Petroleum Council,[25] National Academy of Engineering,[26] and Arthur D. Little, Incorporated[27] include estimates of the capital costs for energy facilities needed by 1985, which range from $380 billion to $457 billion (in 1973 dollars). Commenting on these estimates in 1975, Secretary of the Treasury William E. Simon stated that additional capital requirements identified since these studies were prepared, plus anticipated inflation, would raise the outlays needed to satisfy the 1985 goals to about $1 trillion (in current dollars).[28] Since many of the technologies needed to cope with energy processes, pollution problems, and rising safety standards are not now commercially available, future projections of capital costs are difficult to determine. For illustration, compare the estimates in Table 19.[29]

All indicators for capital costs in new energy sources, which are a sizable share of total investment in the economy, point upward.

Aggregate Productivity

In addition to quantifying expected future trends in the labor force size, a second essential calculation is the projected increase in aggregate (economy-wide) labor productivity. Aggregate productivity, as measured by the Bureau of Labor Statistics, is a weighted sum of productivity in three sectors: government, agriculture, and nonagriculture.[30]

Agriculture has been the sector of fastest-growing productivity, with an annual increase rate of about 5.5 percent over the two decades ending in 1968.[31] Because of the relatively smaller share of total economic activity that agriculture represents over time, the boost to aggregate productivity is expected to fall from 0.5 percent per year to about 0.1 percent by 1985, unless the export of U.S. food to world markets becomes a large share in our future economic growth.[32]

The nonagricultural private sector has had a long-term productivity growth rate of about 2.7 percent per year. There has been a slowdown in this sector largely as a result of business cycle effects. U.S. Bureau of Labor Statistics projections (which apparently exclude the effects of environmental constraints and related expenditures) do not anticipate the recovery by 1980 of the nonagricultural private-sector productivity growth rate to the 1968 level.

The productivity per worker in the government sector is lower than in the private economy. This is partially explained by the accounting convention that, because government services are, for the most part, given away rather than sold, the output of government is measured by its accounting cost of production instead of by its market price output. Even if one uses market prices to value

TABLE 19. Energy Technologies
Comparison of Capital Investment Estimates

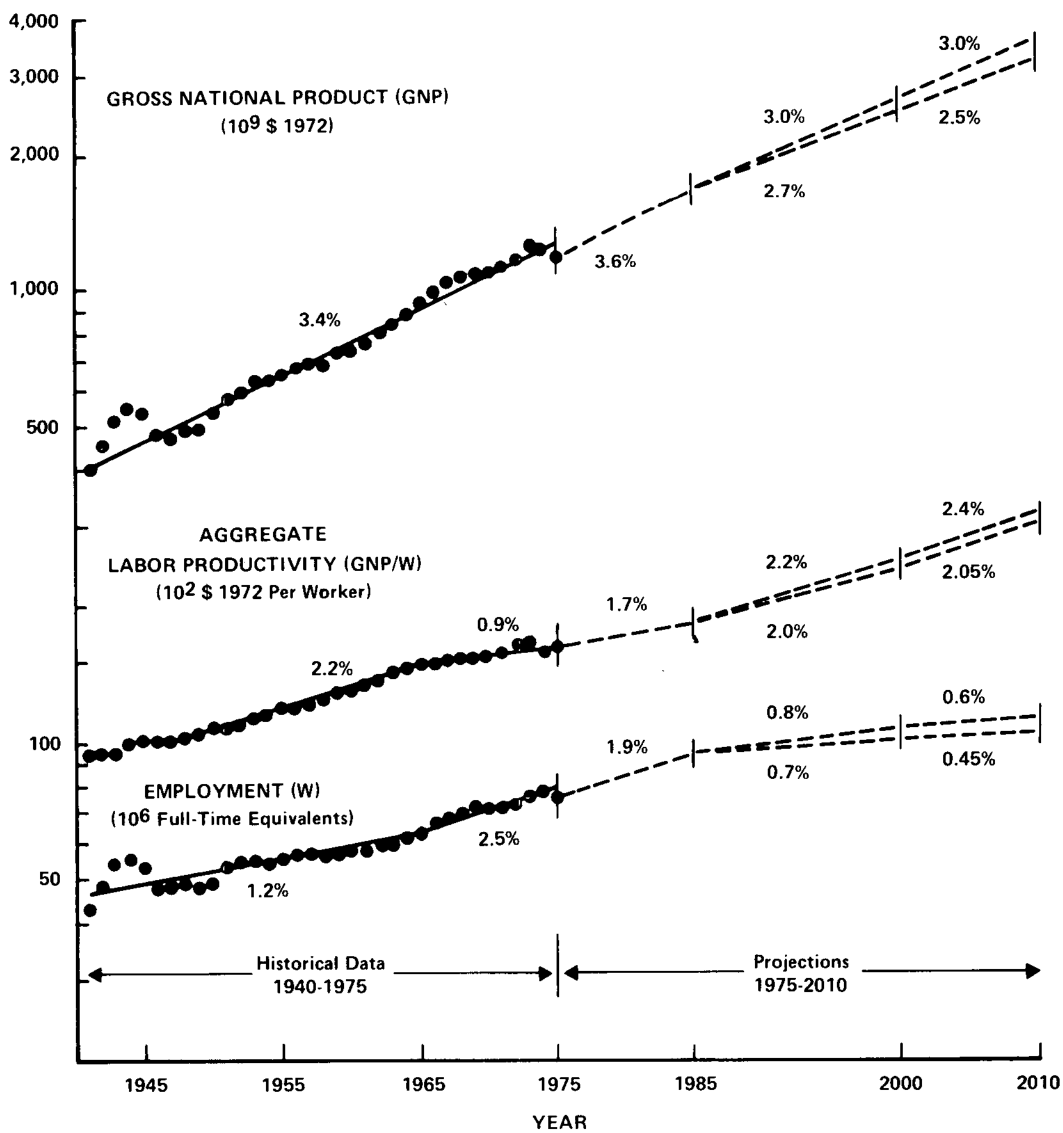
(million dollars per 10^{15} Btu/year)

Process	Original estimate	1975 estimate
LWR (light water reactors)	14,000 (1971)	25,000
SRC (solvent refined coal)	1,500 (1969)	5,000
HYGAS	1,800 (1971)	4,700
Low Btu gas	670 (1970)	1,500

government services, government productivity is lower than private productivity. Since the share of government output has increased from less than 10 percent in 1929 to over 20 percent in 1975, overall economic growth has been restrained.

We expect the rate of growth of government's share to slow down during the projected period. Most civilian-government employment is at the state and local level (12 million out of 14.7 million in 1975)[33] and about half of these jobs are in education. Even allowing for the increased service needs of the aged, the projected decline in school-age population should cut the future rate of growth of government jobs.

Putting the three sectors together and making a modest allowance for environmental costs, and assuming man-hour trends do not deviate from historic trends, one obtains an estimate for the rate of growth of long-term aggregate labor productivity. A sharp recovery from the low 1965–1975 experience (0.9 percent annually) to levels approximating the 1945–1965 record (2.2 percent) for the low case is anticipated as shown in Figure 2. However, to achieve the 1945–1965 rate of productivity increase may require federal intervention, including overhaul of the tax laws.



The Potential for More Rapid Economic Growth

Based on available information, the foregoing arguments favor an annual increase rate in GNP of 3.6 percent for the 1975–1985 period, an average of 2.7 percent/year during 1985–2000, and 2.5 percent/year during 2000–2010. This growth pattern forms the basis for our low scenario. The projected lower economic growth rate after 1980 does not imply that a higher level of unemployment is expected in the future. Lower economic growth reflects a sharply reduced rate of labor force expansion. Individual incomes are calculated to grow by nearly 50 percent between 1980 and 2000, measured in constant dollars.

There are, however, several factors which could lead to a more rapid economic growth. Since this study is concerned with projections covering approximately one-third of a century, a picture of the future (based on presently discernible factors) may change in another decade or two. In particular, any or all of the following factors could lead to more rapid economic growth:

(1) A marked reversal in the downward trend of fertility rates from the present 1.8 to something higher, or an increase in planned immigration. Should either occur, more persons would be added to the population by the year 2000 than we now expect. The labor force growth would continue to moderate but could expand at an annual rate of 0.54 percent in the final decade (2000–2010). This is higher than the 0.37 percent calculated from the Census Bureau's Series III population projections. The rate of growth of GNP as a consequence of the larger labor force and other factors could remain at 3.0 percent annually, particularly if labor productivity in the private sector were to climb back to the level of the 1950s and late 1930s.

(2) The present trend to earlier retirement from the labor force could also be reversed in the face of longevity increases. If we move back to the participation rates of the early 1950s for the over-60-years-of-age group, the size of the labor force could continue to expand at a higher rate than we have calculated, since by the year 2000 there will be over 30 million persons in this age group alone.

(3) Improvements embodied in new technology, if widely adopted, might offset the added capital cost to industry of complying with federal air and water pollution standards. A revision of the tax laws to permit full capital recovery could stimulate business savings and have the effect of improving productivity.

In order to account for factors which lead to larger growth rates in the economy, we have chosen higher population projections combined with a sustained 3.0 percent annual increase in GNP from 1985 to 2010.

Conclusions

Apart from developments which cannot now be foreseen, the two cases presented here represent optimistic assumptions for the actual path of the economy during the next 35 years.

The growth projections for the labor force are based on different assumptions about the future fertility rates for women of the United States. The lower projection is based on the assumption of a future modest (from 1.8 to 1.7) decline in the fertility rate, a much slower rate of decline than experienced since World War II. The higher projection assumes a reversal in the fertility rate such that it increases from the current 1.8 to 1.9. In each case the participation rate is assumed to increase from the current 0.61 to 0.63 by the year 1990 to include a continued increased participation rate for women and minority groups, and a continued trend toward earlier retirement for the older age groups.

The growth in aggregate labor productivity or output per worker depends on the several factors indicated earlier, but the trend since 1940 shows an average 1.6 percent per year growth, as depicted in Figure 2.

For this analysis, a productivity growth rate of 1.7 percent per year is assumed to 1985, a 2.0 percent rate from 1985 to 2000, and a 2.05 percent rate from 2000 to 2010, for the low case. For the high case, the annual growth rates for aggregate labor productivity are 1.7 percent, 2.2 percent, and 2.4 percent for each of the three periods. These average productivity rates include the service as well as the manufacturing sectors and are considered to be rather high or optimistic rates in light of past accomplishments.

If one combines the assumed growths in productivity with the projected growths in labor force, the rates for economic growth (GNP) shown in Table 20 are obtained.

TABLE 20. Annual Growth Rates (Percent)

Period	Participating labor force	Average* productivity	GNP
Low Case			
1975–1985	1.9**	1.7	3.6
1985–2000	0.7	2.0	2.7
2000–2010	0.45	2.05	2.5
High Case			
1975–1985	1.9**	1.7	3.6
1985–2000	0.8	2.2	3.0
2000–2010	0.6	2.4	3.0

*See reference 30.

**Assumes a reduction in unemployment to the long-term average level during this decade.

The Issue of Energy Demand and Economic Growth

The discussion in the preceding section addressed the main determinants of economic growth—population, labor force, productivity, and capital requirements. In this section we put forward a qualitative view of future energy demand based on projections of several key determinants which influence energy consumption.

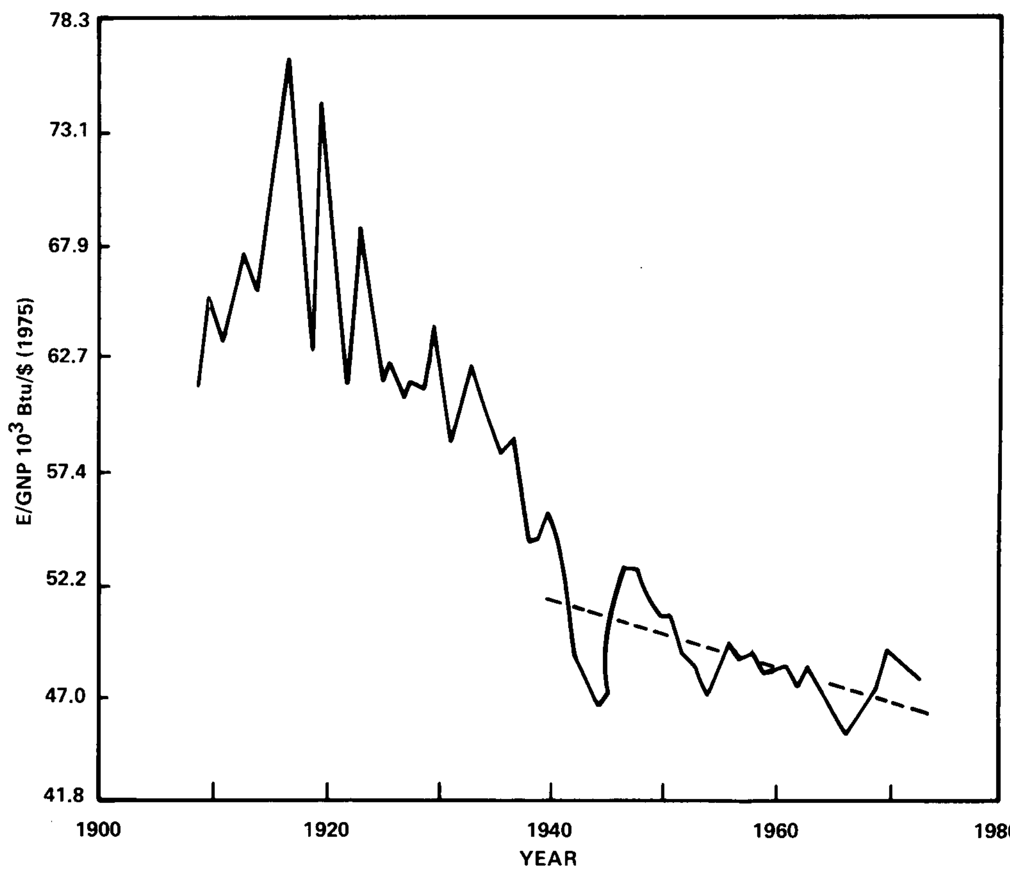
The discussion here deals with a wide range of issues, some on the "hard," some on the "soft" side of the social science spectrum. Several of the factors considered lend themselves to reasonably rigorous analysis and to conclusions which can be stated with a degree of confidence; others permit only judgmental consideration and tentative conclusions. We are sensitive to the perils of forecasts and projections over several decades when so many determining factors, including individual whims and societal caprices, are unknown. On such a time scale it is well to acknowledge that a good "guess" is about as close in approximation to the ultimate truth as may be possible from the present vantage point. It should be noted, however, that the method used here is not different from that used by those who have developed qualitative rationales for other energy-demand scenarios.

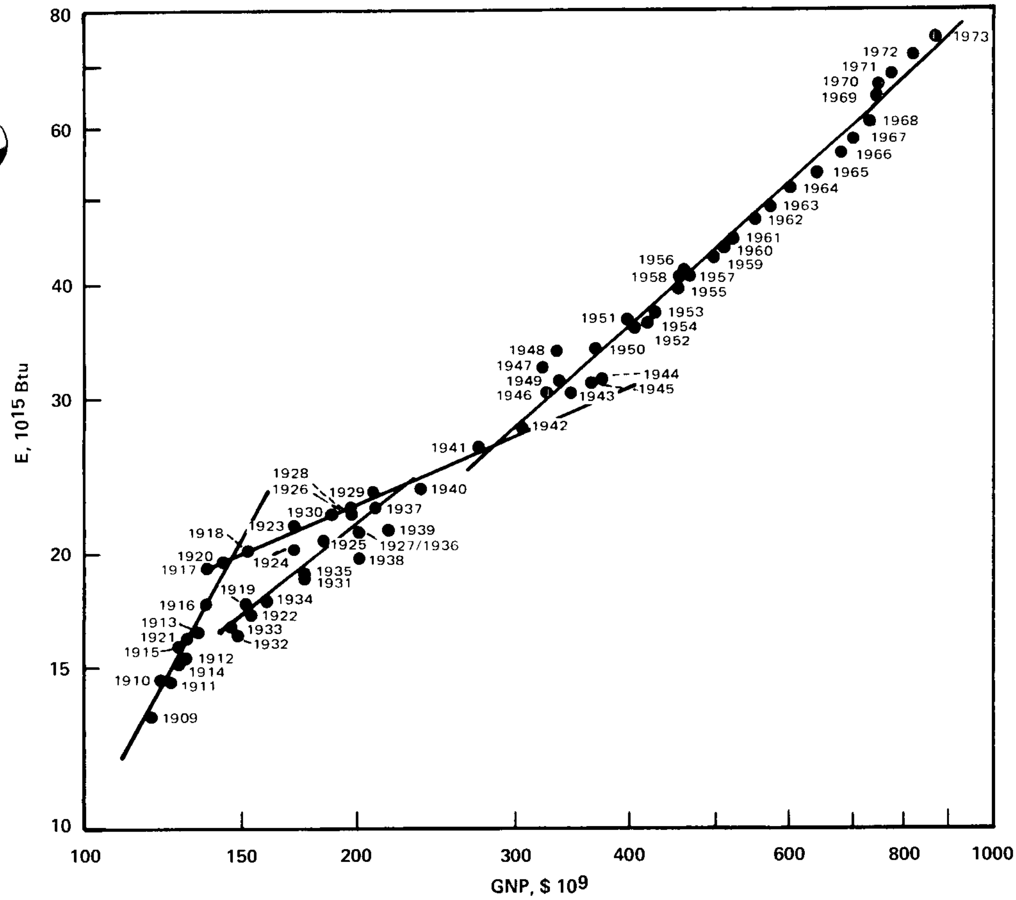
The issues discussed here have significant implications for those responsible for long-range energy planning. The discussion touches on sensitive aspects of overall national energy policy which have, in the past, been predicated on a higher demand for energy than this analysis would indicate. Our approach has been to deal with what is *likely* to happen on the basis of currently available information, not with what *ought* to happen. From this perspective, national economic growth and energy demand are likely to be significantly lower than projected in many of the other scenarios and studies now in use.

Threading its way through the entire analysis is a critical, quantitative link between economic growth and energy demand. This link depends on important economic, technical, and social considerations. In the end, however, this relationship can be reduced to an average coefficient which is functionally related to the economic growth projections. The analysis establishing the specific relationship between economic growth and energy demand is developed in the next section of this report.

Historic Energy-to-GNP Ratio

A crude correlation between energy consumption (E) and the gross national product (GNP) can be established by examining historic data.[34] However, the ratio of E to GNP has not been constant, as indicated by Figures 3 and 4.[35] Most estimates forecast that the ratio of energy use to GNP will continue to decline. The historic data indicate three or more periods since 1909 when the specific correlation between E and GNP has been different. Figure 4, showing log E vs. log GNP, has at least four periods of strong correlation between the two variables. The long-term downward trend in the energy-to-GNP ratio observed from 1947 to 1967 reversed in 1967 and climbed until 1970. Since 1971 the ratio has continued downward. In 1975 the ratio averaged 47,400 Btu per dollar (measured in





1975 dollars), down from 47,600 Btu per dollar in 1974, 47,900 in 1973, 48,700 in 1972, and 49,100 in 1971.[36]

What follows is a qualitative discussion of the key factors that affect the energy-to-GNP ratio. That, in turn, permits an examination of the relationships between growth of GNP and growth in energy demands. Some of these factors, such as the conservation potential and losses in conversion, can be quantified. Others, such as the impact of changing life styles, are more difficult to measure and consequently the findings tend to be largely judgmental.

Conservation of Energy

Conservation (defined to include increases in energy-use efficiencies) appears to be the largest single variable that must be estimated in moving from growth in GNP to future growth in energy demand. As noted above, there has been some decline in the energy-to-GNP ratio during the postwar years. The striking characteristic of this changing energy use has been the fact that, as a result of technical improvements and better energy management, the savings took place in a period when energy was becoming less expensive relative to other commodities.

Energy prices fell relative to all other prices between 1947 and 1970. Since 1970 the price trends have reversed. The cost of energy, which once amounted to a trivial part of individual, corporate, and institutional budgets, has recently become more significant.[37] This new trend is unlikely to change over the next several decades. Average fuel prices in the United States increased over 45 percent during 1974 and 1975. One can reasonably expect that, after a delay to allow for amortization of durable energy-consuming equipment, price pressures will bring about new and significant energy conservation measures. For the foreseeable future, conservation will be increasingly a cost-induced rather than an ethical or moral exercise; as such, it will have an important effect on total energy demand.

Energy-saving technologies exist now which could be incorporated into the U.S. energy system to raise our productivity and to sustain a reasonable economic growth. Table 21 summarizes the results of several recent studies[38-41] on the potential for conservation in the U.S. energy system; Table 22 summarizes the results of a study which compares energy use in West Germany to that of the United States. The implementation of a list of modest conservation technologies is proposed to reduce the total U.S. energy requirements per unit of output, and to shift the fuel demands from oil and gas to electricity and to the direct use of coal. Heat from the cogeneration of electricity can also play a significant role. The incorporation of the suggested new technologies can be timed to coincide with the normal retirement of capital stock in transportation, housing, commerce, and manufacturing, without placing an undue burden on investments which otherwise would be required under a more austere and controlled program.

In addition to the studies listed in Table 21, other studies on specific sector savings have been examined. These include studies by the National Petroleum Council,[42] Dow Chemical Company,[43] Oak Ridge National Laboratory,[44-46] and the Council on Environmental Quality.[47] In this study we have made conservative assumptions regarding the effect of potential improvements in end-use efficiencies. Each of our assumptions is discussed later when we address the transportation, residential and commercial, and industrial energy sectors.

A recent study sponsored by the Federal Energy Administration[48] compares energy consumption between West Germany and the United States by sector on a per capita basis. The results are summarized in Table 22. These comparisons between West Germany and the United States illustrate the potential energy savings in the United States if energy prices rise high enough, and if feasible conservation goals are followed. West Germany uses only one-half as much energy per capita as the United States. Total energy use in West Germany, relative to national income, is only about two-thirds that of the United States; the ratio for

TABLE 21. Potential Energy Savings

	10^{15} Btu					
Study or report	Demand in 2000	Transportation	Residential & commercial	Industrial	Total	Percent savings by 2000
"The Nation's Energy Future"	192	5.0	23.5	23.0	51.5	26.8
ERDA-48 Report (Scenario 0 to Scenario I)	165	7.4	15.3	19.4	42.1	25.5
Energy Policy Project (base case to technical fix)	187	13.7	15.2	33.8	62.7	33.5
This study	149.3	5.2	7.0	11.2	23.4	15.7
American Physical Society Report (potential savings for 1973 only)	75 (1973 demand)	9.1	11.6	10.4	31.1	41.5 (percent demand)

TABLE 22. West Germany Per Capita Energy Use as Percent of U.S. Per Capita Energy Use

Sector	Percent
Transportation	27
Road transport	29
Air transport	20
Railroads	75
Inland and coastal shipping	33
Military	13
Residential	48
Space heating	67
Hot water	37
Cooking	60
Air conditioning and clothes drying	1
Other	18
Commercial	56
Industrial	58
Total	49

residential use is 48 percent, the ratio for industrial use is 58 percent.

Some of the differences in per capita energy uses in transportation for both passengers and freight can be explained by the great differences in population density; the West German population density is about ten times that of the United States. The balance is most likely caused by the higher fuel prices in West Germany, which result in the use of more efficient autos and public transport systems.

Some of the differences in the residential and commercial sectors can be explained in terms of the life styles that are characteristic of the two societies. Other differences are due to building design and insulation, methods of heating water, and varying levels of appliance saturation.

One of the interesting differences in energy use is seen by examining the energy requirements per unit of output in some of the industrial sectors, as shown in Tables 23 and 24.

The Energy Policy Project of the Ford Foundation[49] finds that, through available conservation techniques, U.S. energy demand in the year 2000 could be reduced from an estimated 187 q (the Ford "high" scenario) to 124 q (the "technical fix" scenario), a reduction of one-third. According to the Ford study, such a reduction would have little or no effect on the growth of per capita income.

In terms of total energy requirements needed to sustain economic growth and employment, our low-scenario totals are not very different from those given in the Ford Zero Energy Growth case. However, our low scenario (101.4 q by the year 2000) was not reached by imposing a life style on the United States (as was the case in the Ford study), but by calculating technically feasible energy coefficients which could be carried out in the future, and by our judgment that future economic growth rates will be less than those used in the Ford study.

Conservation possibilities extend to all forms of energy consumption.[50-52] Industrial consumption, the largest single energy-using sector, can benefit from improved boiler design and heat recovery processes. The manufacture of lighter-weight automobiles and service trucks with more efficient engines could double the average miles per gallon (mpg) for the operational fleet by the year 2000, compared to present efficiencies. Household and commercial consumption

TABLE 23. Industrial Energy Use for 1972 the United States and West Germany

	Total (10^{15} Btu)		10^3 Btu/$ of shipments		10^3 Btu/employee	
	U.S.	West Germany	U.S.	West Germany	U.S.	West Germany
Primary metals	5.65	1.21	97	78	5.0	2.0
(iron/steel/aluminum)	(3.63)	(0.98)	(151)	(111)	(7.7)	(3.1)
Chemicals	4.10	0.73	72	41	4.9	1.3
Petroleum and coal products	3.20	0.38	112	56	23.0	9.1
(petroleum refining)	(3.12)	(0.36)	(120)	(55)	(30.9)	(9.8)
Paper	2.93	0.17	104	39	4.6	0.9
Stone, clay, and glass	1.61	0.49	75	55	2.6	1.2
Food processing	1.36	0.17	12	8	0.9	0.4
Other manufacturing	4.20	0.77	9	7	0.3	0.1
Other industries (mining and nonindustrial)	4.43	0.77	—	—	—	—
Total	27.49	4.69	35	25	1.4	0.6

could improve with better building design and insulation, the market penetration of improved heat pumps and the solar-assisted Annual Cycle Energy System (ACES), and the retrofitting of existing buildings.

All these changes will take time. The number of new dwelling units built each year, for example, amounts to only about 3 percent of the existing inventory. Retrofitting existing buildings at the rate of 1–2 percent each year increases the improvements to a 4–5 percent rate. Changing over the automobile inventory is a decade-long task. As we shall show below, what can be accomplished in the longer run without straining the limits of existing technology is impressive.

Intervention

One major instance of government intervention to reduce energy consumption has been cited—mandatory increases in car gasoline mileage.[53] There are many other instances where government intervention could increase or decrease energy demands in the future. For example, the fertility rate could be increased if abortions were made illegal or if the government gave baby bonuses (in the form, say, of additional tax incentives), as the French government did in the 1920s. While conceivable, such policies seem highly unlikely. It is difficult to believe that the government would reverse its stand on abortions or take steps to inhibit the availability of contraceptive information and techniques. If anything, the trend

TABLE 24. Energy-Output Ratios of Four Industries

	10^6 Btu per short ton	
	U.S.	West Germany
Iron	45.0	27.8
Steel	27.3	18.6
Paper	46.6	26.6
Petroleum products	4.9	3.3

will be to make contraception information more widely available to young people and to improve the safety and effectiveness of contraceptive devices. In any case, if "bonuses" were to have a significant effect on the national fertility rate, they would need to be much higher than any administration is likely to contemplate. In short, government intervention to increase the fertility rate is unlikely and even if it occurred would make no more than a marginal and temporary difference.

The economic area is still another matter. A return to the vigorous full economic employment of the 1950s and 1960s would increase the rate of GNP growth and therefore the rate of energy demand. As we have already noted, however, other factors such as continuing inflation, persistent problems of capital accumulation, and the increasing prospect of large government deficits at all phases of the business cycle would act as countermeasures. A general shortening of the workweek by either government or union intervention would have some effect on energy demand by reducing the number of unemployed on the one hand and by increasing the amount of leisure time for those employed on the other.

More important in terms of energy demand would be direct government intervention with respect to energy use. Many steps could be taken by government (indeed, some already have been[54]) that do not involve draconian measures: tax penalties or inducements for energy-intensive industries, building code changes, maintenance of the 55 mph speed limit, relaxation of environmental constraints, support of recycling techniques, or a horsepower tax on automobiles, to list a few. In terms of direct government intervention, anything more drastic will depend on a host of developments which include the political party in power, the style of presidential leadership, and the course of international events.

When all is said, the degree and type of intervention likely to occur over the next several decades are hard to foresee and may even be unforeseeable. This much seems clear: during the period that concerns us, federal and local governments are unlikely to undertake programs consciously and directly designed to accelerate the pace of energy consumption. Obviously, such major government-sponsored programs as water treatment and recycling will involve increased energy expenditures, but energy-oriented programs such as setting minimum miles-per-gallon standards for new cars will be designed to decrease consumption.

There has already been government intervention in the appliance field. The new energy bill signed into law by President Ford covers more than mandatory savings for automobiles—it also orders the Federal Energy Administration to set standards requiring manufacturers of furnaces, television sets, stoves, and refrigerators to improve efficiencies so that they use 20 percent less energy per unit by 1980.

Of course, there are other sources of intervention. The labor unions represent one such nongovernment source. In the 1970s there has been a higher level of persistent unemployment than the United States has been accustomed to since 1942. Under these circumstances, organized labor may press for more use of manpower as opposed to mechanical energy, or resist further mechanization (the higher cost of energy, in any case, is likely to result in a substitution of labor for energy where it is economical to do so). Intervention along these lines is more likely to have the effect of slowing energy consumption than increasing it.

Public interest groups will also play a key role. Chief among them are the environmental pressure groups. The effect here, however, will be mainly on energy supply rather than energy demand (although some pollution control devices such as automobile emission controls have had the effect of reducing the efficiency of gasoline consumption). By indirectly constraining supply and increasing prices to comply with the costs of environmental standards (as in the case of high-sulfur coal, strip-mined coal, or nuclear energy), relative energy costs will rise and consumption will tend to decrease—although the extent and timing of the decrease for each type of energy use will depend on the elasticity of demand.[55]

In short, the effect of intervention (whether from government or nongovernment sources) must be factored into the economic and energy projections. While the effect of policy intervention is not easy to predict and quantify, it will be likely to take the form of dampening energy consumption during the period under consideration rather than increasing it.

Saturation of Energy Use

One consideration frequently missing in historic projections of energy consumption (and also of economic growth) is that of saturated markets. In the past, the idea that demand for almost any consumer-durable good would slacken off was virtually unthinkable; with an inexorable rise in the overall standard of living it seemed inconceivable that anything like market saturation could occur. Yet this has already occurred for electric lighting in the home. Telephones are another example: in 1941, only about 40 percent of American homes had telephones; by 1975, more than 94 percent had telephones and many had two or more.[56] Automobiles are yet another: in 1972, there were 200,000 more automobiles registered in the United States than there were licensed drivers. While some of this, of course, can be attributed to taxicabs and car rental fleets, there was still approximately one registered automobile for every American who could legally drive.[57] (Privately owned automobiles totaled about 105 million in 1975, compared to an "over-16" population of 153 million.)

The matter of future automobile numbers is worth examining somewhat more closely. Clearly, the future growth of automobiles in service will be geared much more closely to the annual increase in the size of the driving population. Since the number of new drivers (i.e., those people reaching 16 years of age) has now stabilized and will soon slacken significantly (a decline of 670,000 in 1985 compared to 1975), a decline in rates of growth of the automobile inventory is likely. This is especially significant because of the important role automobiles play in energy demand. In 1972, passenger cars used 14 percent of the total energy and over 28 percent of the petroleum. Although gasoline consumption grew at about a 5 percent annual rate over the past decade,[58] price increases and the improvement in miles per gallon may reduce this growth significantly within a few years. According to a recent prediction (May 1976) by Dr. E. N. Cantwell, Jr. of the DuPont Company's Automotive Emissions Division, the U.S. gasoline demand will increase through 1980 and then decline by 1985 to the 1975 level of consumption. Combined with market saturation, the improved efficiencies could have the effect of dampening the rate of increase in total energy demand beyond that factored into many of the current energy-growth projections. (These considerations are dealt with quantitatively in the following section.)

A second area of likely saturation, which is important although not accompanied by the same energy-saving potential as passenger cars, is *household appliances*. The post-World War II years have seen the approach of saturation for most of these—refrigerators, cooking ranges, space heating, water heating, etc. According to some surveys,[59-61] virtually all American households, "poor" and "well off," are equipped with stoves, refrigerators, and television sets; almost half of the lower-middle-income households have air conditioners and clothes dryers; almost two-thirds of the "poor" households have washing machines. The Energy Policy Project study mentioned earlier would place the time of saturation for currently known household appliances at about 1985.

The future growth in household electricity consumption will be more closely tied to the increase in the total number of housing units, without the additional consumption which has typically accompanied the expansion of appliances for existing housing units in the past. New appliances (such as trash compacting units and microwave ovens) may gain popularity, but the market seems close to saturation for most major basic energy-consuming appliances except air conditioners.

Life Styles

"Quality of life" has recently become a term in common use. While there are major uncertainties about just what is meant, the concept has its latter-day roots in the rapid economic growth that has characterized the United States since World War II and bears the seeds of a profound change in U.S. life styles over the remainder of the century. Young people are more vocal about their aspirations, but their parents seem no less earnest in their own quest for something more than quantity of material things. Of course, this is not a universal phenomenon; there are still Americans all over the country who wish to own snowmobiles, a third color TV, and a motor cruiser. However, evidence is growing that many people now desire less tangible things. Somehow, we must try to take this into acount as we anticipate future energy demand.

The question of life styles and energy consumption is an elusive one. Three major uncertainties stand in the way of making positive judgments: how to generalize about life styles, how to predict future life styles, and how to relate a given life style to the consumption of energy. This having been said, it must be acknowledged that life style (i.e., the bundle of goods and services that would be selected if one had a meaningful choice) surely must have some impact on per capita energy consumption.[62] A style of leisurely activity centered in the home or in the local community would consume less energy than one dominated by tourism and regional spectator sports. Urban living consumes somewhat less energy per capita than a suburban style. What does it all add up to for the future? How does one quantify the energy use? As energy costs go up relative to the costs of other goods and services, will our life styles begin to approximate those of Western European industrial nations?

Although it is difficult to generalize about such a subjective and shifting concept as life style or quality of life, one can advance a few propositions with some confidence. For example, since the late 1960s, popular concern about the environment has gone well beyond the point where the issue is left solely to the Sierra Clubs. In a recent survey conducted by the Opinion Research Corporation,[63] 48 percent of all people polled felt that it was more important to have pollution controls on automobiles than to have less expensive cars; 38 percent felt that lower car prices were more important. The results were not much different when environmental activists were polled: 50 percent opted for pollution controls, 34 percent for lower auto prices. On another issue, 43 percent of the total people surveyed felt it was more important to have strip mine regulations than to have lower electric rates, 41 percent preferred lower rates. This compared to 62 percent of the environmental activists who opted for strip mine regulations and 31 percent who opted for cheaper energy. Many people who do not describe themselves as environmental activists seem ready to pay a price for less pollution. High sensitivity to environmental considerations need not necessarily lead directly to lower energy consumption. As we have noted already, environmental safeguards tend to increase the cost of energy and thus consumption is likely to be lowered.

Will current environmental concerns turn out to be a sometime thing? Possibly—but environmental cleanup laws are already on the books and the odds seem high that clean air, clean water, and the preservation of scenic amenities will remain live issues over the next several decades. Since these concerns are now most deeply rooted in the younger components of the population, it would seem safe to assume that a life style that calls for a high degree of environmental protection will remain with us at least through this century.

There are a host of other factors that comprise the life-style bundle; the work-leisure tradeoff is one. Aside from the implications of an aging population referred to in an earlier section, there may be a shorter workweek, longer vacations, and more paid holidays. Since the 1960s, for example, paid vacations per year in America have increased by 49 percent while the labor force increase was only 25 percent.[64] The thirty-hour week or the ten-hour-a-day, four-day week is by no means uncommon; shorter hours and increased fringe benefits are beginning to rival increases in real wages as an employee bargaining issue.

The affluence that Americans have attained and have come to expect manifests itself in many ways, but the quest for more leisure time is surely one important by-product of our wealthy society. This affluence, with its accompanying disposable income and disposable time, adds a new and as yet incompletely understood dimension to the relationship between economic activity and energy consumption. With affluence comes the quest not only for more leisure but also for more and better social services—schooling, adult education, medical care, police protection, and public recreation facilities.

Perhaps these public programs will only marginally affect energy consumption. There are other, more energy-related expectations that evolve in an affluent society—expectations of more and better roads, reliable mass transit facilities, better public sanitation, and more efficient airports. Some of these (e.g., better and more highways) will tend to increase per capita energy consumption; others (e.g., better mass transit) will decrease long-term per capita consumption. Until more information is available, we will assume that the net effect of better public services, at least during their expansion phase, will probably be an increase in the demand for energy.

Affluence creates not just a demand for social services but, more importantly, a demand for a higher level and greater variety of personal consumption. Every improvement in an individual's economic well-being is amplified by growing expectations for more. In the early nineteenth century, David Ricardo described man's appetite for material things as he perceived it: "The desire for food is limited in every man by the narrow capacity of his stomach, but the desire for the conveniences and ornaments of building, dress equipage, and household furniture seems to have no limit or certain boundary."[65] Ricardo's description would probably also apply to twentieth-century America.

Historically, per capita energy consumption (direct plus indirect) has certainly increased almost in proportion to per capita income.[66] However, we may question whether this trend will continue in the future. The historic relationship evolved during periods when energy prices were, in general, falling in relation to other prices—when the more affluent bought extra automobiles and a second home, traveled more, and required energy to construct and maintain these new ventures. Affluence permits greater choice which can, and to some extent already has, manifest itself through nonintensive energy substitutes such as new high-fidelity sound equipment, fancy hand calculators, cameras, bicycles, and fancy foods. Higher energy prices and added taxes on second automobiles, homes, and air travel also could serve to slow these energy-expensive activities.

Aging and Energy Demand

A relatively low fertility rate has been assumed for each of the energy-demand scenarios. One result of the lower fertility rate discussed in an earlier section is a population shift toward the older age brackets. If fertility rates do not increase significantly in the future, and if expected increases in longevity occur, over 30 million Americans (12.5 percent compared with the present 10.5 percent) will be in the senior-citizen or 65-and-over category by the year 2000.

The consequences of an aging population are usually not taken into account in projections of energy demand. A person at leisure would seem to require less energy than one engaged in industrial activity. One certain result of withdrawal from the labor market is the ending of the energy requirement that is associated with a job in industry and commutation back and forth to the workplace. What are the energy requirements associated with increased medical care for an aging population? What patterns of urban/suburban settlements are implied by a growing proportion of retired folk? What will be their travel patterns? Many retirees move to warm climates where more air conditioning is required, but this is offset by the decrease in heating requirements. Detailed analyses of all these issues are obviously necessary. Our hunch is that a population that is not only older but characterized by more people living on retirement incomes will be more sensitive to the increasing cost of energy; for this growing group, per capita energy use may decline.

In sum, the projections of energy demand based only on *numbers* of people may mask the effects attributable to shifts in the age composition and exaggerate demand.

The Potential for Increased Energy Demands

We have been discussing factors which, on the whole, would be expected to moderate the growth in energy demand. The following factors could produce the opposite effect:

(1) Energy price and income elasticities could change such that rising energy prices do not produce curtailed energy consumption to the extent now expected.

(2) Intensive energy R&D programs could conceivably bring new production technologies into being which would repeat the experience of the 1960s, when energy consumption escalated sharply as its relative price dropped and personal income rose.

(3) Added energy requirements (needed to take care of environmental problems, generate synthetic fuels, recycle water, expand trade in agriculture and manufactured goods, and recover needed minerals from lower-grade ores) could partially offset the estimates of consumption savings.

While any of these factors could exert a significant influence on long-term energy demand, the most important one statistically seems to be the consumption patterns or the level of energy intensity that people choose. There are authorities who believe that gross energy inputs per capita will exceed 600 million Btu in 2000, compared to 330 million Btu per capita in 1975.[67] Under these assumptions, energy consumption by 2000 could conceivably reach 163 q if little were done to improve the efficiencies of energy utilization.

Demographic and Life-Style Assumptions

Each of the population projections discussed in the preceding section is coupled with a different growth in housing, transportation, labor force, and economic output. The projections for the number of households are based on assumptions about household formation among adults. The current trend shows an increase in single-adult households, but the question is how long this trend will continue. Our scenarios assume that the trend of more single households will continue for the next 20 years and then saturate. In each case, it is assumed that one out of four households will be headed by a single adult in 1995, compared to one out of five now, although the high case requires more energy per household because of the size and kind of household.

The commercial floor space projections are based on two different levels of demand for services per household. In the low case, the commercial space requirements per household are projected to remain constant at 350 ft^2 per household. In this case, the school-age population will decrease, but this decrease will be offset by increases in requirements for more households, service shops, nursing homes, and other service space. The overall increase in commercial space in this case follows the growth of households. Based on about one-third the rate of increase in total GNP, the high case assumes an average increase of 1 percent per year in commercial floor space requirements per household. This is justified by the slight upturn in school-age population due to the higher fertility rate and the trend toward an increase in commercial services which include schools, hotels and motels, shopping centers, government buildings, and small businesses. Although some of these service sectors are perhaps currently overbuilt (compared to estimated future demands), the long-range trend is projected to rise 1 percent per year faster than households for the high case.

The automobile projections for the low and high cases are based on different assumptions about automobile use. In the low case, the participation rate will decrease slightly to 64 autos per 100 persons of driving age by the year 1985, and remain constant thereafter. In this case, a larger percentage of the population will be expected to use public transportation and to share in the use of automobiles. The high case is based on a continuation of current trends toward a greater use of automobiles among those who are eligible to become licensed drivers. Here, an increase is assumed from the current 67 automobiles per 100 persons 16 years of age and older, up to 79 autos per 100 persons by the year 2010. Currently, there is approximately one automobile for every two persons (men, women, and children). These projections lead to one auto for every 1.93 persons by the year 2000 in the low case and to one auto for every 1.67 persons by the year 2000 in the high case.

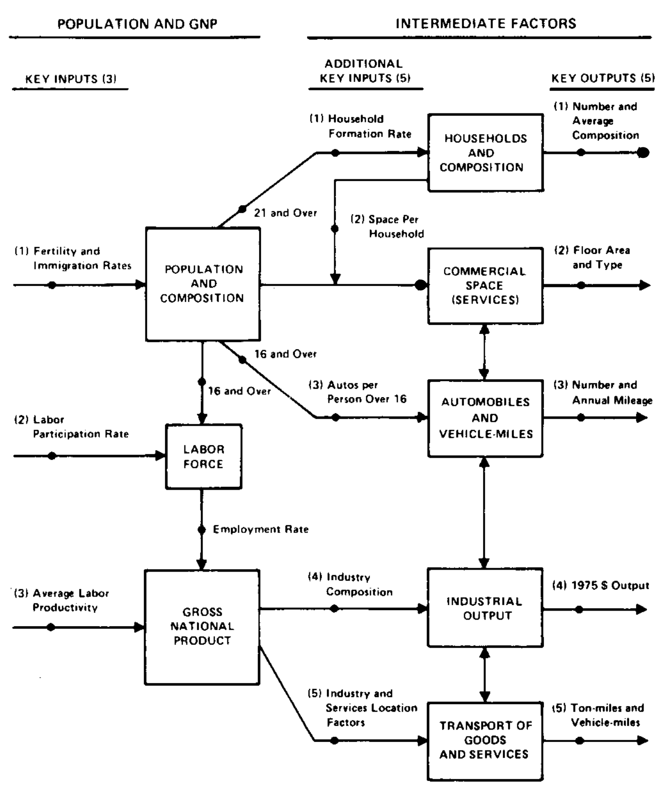


TABLE 25. Gross National Product (GNP) and Labor Force

Year	Population 16 and over (10^6)	Labor: Jobs per 16 and over	Labor: Labor force (10^6)
		Low case	
1975	156	0.61	95
1985	177	0.625	110
2000	195	0.63	123
2010	204	0.63	128
		High case	
1975	156	0.61	95
1985	177	0.625	110
2000	197	0.63	124
2010	210	0.63	132

Year	Employment, full-time equiv. (10^6)	Labor* productivity (10^3 1975 $ of GNP per worker)	GNP (10^9 of 1975 $)
		Low case	
1975	77.0	19.5	1,499
1985	92.9	23.0	2,135
2000	103.3	30.8	3,184
2010	108.1	37.7	4,076
		High case	
1975	77.0	19.5	1,499
1985	92.9	23.0	2,135
2000	104.6	31.8	3,326
2010	111.4	40.1	4,470

*See reference 30.

TABLE 26. Projections of Households, Commercial Space, and Autos

Year	Population (10^6): 21 and over	Population (10^6): 16 and over	Households: No. per adult*	Households: No. (10^6)
		Low case		
1975	135	156	0.53	72
1985	158	177	0.55	87
2000	177	195	0.57	101
2010	186	204	0.56	104
		High case		
1975	135	156	0.53	72
1985	158	177	0.55	87
2000	178	197	0.57	101
2010	191	210	0.56	107

Year	Commercial space: Ft² per household	Commercial space: Amount (10^9 ft²)	Autos: No. per 16 and over	Autos: No. (10^6)
		Low case		
1975	350	25.2	0.67	105
1985	350	30.5	0.65	115
2000	350	35.4	0.65	127
2010	350	36.4	0.64	130
		High case		
1975	350	25.2	0.67	105
1985	387	33.7	0.71	126
2000	449	45.3	0.77	152
2010	496	53.1	0.79	166

*In this instance, an adult is considered to be over 21 years of age.

The labor force projections are obtained by combining the population projections from the previous table and the participation rates discussed in the preceding section. In each case, it is assumed that the labor participation rate for those 16 years of age and over increases from the current 61 percent to 63 percent by 1990 and remains constant thereafter. Tables 25 and 26 detail the projections discussed above.

The connections between population and economic growth and the "intermediate factors" (i.e., households, commercial space, automobiles, industrial output, and industrial transport) which determine energy demand more directly are illustrated in Figure 5. Lower growth for the intermediate factors (shown in Table 26) reflects the various demographic and life-style factors which seem to point toward markedly lower energy requirements than have been experienced in the past. However, if the higher demographic and life-style factors are combined with the higher projections for population and economic growth in the last section, a higher scenario results for the intermediate factors.

In the next section, we construct detailed energy-demand scenarios and present the assumptions made with respect to each energy-use category.

Future U.S. Energy Demands: A Technological Approach

This part of the study establishes quantitative relationships between energy demand and economic growth. We have examined here the energy required to operate the service and process equipment in the various sectors of the U.S. economy. The approach we have used to develop these relationships is described.

On the basis of these energy-demand relationships, we have estimated future demands through the year 2010 in light of the various factors governing economic growth and energy consumption discussed in the earlier sections. This, in turn, requires assumptions for household formation, construction rates for commercial space, use of the automobile, and growth in agriculture and the manufacturing sectors which were discussed earlier. It also involves factoring in changes in the projected effective efficiencies of the various energy-use processes which are developed in this section.

We have arrived at our estimates for future U.S. energy demands by dividing energy use into five broad sectors—households, commercial space, the personal automobile, industry, and the transport of goods and services. The future growth of energy demands in each sector was determined by combining demographic-economic assumptions with technical changes in specific energy-consuming devices. The combination of factors used to estimate final demands was traced from the population projections to intermediate factors of households, commercial space, automobiles, and GNP, and then to final energy-use categories for each economic sector. The specific energy demands obtained by analyzing each sector were then summed to obtain total energy demand.

In the last section, we developed two economic-demographic growth scenarios. Future energy demands required to sustain these scenarios were determined by assuming certain efficiency changes and rates of introduction of new technologies for automobiles, service trucks, space heating and cooling equipment, household and commercial service appliances, and various industrial boilers and process equipment.

Our low-energy scenario is based on a conservative population projection (Series III of the U.S. Bureau of the Census), an optimistic estimate of future growth in productivity, assumptions about saturation for certain energy-using consumer goods after 1985 (as discussed earlier), and the implementation of modest improvements in energy efficiencies.

Our high-energy scenario includes a higher population (intermediate between Series III and Series II), an optimistic rate of improvement in productivity, continued growth in GNP and energy demand through 2000 (with some saturation thereafter), and an implementation of improved energy-efficient equipment and processes. For both scenarios, energy consumption by end-use device and by fuel type was examined in detail for each sector of the economy.

Growth in the number of energy-consuming devices in each sector has been predicated on the estimates of demographic and economic growth discussed earlier. The number of automobiles and households, the commercial floor space, freight and air transport, and the output of each manufacturing sector were tied to the low-growth or the high-growth assumptions which we addressed in the last section. We estimated that the most important components of the economy—industry, transport, and services—would grow at the same rate as GNP.

In the case of the service industries, we have made an adjustment over and above our estimates of efficiency changes in such uses as the heating and cooling of buildings. We have assumed that the composition of the services sector will shift from relatively energy-intensive demands toward less intensive ones. This follows from our projections that the population will include a lower proportion of school-age children and a higher proportion of persons in the 60-year-and-older age bracket within the time covered by our scenarios. Energy implications of structural changes in the composition of the services sector are significant. Consequently, the growth of commercial space (the general surrogate for service industries) has been lowered from 3 to 2.2 percent annually in the 1985–2000 time period. In Table 27 the energy coefficients, calculated for 1971, illustrate the point.[68]

The current energy requirements used to operate each energy-consuming device or process have been examined along with the potential for future energy conservation. The technical strategies we have used for conservation were based on the modest introduction of currently available technology timed to coincide

TABLE 27. Comparison of Energy Requirement for Service Sectors

Sector		Title	Btu/$ output
From	76	Private higher education	34,844
	77	Private elementary and secondary schools	34,844
	78	Other private education	32,723
To	37	Physicians	10,345
	40	Private hospitals	26,106
	73	Commercial amusements	18,718

with normal replacement of capital stock. Finally, the total energy demand for each case is obtained by building up the sector demands on the basis of specified energy use and economic activities.

Energy Demands by End Use and Fuel Type

U.S. energy demands by end use can be divided into five broad categories—households, commercial space, automobiles, transport of goods and services, and industry. These broad categories can be further subdivided into more specific uses as illustrated in Table 28.[69,70]

The household and commercial sectors currently consume about 35 percent of the total fuel input to the U.S. system and depend primarily on electricity, natural gas, and fuel oil. The largest energy use in these sectors is for space heating and cooling, which consumes over one-half the sector demand, or 19 percent of the total. Forty percent of the fuel for heating and cooling is obtained directly from natural gas, 40 percent directly from fuel oil, 18 percent through the use of electricity generated from various fuels, and 2 percent directly from the use of coal. Lighting and small appliances which use electricity and hot water heaters and large appliances which use electricity, natural gas, and fuel oil constitute the balance of the demand in these sectors.

The transportation sector relies primarily on liquid fuels and represents about 26 percent of the total fuel input to the U.S. energy system. Approximately 60

TABLE 28. Summary of 1975 U.S. Energy Demands by Source (fuel inputs to sectors in 10^{15} Btu)

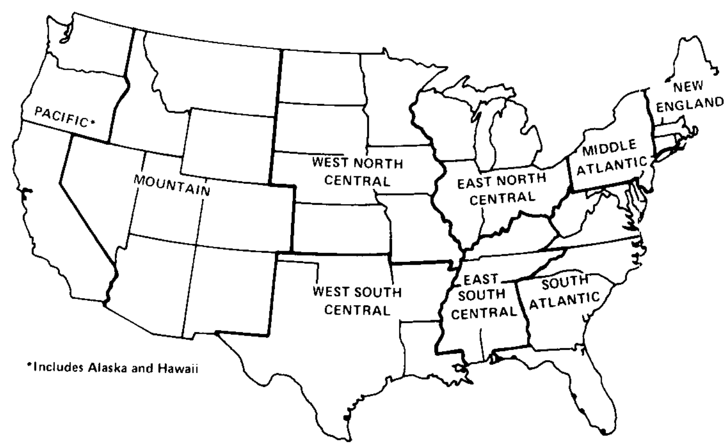
Use category	Coal	Oil	Gas	Elect.	Other elect.	Total
Households		3.8	4.9	7.1		15.8
Space heating/cooling		3.1	3.7	1.5		8.3
Lighting/small appliances				3.8		3.8
Water/large appliances		0.7	1.2	1.8		3.7
Commercial space	0.3	2.0	2.5	4.5		9.3
Space heating/cooling	0.3	1.9	2.1	0.9		5.2
Lighting/small appliances				3.3		3.3
Water/large appliances		0.1	0.4	0.3		0.8
Automobiles		8.3				8.3
Transport of goods and services		9.6	0.6	0.1		10.3
Service vehicles		2.8				2.8
Truck/rail/bus/tractor		3.5		0.1		3.6
Air transport		2.4				2.4
Ship/barge/pipeline		0.9	0.6			1.5
Industrial processes	4.3	5.7	9.0	8.4		27.4
Process steam/heat—high, low	1.7	1.9	8.3			11.9
Iron/steel	2.4			0.4		2.8
Aluminum				0.8		0.8
Electric drive/lighting				7.2		7.2
Feedstocks	0.2	3.8	0.7			4.7
Electricity inputs	8.8	3.3	3.2	(20.1)	4.8	
Totals (10^{15} Btu)	13.4	32.7	20.2		4.8	71.1
Percent of total	18.7	46.0	28.4	(28.3)	6.9	100.0

percent of that amount (15.6 percent of the total) is used as gasoline to power automobiles and light service trucks. The end-use device in this sector, which must be closely examined for efficiency improvement, is the automobile and service truck gasoline engine. An improvement in this engine and in the weight of the vehicle could have the largest single impact on the sector. The other transport categories—freight trucks, rail, buses, and tractors primarily using diesel fuel; air transport primarily using jet fuel; and ships, barges, and pipelines using diesel fuel and natural gas—make up the balance of the transportation sector. These end-use devices can also offer better fuel efficiencies.

Each of the broad sectors uses electricity, although transportation consumes only a trivial amount. The largest uses of electricity are for residential and commercial lighting and appliances and for industrial electric drive and lighting. Space heating and cooling, process steam and heating, aluminum processing, and iron and steel processing use the balance of the electricity.

U.S. Regional and Industrial Use of Energy

The pattern of U.S. energy consumption per capita varies widely from one Bureau of the Census region to another, with the highest value in the West South Central Region, and the lowest in the New England and Rocky Mountain Regions (as shown in Figure 6). The geographic variation in per capita energy use in the



	Household-commercial	Industrial	Transportation	Total
New England	141.3	42.6	68.0	251.9
Middle Atlantic	121.0	79.6	68.7	269.3
East North Central	134.6	136.5	74.6	345.7
West North Central	140.9	88.5	97.6	327.0
South Atlantic	104.2	88.1	84.2	276.5
East South Central	105.0	160.7	90.7	356.4
West South Central	115.7	330.3	113.4	559.4
Mountain	150.5	137.0	110.5	398.0
Pacific	109.2	84.5	92.7	286.4
Total U.S.	121.9	123.1	85.1	330.1

household, commercial and personal transportation sectors can largely be explained in terms of variations in climate and population density. The largest variation in per capita energy use, however, is due to differences in the industrial energy sector. Here, the variation results from the large concentration of energy-intensive manufacturing in a few locations.[71,72]

Table 29 gives a geographic U.S. energy-use pattern for the industrial sector for 1972 by U.S. Bureau of the Census regions.

TABLE 29. Industrial Energy Use by Region

Region	% of total
New England	2.4
Middle Atlantic	17.9
East North Central	13.6
West North Central	13.5
South Atlantic	10.6
East South Central	8.3
West South Central	20.7
Mountain	2.2
Pacific	10.8
Total	100.0

The U.S. industrial sector currently uses about 39.5 percent of total fuel input. About one-sixth of this (or 6.6 percent of the total) is used for such nonfuel purposes as petrochemical feedstocks. The remaining 33 percent is used for process steam and heat; for electric drive and lighting; and for iron, steel, and aluminum processing. The largest single industrial use of energy is for process steam and heat (42 percent of the sector demand and 16.7 percent of the U.S. total). Most of this is for petroleum refining, the manufacture of chemicals and allied products, the pulp and paper industry, food processing, and the production of stone, clay, and glass.[73] Over two-thirds of the total U.S. industrial energy use is concentrated in four specific geographic regions, and over 80 percent is used in six industries. Almost 80 percent of the fuel for process steam and heat comes from oil and natural gas. The balance represents electricity and the direct use of coal. The largest user of coal, other than the electric utilities, is the iron and steel industry.[74]

Table 30 lists the U.S. industrial energy-use patterns by type of industry and industrial process for 1972.

Energy-Saving Technologies

Having examined the lists of currently available and potential energy-saving technologies appropriate for various services and processes in the U.S. economy, we have singled out four specific technologies not now uniformly or widely used.[75,76] If these are increasingly adopted during the next 35 years under price or supply pressures, tax differentials, or government intervention, they would have the largest impact on energy and/or dollar savings. These technologies are as follows:

(1) New building construction with improved design and heat insulation standards, and with electric heat pump systems and a heat storage tank for heating and cooling.

(2) Smaller and lighter-weight automobiles and service trucks with more efficient engines and transmissions, and involving less steel and aluminum.

(3) Industrial boiler design and heat recovery processes in the various

energy-intensive manufacturing industries with fuel shifted from oil and gas to the direct use of coal and nuclear heat or to electricity.

(4) Electric load-level switching for the small consumer of electricity as well as for the large consumer. Although this would not save energy, it would save the high cost of peaking power.

The introduction of the major technologies suggested here can be timed to coincide with the normal retirement of capital stock when they are cost effective in each case. The use of these energy-saving technologies with the others listed in Table 31 would reduce the total U.S. energy requirements and would shift the fuel demands from oil and gas to electricity and the direct industrial use of coal and nuclear heat. Each technical strategy suggested is associated with energy-use categories in a particular sector. We discuss these more fully as each sector demand is examined.

TABLE 30. U.S. Industrial Energy-Use Patterns for 1972*

		Industrial process						
Industry	**Total use (10^{15} Btu)**	**Process steam**	**Direct heat**	**Electric drive**	**Feed-stocks**	**Electrolytic process**	**Other**	**Total**
		10.9	4.6	6.4	4.7	0.8	0.1	27.5
Primary metals	5.65							
(iron/steel/aluminum)	(3.63)							
Chemicals	4.10							
Petroleum and coal	3.20							
(refining)	(3.12)							
Paper	2.93							
Stone, clay, glass	1.61							
Food processing	1.36							
Other manufacturing	4.20							
Other industry (mining and non-industrial)	4.43							
Total	27.50							

*Decomposed numbers for industrial processes by industry are not completely developed. Hence, only aggregated numbers are used here.

Market Penetration and Future Energy Demands

The market penetration of the proposed energy-saving technologies will vary from region to region and will depend on the cost effectiveness of the changeover and the normal life of the particular existing devices which consume energy. In this analysis the market penetration of the new devices is assumed to coincide with the normal retirement of existing devices and to be driven by price and supply pressures which differ by geographic region.[77] Tax differentials or government intervention of various sorts could drive the changeover of particular devices at a faster pace than assumed here. Table 32 lists normal life assumed for the various energy-consuming devices.

These listed average lifetimes are used to arrive at the efficiency improvement factors given in the following discussions.

TABLE 31. Major Energy-Saving Technical Strategies

1. Household and commercial heating, cooling, hot water, lighting, and appliances

A. Construct new buildings with better design and insulation standards and with electric heat pump systems and a heat storage tank. Cut average heat losses by 1.3 and fuel requirements by 1.5 on all new construction. Retrofit existing buildings to cut fuel requirements by an average of 1.69 on retrofits. Shift oil- and gas-fired systems to be retired to electric heat pump systems.

B. Improve water heater insulation and eliminate severe pipe losses. Improve large appliance efficiencies. Fuel requirements decrease by 1.05 by 1985, 1.08 by 2000, and 1.10 by 2010 for hot water, cooking, refrigeration, and clothes drying.

C. Improve H/C electric lighting and small electric appliance efficiencies by 1.05 by 1985, 1.08 by 2000, and 1.10 by 2010.

2. Transportation

A. Manufacture lighter-weight automobiles and service trucks with more efficient engines and transmissions using less steel and aluminum per vehicle. Increase the average miles per gallon for auto fleet from current 14 to 20 by 1985, to 27 by 2000, and to 30 by 2010; and for service trucks from current 11 to 14 by 1985, to 18 by 2000, and to 20 by 2010.

B. Improve the efficiencies in other transport modes through improved engine efficiencies, vehicle design, and vehicle load and route strategies. Improve overall efficiencies by 10 percent by 1985, 15 percent by 2000, and 17 percent by 2010.

3. Industrial process steam and heat, and electric drive

A. Improve industrial boiler design and heat recovery processes, cutting fuel consumption by 1.15 by 1985, 1.25 by 2000, and 1.30 by 2010. Shift industrial boilers for low-temperature heat and steam from oil and gas to the direct use of coal and nuclear heat or to electricity.

B. Improve iron/steel processes and aluminum processes to decrease average energy use per ton by 1.05 by 1985, 1.10 by 2000, and 1.12 by 2010.

C. Improve industrial electrical lighting efficiencies by 1.10 by 1985, 1.17 by 2000, and 1.20 by 2010.

4. Electricity generation and distribution

A. Decrease expensive electricity generation peak load requirements by implementing load-leveling technologies for the small consumer as well as the large one. This would include heat storage and heat pump systems in the household, commercial, and industrial sectors, and automatic load-level switching for hot water and large appliances in H/C sector.

B. Use cogeneration of electricity and process steam and heat where economical. Decentralize electric generating systems to be near the consumer when feasible, decreasing distribution load losses. Encourage solar, geothermal, waste, and wind energy systems in those geographic areas where such systems are plausible.

---

1. Future household energy demands

For both household and commercial sectors, the largest use of energy is for space heating and cooling.[78] Tables 33 and 34 summarize the low and high projections for the household energy demands by specific end uses based on the number of housing units projected in the last section.

For space heating and cooling in both the low and high scenarios, we have assumed that new construction will be of improved design and insulation and thus heat losses will be cut by an average factor of 1.3. We have also assumed that some new units will have either improved air-to-air heat pumps or solar-assisted heat pump systems which exchange heat with a tank of water. We have assigned an average coefficient of performance of 3.0 to the heat pump systems and an

TABLE 32. Assumed Average Life for Various Devices

Energy-consuming device	Assumed average life (years)
House design	50
Heating and cooling system (household)	25
Water heaters and large appliances	15
Electric lighting systems	25
Small appliances	5
Electric light bulbs	1
Commercial building design	50
Heating and cooling system (commercial)	25
Water heaters and large appliances	15
Automobiles	10
Service trucks	8
Industrial boilers	15
Iron and steel furnaces	25
Aluminum smelters	25
Feedstock users	25

average efficiency of 0.33 to the electric conversion system. This gives an effective 1.5 improvement when compared to oil- or gas-fueled systems and an even larger improvement of 3.0 over an electric resistance heating system. We regard this as conservative, since the coefficient of performance claimed for the Annual Cycle Energy System is 4.5, and heat pump systems have an ideal coefficient of performance of about 6.0 for the operating temperatures for heating and cooling buildings.[79,80]

The retrofitting of housing has been assumed to proceed at a rate of 2 percent per year for existing housing in the low case and at only 1 percent per year for the high case. The average life of a house unit has been conservatively put at 50 years. We have projected an improved insulation factor of 1.3 and an average efficiency improvement factor of 1.3 for each retrofitted unit. This allows for an

TABLE 33. Household Energy-Demand Projections

Low case	1975	1985	2000	2010
Totals—energy inputs (10^{15} Btu)	15.8	17.2	18.0	17.7
Households (10^6 units)	72	87	101	104
Heating and cooling (10^{15} Btu)	8.3	8.5	8.3	7.8
New units (design factor)	1.0	1.3	1.3	1.3
New units (equipment efficiency)	1.0	1.5	1.5	1.5
Retrofits (insulation) (2%/year)	1.0	1.3	1.3	1.3
Retrofits (equipment efficiency)	1.0	1.3	1.3	1.3
Energy intensity (10^6 Btu/unit)	115.3	97.8	82.4	75.2
Water heating/large				
Appliances (10^{15} Btu)	3.7	4.3	4.8	4.9
New units (design and efficiency)	1.0	1.05	1.08	1.10
Energy intensity (10^6 Btu/unit)	51.4	49.0	47.6	46.7
Electric lighting/				
Small appliances (10^{15} Btu)	3.8	4.4	4.9	5.0
New units (design and efficiency)	1.0	1.05	1.08	1.10
Energy intensity (10^6 Btu/unit)	52.8	50.3	48.9	48.0

TABLE 34. Household Energy-Demand Projections

High case	1975	1985	2000	2010
Totals—energy inputs (10^{15} Btu)	15.8	19.3	24.3	26.8
Households (10^6 units)	72	87	101	107
Heating and cooling (10^{15} Btu)	8.3	9.8	11.8	12.8
New units (design factor)	1.0	1.3	1.3	1.3
New units (equipment efficiency)	1.0	1.5	1.5	1.5
Retrofits (insulation) (1%/year)	1.0	1.3	1.3	1.3
Retrofits (equipment efficiency)	1.0	1.3	1.3	1.3
Energy intensity (10^6 Btu/unit)	115.3	113.5	117.3	123.0
Water heating/large				
Appliances (10^{15} Btu)	3.7	4.7	6.2	6.9
New units (design and efficiency)	1.0	1.05	1.08	1.10
Energy intensity (10^6 Btu/unit)	51.4	54.1	61.0	66.2
Electric lighting/				
Small appliances (10^{15} Btu)	3.8	4.8	6.3	7.1
New units (design and efficiency)	1.0	1.05	1.08	1.10
Energy intensity (10^6 Btu/unit)	52.8	55.5	62.7	68.0

improvement factor of 1.1 in one-half of the retrofitted units without a furnace replacement, and a change to an improved heat pump system with a gain of 1.5 for the other one-half of the retrofits. In the high case, the energy intensity for heating and cooling increases at the rate of 1 percent per year to account for the expected increased market penetration of air conditioning in new and retrofitted units. (We have not duplicated the increase by incorporating any additional growth for window air conditioning units.)

For the purposes of this analysis, the efficiencies of household water heating, large appliances, lighting, and small appliances are estimated to improve by a factor of 1.05 by 1985, 1.08 by 2000, and 1.10 by 2010 in both the low and high cases. In the low case, we have not projected any additional market penetration. In the high case, we have factored in an additional 1 percent per year growth in energy intensities. This allows for an increase in the average number of bathrooms and for an increased market penetration of small electric appliances and automatic control units which may not have reached saturation.[81]

2. Future commercial energy demands

For the commercial sector, improvement factors for heating and cooling are not as large as for the household sector since these units are already better designed and insulated. Improvement factors for water heating, cooking, refrigeration, lighting, and small electric appliances are the same, however, as for the household sector end uses. We have assumed that the commercial floor space existing in 1975 will be retrofitted at the rate of 2 percent per year in the low case and at 1 percent per year in the high case (Tables 35 and 36). These are modest improvements when compared to the actual potential improvements which have been projected in several other studies.[82]

The difference in the low- and the high-energy scenarios in the commercial sector is the difference in projected commercial floor space. We have already discussed this in an earlier section.

3. Future transportation demands

Tables 37 and 38 present low- and high-energy projections for the

TABLE 35. Commercial Energy-Demand Projections

Low case	1975	1985	2000	2010
Totals—energy inputs (10^{15} Btu)	9.3	10.2	10.9	10.8
Commercial space (10^9 ft^2)	25.2	30.5	35.4	36.4
Heating and cooling (10^{15} Btu)	5.2	5.5	5.6	5.4
New units (design factor)	1.0	1.2	1.2	1.2
New units (equipment efficiency)	1.0	1.5	1.5	1.5
Retrofits (insulation) (2%/year)	1.0	1.2	1.2	1.2
Retrofits (equipment efficiency)	1.0	1.2	1.2	1.2
Energy intensity (10^5 Btu/ft^2)	2.06	1.80	1.58	1.48
Water heating/large				
Appliances (10^{15} Btu)	0.8	0.9	1.0	1.1
New units (design and efficiency)	1.0	1.05	1.08	1.10
Energy intensity (10^{15} Btu/ft^2)	0.32	0.30	0.29	0.29
Electric lighting/				
Small appliances (10^{15} Btu)	3.3	3.8	4.3	4.3
New units (design and efficiency)	1.0	1.05	1.08	1.1
Energy intensity (10^5 Btu/ft^2)	1.31	1.25	1.21	1.19

TABLE 36. Commercial Energy-Demand Projections

High case	1975	1985	2000	2010
Totals—energy inputs (10^{15} Btu)	9.3	11.8	15.4	17.9
Commercial space (10^9 ft^2)	25.2	33.7	45.3	53.1
Heating and cooling (10^{15} Btu)	5.2	5.9	7.1	7.7
New units (design factor)	1.0	1.2	1.2	1.2
New units (equipment efficiency)	1.0	1.5	1.5	1.5
Retrofits (insulation) (1%/year)	1.0	1.2	1.2	1.2
Retrofits (equipment efficiency)	1.0	1.2	1.2	1.2
Energy intensity (10^5 Btu/ft^2)	2.06	1.76	1.49	1.38
Water heating/large				
Appliances (10^{15} Btu)	0.8	1.0	1.3	1.5
New units (design and efficiency)	1.0	1.05	1.08	1.10
Energy intensity (10^5 Btu/ft^2)	0.32	0.30	0.29	0.29
Electric lighting/				
Small appliances (10^{15} Btu)	3.3	4.9	7.0	8.7
New units (design and efficiency)	1.0	1.05	1.08	1.1
Energy intensity (10^5 Btu/ft^2)	1.31	1.45	1.55	1.69

transportation sector. Each projection has been based on a specific set of assumptions about the growth in end-use demand.

The projection for automobile energy use was based on our earlier estimates of the number of automobiles. In projecting our low case, the annual miles driven per auto remains at 10,000. For the high case, we have assumed that the annual miles per automobile will increase from the current 10,000 to 11,000 by 1985, and to 12,000 by 2000. In each case, we have increased the average fleet fuel efficiency of automobiles in use from the current 14 miles per gallon to 20 mpg by 1985, to 27 mpg by 2000, and to 30 mpg by 2010. These estimates are more conservative than those expected if the mpg standards incorporated in recent

TABLE 37. Transportation Energy-Demand Projections

Low case	1975	1985	2000	2010
Totals—energy inputs (10^{15} Btu)	18.6	19.2	22.2	25.3
Automobiles				
(10^6 vehicles)	105	115	127	130
(10^{11} vehicle-miles)	1.05	1.15	1.27	1.30
(Miles per gallon)	14	20	27	30
(10^{15} Btu)	9.8	7.5	6.1	5.7
Service trucks				
(10^9 vehicle-miles) (%/year)*	99 (3.6)	141 (2.7)	210 (2.2)	261
(Miles per gallon)	11	14	18	20
(10^{15} Btu)	1.3	1.5	1.7	1.9
Truck/bus/rail freight				
(10^9 ton-miles) (%/year)*	505 (3.6)	720 (2.7)	1074 (2.2)	1335
(Efficiency factor)	1.0	1.05	1.10	1.12
(10^3 Btu/ton-mile)	7.1	6.8	6.5	6.3
(10^{15} Btu)	3.6	4.9	6.9	8.5
Air transport				
(Efficiency factor)	1.0	1.05	1.10	1.12
(10^{15} Btu) (%/year growth)*	2.4 (3.6)	3.3 (2.7)	4.6 (2.2)	5.7
Ship/barge/pipeline				
(Efficiency factor)	1.0	1.05	1.10	1.12
(10^{15} Btu) (%/year growth)*	1.5 (3.6)	2.0 (2.7)	2.9 (2.2)	3.5

*Growth factors in percent per year are shown in parentheses for service and freight sectors for each time period.

TABLE 38. Transportation Energy-Demand Projections

High case	1975	1985	2000	2010
Totals—energy inputs (10^{15} Btu)	18.6	21.4	28.1	33.9
Automobiles				
(10^6 vehicles)	105	126	152	166
(10^{12} vehicle-miles)	1.05	1.39	1.82	1.99
(Miles per gallon)	14	20	27	30
(10^{15} Btu)	9.8	9.1	8.8	8.7
Service trucks				
(10^9 vehicle-miles) (%/year)*	99 (3.6)	141 (2.8)	213 (2.5)	273
(Miles per gallon)	11	14	18	20
(10^{15} Btu)	1.3	1.5	1.7	2.0
Truck/bus/rail freight				
(10^9 ton-miles) (%/year)*	503 (3.6)	719 (2.8)	1088 (2.5)	1393
(Efficiency factor)	1.0	1.05	1.10	1.12
(10^3 Btu/ton-mile)	7.1	6.8	6.5	6.3
(10^{15} Btu)	3.6	4.9	7.0	8.8
Air transport				
(Efficiency factor)	1.0	1.05	1.10	1.12
(10^{15} Btu) (%/year growth)*	2.4 (5.6)	3.9 (4.8)	7.7 (4.5)	10.7
Ship/barge/pipeline				
(Efficiency factor)	1.0	1.05	1.10	1.12
(10^{15} Btu) (%/year growth)*	1.5 (3.6)	2.0 (2.8)	2.9 (2.5)	3.7

*Growth factors in percent per year are shown in parentheses for service and freight sectors for each time period.

energy legislation were to be strictly followed.[83]

Service truck energy demand was projected at or somewhat below the economic growth rates developed earlier.[84] Service vehicle-miles grow in the low case at the same rate as the GNP to the year 2000: 3.6 percent to 1985, 2.7 percent between 1985 and 2000, and 2.2 percent between 2000 and 2010. In the high case, vehicle-miles grow at an average annual rate of 3.6 percent to 1985; thereafter, they increase somewhat more slowly than GNP (2.8 percent between 1985 and 2000, and 2.5 percent between 2000 and 2010). In both the low and high cases, the fuel efficiency for service trucks increases from the current 11 mpg to 14 mpg by 1985, to 18 mpg by 2000, and to 20 mpg by 2010. We have projected the use of trucks, buses, and rail freight in ton-miles at the same rates as service trucks. That is to say, usage will largely follow the general economic growth rates. (These growth rates are shown in parentheses in Tables 37 and 38 for each time period.) In addressing fuel efficiency for freight in Btu per ton-mile, we have assumed that, in each case, this will improve by a factor of 1.05 by 1985, 1.10 by 2000, and 1.12 by 2010.

Air transport energy demand is assumed to grow at the same rate as the industrial sector demands in the lower case. In the high case, it grows at an average annual rate 2 percent higher than overall economic growth.[85] For each case, we have assumed that the effective fleet fuel efficiency for air transport will improve modestly: 1.05 by 1985, by 1.10 by 2000, and by 1.12 by 2010.

For ships, barges, and pipelines, the demand for fuel is assumed to follow general economic growth. Thus we have projected the same rates of growth for service trucks and freight in both the low and high cases. Fuel efficiencies will improve modestly (as in the case for air transport): 1.05 by 1985, 1.10 by 2000, and 1.12 by 2010.

It should be noted that the effective end-use efficiencies are assumed to improve on the same schedule and to the same degree for the low and high cases. The difference in the two scenarios represents a difference in life styles for the use of the automobile and a difference in general economic growth for the other transport sectors.

4. Future industrial energy demands

The industrial demands for energy grew at almost 4 percent per year during the last decade.[86] In the industrial scenarios developed for this study, the low-case growth averages 3.6 percent to 1985, 2.7 percent from 1985 to 2000, and 2.5 percent after 2000. The high-case growth averages 3.6 percent through 2000 and 3.0 percent from 2000 to 2010. In each case, we have assumed a moderate amount of energy conservation.[87] In the low case, the improved efficiency factors for the total sector average 1.10 by 1985, 1.16 by 2000, and 1.18 by 2010; for the high case, 1.10, 1.14, and 1.15, respectively. A summary of the low and high industrial demand projections by end use is shown in Tables 39 and 40.

Output of iron and steel in the low case is assumed to increase at the rate of 2.0 percent per year through 1985 and at 1 percent thereafter. Allowance is made here for a modest increase in the domestic use of steel and for a limited amount of exports. Improved efficiency is projected at 1.05 by 1985, 1.10 by 2000, and 1.12 by 2010. This production, despite the decreased requirements of iron and steel due to lighter-weight automobiles, provides for a healthy increase in per capita steel production. In the high case, output grows at 2 percent through 2010; improved efficiency factors are the same as for the low case. This growth allows for increases in the domestic use of steel as well as for increased exports.

The aluminum industry grows in the low case at 4.6 percent to 1985, 3.6 percent from 1985 to 2000, and 3.0 percent after 2000, and for the high case at a healthy 4.6 percent per year through 2000 and at 2.5 percent after 2000. In

TABLE 39. Industrial Energy-Demand Projections

Low case	1975	1985	2000	2010
Total				
(10^{15} Btu)*	27.4 (3.6)	35.5 (2.7)	50.3 (2.2)	61.3
(Average efficiency factor)	1.0	1.10	1.16	1.18
Iron/steel				
(10^{15} Btu)*	2.8 (2.0)	3.2 (1.0)	3.6 (1.0)	3.9
(Efficiency factor)	1.0	1.05	1.10	1.12
Aluminum				
(10^{15} Btu)*	0.8 (4.6)	1.2 (3.6)	1.9 (3.0)	2.5
(Efficiency factor)	1.0	1.05	1.10	1.12
Other process heat				
(10^{15} Btu)*	11.9 (3.6)	14.7 (2.6)	19.9 (2.0)	23.3
(Efficiency factor)	1.0	1.15	1.25	1.30
Electric drive/lighting				
(10^{15} Btu)*	7.2 (4.6)	10.3 (3.6)	16.5 (3.0)	21.6
(Efficiency factor)	1.0	1.10	1.17	1.20
Feedstocks				
(10^{15} Btu)*	4.7 (3.6)	6.1 (2.6)	8.4 (2.0)	10.0
(Efficiency factor)	1.0	1.10	1.17	1.20

*Growth rates in percent per year are shown in parentheses for each sector and time interval.

TABLE 40. Industrial Energy-Demand Projections

High case	1975	1985	2000	2010
Total				
(10^{15} Btu)*	27.4 (3.6)	35.5 (3.6)	58.1 (3.0)	73.1
(Average efficiency factor)	1.0	1.10	1.14	1.22
Iron/steel				
(10^{15} Btu)*	2.8 (2.0)	3.2 (2.0)	4.2 (2.0)	5.0
(Efficiency factor)	1.0	1.05	1.10	1.12
Aluminum				
(10^{15} Btu)*	0.8 (4.6)	1.2 (4.6)	2.2 (2.5)	2.8
(Efficiency factor)	1.0	1.05	1.10	1.12
Other process heat				
(10^{15} Btu)*	11.9 (3.6)	14.7 (3.6)	23.0 (2.5)	28.3
(Efficiency factor)	1.0	1.1	1.25	1.30
Electric drive/lighting				
(10^{15} Btu)*	7.2 (4.6)	10.3 (4.6)	19.0 (3.0)	24.9
(Efficiency factor)	1.0	1.10	1.17	1.20
Feedstocks				
(10^{15} Btu)*	4.7 (3.6)	6.1 (3.6)	9.7 (2.5)	12.1
(Efficiency factor)	1.0	1.10	1.17	1.20

*Growth rates in percent per year are shown in parentheses for each sector and time interval.

each case, the improved process factors are 1.05 by 1985, 1.10 by 2000, and 1.12 by 2010. Our projected large growth for aluminum allows for many new product uses and substitutions of aluminum. Obviously, increased production will result in a greater demand for electricity.

The process heat category includes process steam and heat used in the chemical industries, petroleum refining, paper and allied industries, food processing, and other industries.[88] About 60 percent of the energy inputs here are for producing process steam and the other 40 percent for direct process heat. Feedstocks (nonfuel uses), electric drive, and lighting for these industries are included in other categories. Process heat is assumed to grow in the low case at 3.6 percent to 1985, 2.6 percent from 1985 to 2000, and 2.0 percent after 2000; and for the high case at 3.6 percent per year through 2000 and at 2.5 percent after 2000. Since this sector has the largest potential for energy conservation, we have assumed that the improved process factors will be 1.15 by 1985, 1.25 by 2000, and 1.30 by 2010.

Electric drive and lighting are expected to grow at a faster rate due to increased process automation and additional industrial lighting.[89] This demand grows in the low case at 4.6 percent to 1985, at 3.6 percent from 1985 to 2000, and at 3.0 percent after 2000. For the high case, it grows at a 4.6 percent rate through 2000 and at 3.0 percent after 2000. In each case, the efficiency factors are 1.10 by 1985, 1.17 by 2000, and 1.20 by 2010.

We estimate that, in the low case, feedstocks for the various industries will grow at 3.6 percent to 1985, at 2.6 percent from 1985 to 2000, and at 2.0 percent after 2000. In the high case, the growth will be 3.6 percent to 2000 and 2.5 percent afterward. In each case, the improvement in feedstock use is assumed to be 1.10 by 1985, 1.17 by 2000, and 1.20 by 2010.[90]

Low- and High-Energy Scenarios

By combining the growth factors developed in the earlier section with the improved efficiency factors discussed in this section, we have obtained the energy demands by sector for each of our cases. This is shown in the next two tables.

These energy-demand scenarios are different from most other projections; the total energy required is much lower than most other estimates (101 q by the year 2000 in the lower case, and 126 q by 2000 in the higher case).[91-93] It should be noted, however, that the estimates for electricity are only slightly lower than other estimates, and that the savings are mostly in oil and gas, which are in short supply (47 q of fuel for electricity by the year 2000 in the lower case, and 64 q in the higher case).

The specific fuel demands shown in Tables 41 and 42 result from technical strategies used for conservation and from a deliberate shift from oil and gas to coal and electricity. The introduction of available newer technology timed to coincide with the normal replacement of energy-using devices will shift the mixture of future fuel demands. The results from using the specific growth assumptions and technical efficiencies and summing the individual energy demands give the total energy demands.

Historic data and projections for total energy demand, total GNP, GNP-to-energy ratio, per capita energy use, and per capita GNP are presented in Figures 7 and 8. Note that in the high scenario the growth rate in per capita energy use for the next 35 years is higher than the average growth rate for the past 35 years, and the projected growth in per capita GNP exceeds the average historic growth rates by almost 50 percent.

Table 43 compares the two scenarios developed in this analysis with those from other sources, by sector, where the data are available (including two Energy Policy Project scenarios[94]).

TABLE 41. Summary of Total and Sector Energy Inputs (1975–2010) by Source, Quads or 10^{15} Btu

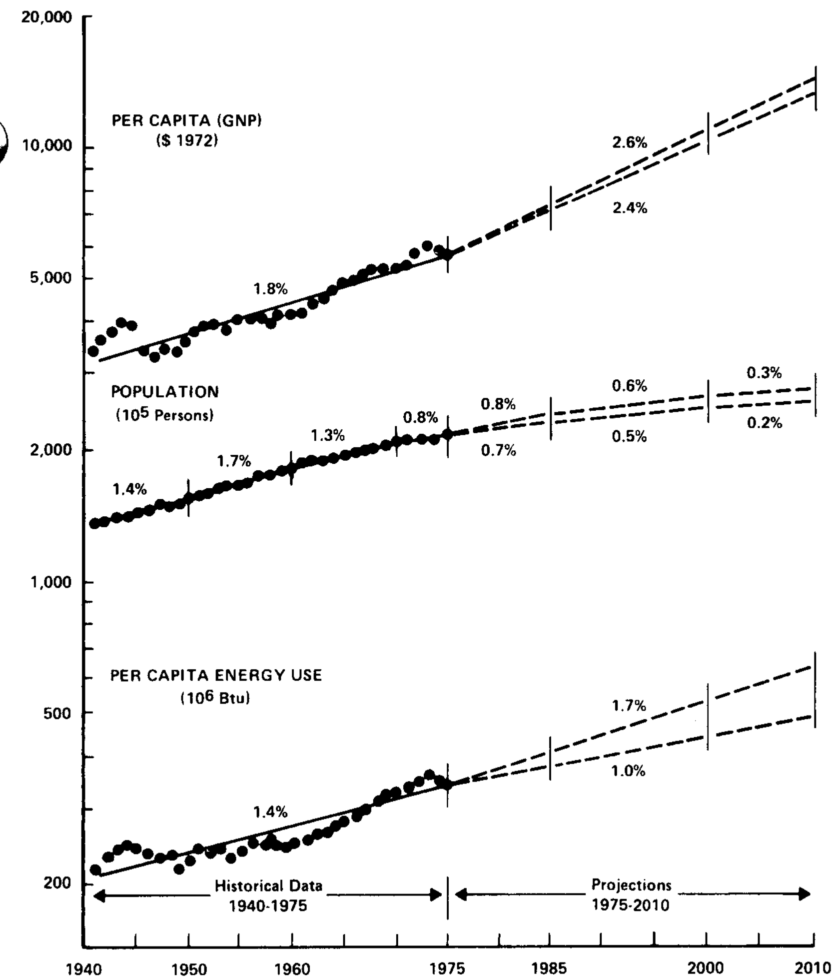
(lower scenario—101.4 q by 2000)

	Direct fuels					Heat
	Total	Coal	Oil	Gas	Elect.	Geothermal, solar, and cogeneration
1975						
Transportation	18.6		17.9	0.6	0.1	
Residential/commercial	25.1	0.3	5.8	7.4	11.6	
Industrial	27.4	4.3	5.7	9.0	8.4	
Total	71.1	4.6	29.4	17.0	20.1	
1985						
Transportation	19.2		18.4	0.6	0.2	
Residential/commercial	27.4	0.1	2.7	7.4	17.2	
Industrial	35.5	6.1	4.7	10.7	13.4	0.6
Total	82.1	6.2	25.8	18.7	30.8	0.6
2000						
Transportation	22.2		21.2	0.6	0.4	
Residential/commercial	28.9		0.7	2.8	25.4	
Industrial	50.3	10.6	6.0	10.2	21.5	2.0
Total	101.4	10.6	27.9	13.6	47.3	2.0
2010						
Transportation	25.3		24.2	0.6	0.5	
Residential/commercial	28.5			1.3	27.2	
Industrial	61.3	14.2	7.0	7.3	27.8	4.0
Total	115.1	14.2	31.2	9.2	55.5	4.0
Coal to oil conversion losses	3.2					
Total	118.3					

TABLE 42. Summary of Total and Sector Energy Inputs (1975–2010) by Source, Quads or 10^{15} Btu

(high scenario—125.9 q by 2000)

	Direct fuels					Heat
	Total	Coal	Oil	Gas	Elect.	Geothermal, solar, and cogeneration
1975						
Transportation	18.6		17.9	0.6	0.1	
Residential/commercial	25.1	0.3	5.8	7.4	11.6	
Industrial	27.4	4.3	5.7	9.0	8.4	
Total	71.1	4.6	29.4	17.0	20.1	
1985						
Transportation	21.4		20.6	0.6	0.2	
Residential/commercial	31.1	0.1	2.7	7.4	20.9	
Industrial	35.5	6.1	4.2	11.6	13.0	0.6
Total	88.0	6.2	27.5	19.6	34.1	0.6
2000						
Transportation	28.1		27.1	0.6	0.4	
Residential/commercial	39.7		0.7	2.8	36.2	
Industrial	58.1	11.2	7.3	10.2	27.4	2.0
Total	125.9	11.2	35.1	13.6	64.0	2.0
2010						
Transportation	33.9		32.8	0.6	0.5	
Residential/commercial	44.7			1.3	43.4	
Industrial	73.1	14.2	9.1	7.3	38.5	4.0
Total	151.7	14.2	41.9	9.2	82.4	4.0
Coal to oil conversion losses	7.1					
Total	158.8					


PER CAPITA (GNP)
($ 1972)
2.6%
2.4%
1.8%
POPULATION
(10^5 Persons)
1.4%
1.7%
1.3%
0.8%
0.8%
0.7%
0.6%
0.5%
0.3%
0.2%
PER CAPITA ENERGY USE
(10^6 Btu)
1.7%
1.0%
1.4%
Historical Data
1940-1975
Projections
1975-2010
20,000
10,000
5,000
2,000
1,000
500
200
1940
1950
1960
1975
1985
2000
2010

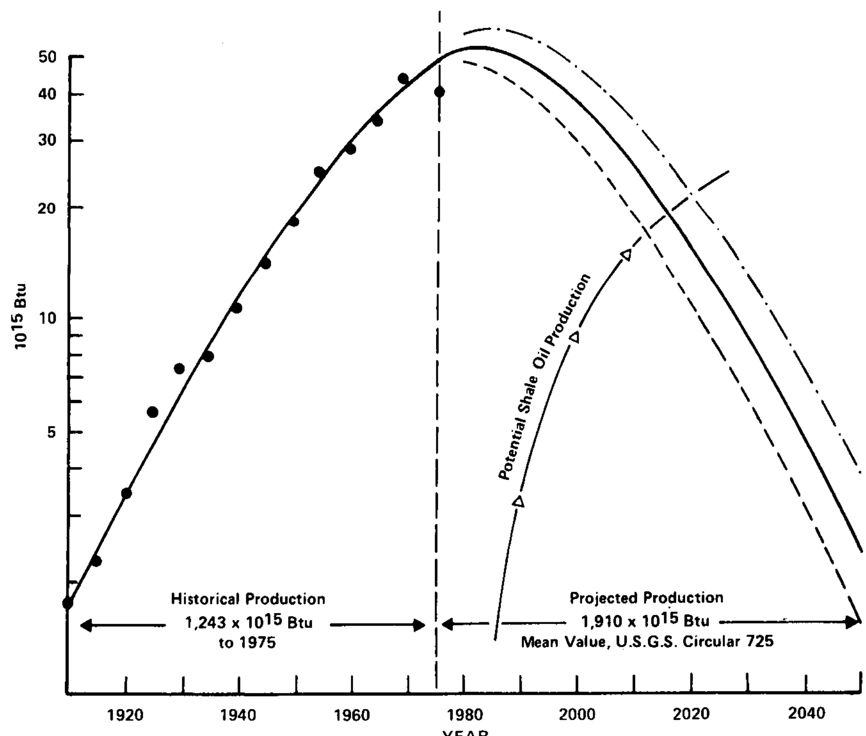

10^15 Btu
50
40
30
20
10
5
Potential Shale Oil Production
Historical Production
1,243 x 10^15 Btu
to 1975
Projected Production
1,910 x 10^15 Btu
Mean Value, U.S.G.S. Circular 725
1920
1940
1960
1980
2000
2020
2040
YEAR

TABLE 43. Comparison with Other Demand Projections for the Year 2000

(energy inputs in quads or 10^{15} Btu)

Low scenario	IEA	EPP-ZEG	ERDA-76-1	EEI Case C
Total	101.4	100	117.9	117.2
Transportation	22.2	17	NA	25.1
Residential	18.0	17	NA	24.0
Commercial	10.9	19	NA	26.2
Industrial	50.3	47	NA	41.9

<table>
<tr><th>High scenario</th><th>IEA</th><th>EPP technical fix</th><th>ERDA-76-1</th></tr>
<tr><td>Total</td><td>125.9</td><td>124</td><td>135.6</td></tr>
<tr><td>Transportation</td><td>28.1</td><td>24.7</td><td>26.0</td></tr>
<tr><td>Residential</td><td>24.3</td><td>19.3</td><td rowspan="2">42.6</td></tr>
<tr><td>Commercial</td><td>15.4</td><td>16.9</td></tr>
<tr><td>Industrial</td><td>58.1</td><td>63.1</td><td>67.0</td></tr>
</table>

Energy Prices and GNP

In the earlier sections of this study, future GNP and energy demand have been estimated from an examination of trends in labor force, productivity, and sectoral energy efficiencies. In these estimates we have not introduced prices of energy explicitly; instead, we have given independent estimates of energy prices, based generally on extrapolation and judgment. However, implicit in our projections are price elasticities, and it is necessary to determine whether these elasticities are plausible. An analysis of future energy prices and elasticities follows in this section. We find elasticities well within the range of elasticities obtained in other studies.[95-105]

As another check to determine whether the assumed prices are consistent with the estimates for energy demand and GNP, a simple one-sector economic growth model has been developed that relates energy, capital, labor, GNP, and energy prices. A short description of this model is given in this section; full details are presented in Appendix A.

Energy Prices

Estimates of future energy prices over the next three and one-half decades obviously involve great uncertainties. In the short term, unsettling events of limited duration could bring sharp but temporary price increases. In the longer term, we expect average energy prices to increase more rapidly than general prices in the economy since world energy demands will keep growing in response to population and GNP growth, and more costly energy resources will be tapped and transported at higher costs to satisfy these demands.

1. Coal

Since coal-fired plants are more likely to substitute for nuclear power than are oil-fired ones, we have given careful consideration to future trends in coal prices in the event of a moratorium. Coal reserves in the United States are very large, and coal does not appear to present a production problem over the next 25 years. However, the lead time needed to develop large underground mines is about 4–5 years. Surface mines, the predominant type of mine in the western United States, can be developed more quickly, but the process is still time consuming. Hence coal supply is not elastic in the short run. In the long run, since production is not concentrated in a few firms and the entry of new firms is not impeded by either institutional constraints or higher capital costs, coal prices are expected to approximate the costs of production, defined to include an economy-wide average rate of profit.

Coal prices to 1985 have been estimated by the Federal Energy Administration for individual geographic regions.[106] For representative regions, these projected price increases between 1975 and 1985 are calculated to be about 22 percent, measured in constant 1975 dollars. We have used the same annual percentage increase (2 percent) for the period beyond 1985.

In a recent study, Zimmerman[107] estimates that a price increase of no more than 22 percent will extend the remaining life of coal resources in the Appalachian and Illinois basins by a factor of 4. At current rates of production, the Illinois basin would be extended to 90 years and the Appalachian resources to 38 years if prices increase by 22 percent (projected 1985 average prices).

Given the slow growth in additional coal-fired generating facilities, would the real costs of coal expansion push coal prices up faster than a net 2 percent per year? The greatest expansion of the coal industry, experts believe, will come about in the western United States. An Argonne Laboratory study[108] of expansion capability for this area in the 1974–1982 period concludes that price increases will be moderate if annual growth does not exceed 25 percent per year. The same study expects actual growth to 1980 to be about 25 percent per year, reaching 120 million tons in that year from mines in Montana and Wyoming. The growth will be accompanied by an annual net price escalation of 3.3 percent. This rate of expansion is far above that required to satisfy the coal needs of our scenarios; hence, we would expect a lower rate of price increase.

2. Oil and natural gas

Domestic oil prices, on the other hand, are expected to increase substantially between now and 1985, and to equal world oil prices in or prior to 1985. Although domestic price controls may be extended beyond May 1979, a net increase in world oil prices of 2.1 percent annually would bring them to $16 per barrel by 1985. (This is the estimated 1985 average price we have used in this analysis.) Thereafter, oil prices are expected to increase more rapidly as domestic production peaks (about 1985), even with the additional production from Alaskan and offshore sources. (The Alaskan oil price structure will not be announced by the President until February 1977.) Extraction of oil in the longer term is expected to involve increasingly difficult (and therefore higher-cost) environments, such as the Beaufort Sea.

As a bargaining tactic, the OPEC organization has insisted that future price adjustments should at least offset Western inflation. During 1974–1975, inflation in other industrialized nations ran much higher than in the United States. These domestic price increases were reflected in goods imported to the Middle East from the West. Over this time period (and for the foreseeable future), the most visible price increases are those for military products imported into the Middle East (for which it is not possible to construct meaningful price indices). This makes so-called inflation price increases for oil a matter of negotiation rather than exact determination. Under these circumstances, OPEC price demands could average 10 percent per year, or substantially more than the rate of U.S. inflation now expected. (If hourly wage increases in the United States can be kept below 9 percent, the anticipated growth in output per hour would hold domestic inflation to 6 percent or less annually.[109]) Under the twin key factors expected to govern future oil prices after 1985—a fall in U.S. oil output and strong OPEC bargaining—domestic oil prices will be determined by world oil prices. In our scenario, we project a 3 percent annual increase above the rate of inflation.

We expect that shale oil will be in commercial use at the equivalent of $16–18 per barrel of oil (1975 prices). This would bring shale into the market during the 1985–1990 period; shale would account for about 9 q by the year 2000, 14 q by 2010, and then be limited by lack of water. Synthetics from coal are higher priced—about $25 per barrel—and are not incorporated in our supply scenarios until after 2000.

Natural gas prices are assumed to increase by 1985 to $2.76 per million Btu, the equivalent Btu price for $16 per barrel of oil. The rapid price adjustment for natural gas, in the face of limited deregulation, began in 1975, when wellhead prices increased 43 percent.[110] Beyond 1985, natural gas prices are assumed to follow oil prices on a Btu basis.

3. Electricity

The future cost of electricity in the United States will depend on the mixture of electric generating plants in service; the economic factors governing discount and inflation rates and fuel costs; the demand for electricity as a substitute for processes now using oil and gas; and the specific regional characteristics related to energy demands and fuel supplies. The future demand for electricity is projected to grow to the year 2000 at an average annual rate of 3.5 percent for the low-demand case and 4.8 percent for the high case.

Our estimated prices of different energy modalities are summarized in Table 44.

TABLE 44. Estimated Prices of Different Energy Modalities

(relative to 1975, in constant dollars)

	1975	1985	2000	2010
Coal	1.0	1.22	1.65	2.00
Oil	1.0	1.54	2.40	3.23
Gas	1.0	6.42	10.00	13.40
Electricity	1.0	1.22	1.65	2.00

Note: The 1975 average prices were as follows: coal, $17.50 per ton, delivered to utilities; oil, $10.40 per barrel, composite cost to refiners; natural gas, $0.43 per thousand cubic feet at the wellhead; electricity, 27 mills per kWhr to consumer.

Elasticities

We have estimated price and income elasticities by sector for each of our two energy-demand scenarios. In estimating these elasticities, it is necessary to compare the projected energy demands and prices with some reference projection which differs from the other cases with respect only to prices and income. For the reference case we have taken the high-demand scenario, but with no efficiency improvement and with essentially no price increases. The price increases shown in Table 44 are assumed to lead to the improvements in efficiency that were discussed earlier. The low demand is the consequence of further price increases and lower income (and GNP). The reference case does include some modest price increases for oil and gas to represent their increasing scarcity, but the increase in this case is not sufficient to allow for the economic development of oil shale or synthetic oil from coal until after 2010. Table 45 summarizes our assumptions regarding energy demands for the various sectors, and Table 46 the relative prices for the various fuels for the year 2010.

In order to determine price elasticities, we first compared the prices and demands in the high and low scenarios with the prices and demands in the reference case. However, because substitutions are possible, it is necessary to assume price cross-elasticities; these were taken from various other sources. For the residential and commercial sectors, cross-elasticities developed by Chern at ORNL are used.[111] For the transportation sector, since we assume oil remains

TABLE 45. Sector Energy-Demand Assumptions for the Year 2010

(quads or 10^{15} Btu)

	Reference base case				
	Coal	**Oil**	**Gas**	**Elect.**	**Heat**
Transportation	–	39.1	0.6	0.5	–
Residential	–	–	0.8	31.6	–
Commercial	–	–	0.5	21.3	–
Industrial	23.1	11.5	7.3	44.0	4.0
Total	23.1	50.6	9.2	97.4	4.0
	High scenario				
	Coal	**Oil**	**Gas**	**Elect.**	**Heat**
Transportation	–	32.8	0.6	0.5	–
Residential	–	–	0.8	26.0	–
Commercial	–	–	0.5	17.4	–
Industrial	14.2	9.1	7.3	28.5	4.0
Total	14.2	41.9	9.2	72.4	4.0
	Low scenario				
	Coal	**Oil**	**Gas**	**Elect.**	**Heat**
Transportation	–	24.2	0.6	0.5	–
Residential	–	–	0.8	16.9	–
Commercial	–	–	0.5	10.3	–
Industrial	14.2	7.0	7.3	27.8	4.0
Total	14.2	31.2	9.2	55.5	4.0

TABLE 46. **Alternative Average Prices for 2010**

(relative price index 1.0 = 1975 prices)

	Coal	Oil	Gas	Elect.
Reference base case (no efficiency improvements)	1.00	1.62	6.70	1.00
High scenario (efficiency improvements)	2.00	3.23	13.40	2.00
Low scenario (efficiency improvements, lower income, lower population)	2.00	3.23	13.40	2.00

the only energy source, the cross-elasticities are taken to be zero. For the industrial sector, price elasticities for total energy have been estimated since no cross-elasticities are available from other published studies. Income elasticities from FEA's PIES model[112] are used to obtain price elasticities which fit our low scenario with the reference case. Table 47 lists the resulting price elasticities.

Houthakker and Taylor,[113] Wilson,[114] Mount, Chapman, and Tyrrell,[115] Anderson,[116] Lyman,[117] Houthakker, Verlager, and Sheehan,[118] Taylor, Blattenberger, and Verlager,[119] Uri,[120] and FEA[121] have all developed price elasticities for residential demand for electricity, and IEA's electric residential projections assume smaller long-range price elasticities than most of the values found in the abovementioned studies. For example, Wilson found an elasticity of –2.00; Anderson obtained –1.12; and FEA obtained –1.46. Thus IEA's estimates of –1.08 and –0.60 compare conservatively with the historic elasticities, lending credibility to our belief that we have not underestimated demand. Price elasticities for electricity in the commercial sector range from FEA's –0.38 and Uri's –0.85 to Mount, Chapman, and Tyrrell's value of –1.36. Our values of –1.19 and –0.61 are well within the historic range. Our industrial elasticities of –0.37 and –0.28 are also conservative when compared to Berndt and Wood's[122] value of –0.475. In general, the price elasticities used in this study are comparable with historically derived values, although they tend to be more conservative.

TABLE 47. **Price Elasticities***

(relative to reference scenario)

	Low scenario				High scenario			
	Elect.	Gas	Oil	Coal	Elect.	Gas	Oil	Coal
Residential	–1.08	–1.21	–0.97	0.0	–0.60	–1.43	–1.03	0.0
Commercial	–1.19	–1.21	–0.97	0.0	–0.61	–1.43	–1.03	0.0
Transportation	0.0	0.0	–0.57	0.0	0.0	0.0	–0.26	0.0
Industrial (total)		–0.37				–0.28		

*Any elasticity value of magnitude less than 0.1 has been rounded to 0.0.

A One-Sector Economic Growth Model

Models can do no more than suggest how alternative future energy pricing policies might affect energy and economic growth, assuming certain future relations will exist between energy use and the economy. These relations are not really known, but they can be inferred from past experience and from estimates about the future. The assumed relationships can be embodied in a model.

The model used here and more fully described in Appendix A is an extension of the so-called constant elasticity of substitution (CES)[1 2 3] models that have been commonly used in econometric analysis. As modified in this study, the model relates labor force, capital requirements, technological change, and energy to gross national product (GNP). An explicit relation between energy use and economic output in terms of GNP is assumed, and the resulting model is then used to estimate the effect of future energy prices on GNP. Then the model is used here to test the consistency of predicted GNP and different energy pricing scenarios for the 1975–2010 period.

This model suggests that the assumed average labor productivity in the earlier sections may be optimistic and that energy-demand projections may therefore be too high. It also indicates that future decreases in energy supplies will have a minimal impact on GNP. Although the validity of the model for rising energy prices has not been adequately checked, the future trends implied by the model suggest that estimates in the earlier parts of this study are plausible.

1. Methodology

A particular form of a GNP production function is assumed, as fully discussed in Appendix A. The assumed equation is a simple, homogeneous function of degree 1 in the factors of production—capital (K), labor (L), and energy (E). The functional form chosen is the energy deflator form of the CES production function:

$$\mathrm{GNP} = ae^{rt}\frac{[bL^{\rho} + (1-b)K^{\rho}]^{1/\rho} \cdot E/c}{[bL^{\rho} + (1-b)K^{\rho}]^{1/\rho} + E/c} = HJ\left[\frac{1}{1 + c(J/E)}\right]$$

where $H = ae^{rt}$, $J = [bL^{\rho} + (1-b)K^{\rho}]^{1/\rho}$, energy deflator $= 1/[1 + c(J/E)]$, and a, b, c, r, and ρ are parameters.

The parameters a, b, c, r, and ρ are determined by fitting the assumed production function to the available 1929–1973 U.S. historic data for GNP, capital (K), labor (L), and energy (E). The fitting process is somewhat complex since there are so many parameters. The steps in the fitting process essentially involve first showing that energy's contribution to economic growth has been hardly measurable in the past. As a result, the parameter c has been very small and the energy deflator term close to a value of 1. The parameters b, r, and ρ are determined simultaneously by fitting the production function and its logarithmic derivative to the historic data for GNP, labor (L), and capital (K). These values are then used with historic data on energy's factor share to determine the parameter a and an initial value for the parameter c. Table 48 presents the best values for the parameters.

Forecasting energy's impact of future GNP requires not only values for the parameters a, b, c, r, and ρ but also projections for the values of L, K, and E. Values for L and E were developed in earlier parts of this study and are exogenous to the model as shown in the next diagram. These same values are used here. However, the variable K is obtained by assuming the following relation:

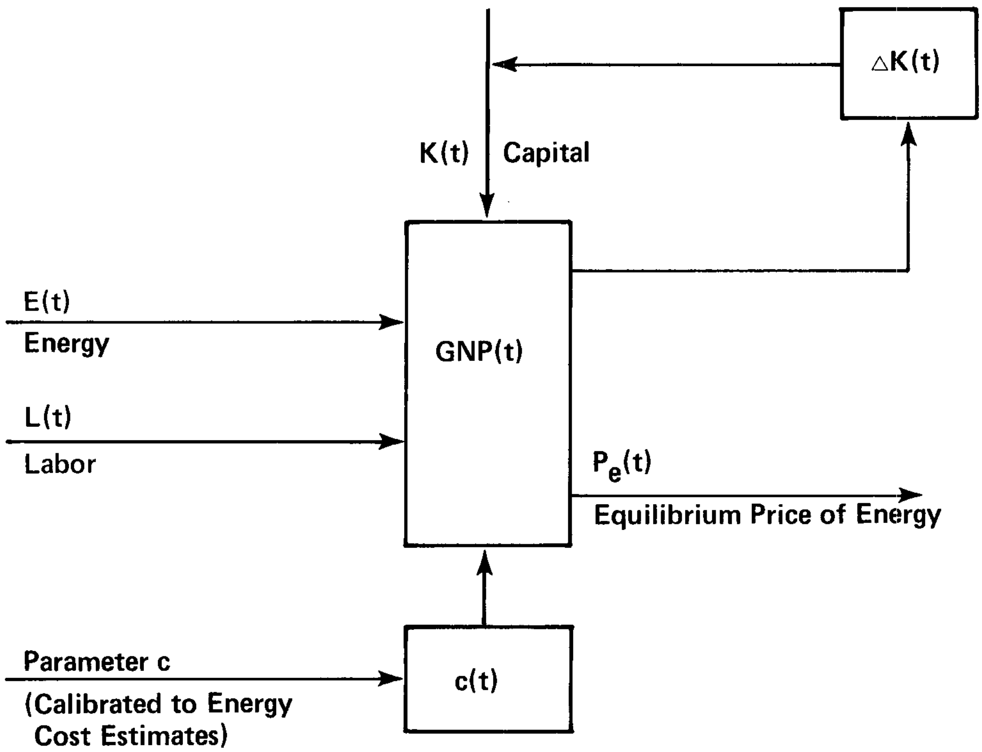
TABLE 48. Parameter Values

Parameter	Best value
a	0.233
b	0.966
c	0.0134
r	0.0180
ρ	−1.256

$$\Delta K = s(\mathrm{GNP}) - \delta K$$

where s is the savings rate and δ is the rate of depreciation, with both derived from historic data which show them to be very stable. They were assumed to be constant over the period 1975–2010. ΔK is the increase in capital stock from one period to the next. The following diagram illustrates schematically how the model yields a set of equilibrium prices for energy, given our exogenous input for energy and labor and an initial value for K.

The model's validity is partially tested by dividing the 1929–1973 data into two periods, 1929–1950 and 1951–1973. The model's parameters are then determined using the data for the earlier period, and the model predicts results for the second period. The predicted and actual data are reasonably close. This validity test is not complete since energy prices were decreasing compared to other prices during both periods of available U.S. historic data. No data are available for the United States over a period of rising energy prices, which is the expected case for the future (1975–2010) period under study. It has been suggested that cross-sectional or pooled time series and cross-sectional data for certain regions of the United States and for certain Western European countries might better serve to test the model's validity, but this possibility has not been explored.



2. Testing the results

The exogenous estimates for future labor force and energy use developed in earlier parts of this report are assumed as inputs to the model. Other estimates of future values could also be used. Alternative estimates of future energy prices are examined using alternative values for the parameter c. A low-energy-price scenario (assuming a 2.3 percent annual rise in the real price of energy for the 1975–2010 period) and a high-price scenario (assuming a 4.3 percent annual rise for the 1975–1985 period, and a 3.3 percent annual rise after 1985) are simulated. The results of the four cases—high energy and labor force growth with high prices and with low prices, and low energy and labor force growth with high prices and with low prices—are shown in Table 49.

The table indicates that earlier estimates for growth in GNP are in general agreement with those developed from this model, and alternate prices seem to have only a minor effect on GNP. Prices seem to have a similar minor impact on average labor productivity, which increases at an annual rate of approximately 1.85 percent in all cases. Energy's share of GNP rises from about 1.32 (the average for 1948–1971) to 1.73 percent in 2010 for the low-price scenario. In the high-price scenario, energy's share rises to 3.1 percent in 2010. The average rate of

TABLE 49. Summary of Modeling Inputs and Results

Year or period	GNP*	Internal growth rate $\left[\frac{\Delta GNP}{GNP}\right]$	Labor force* $[L]$	Labor prod. index $\left[\frac{GNP}{L} = y\right]$	Internal growth rate $\left[\frac{\Delta y}{y}\right]$	Energy factor share $[r_Z]$	Energy price index $\left[\frac{F_Z^t}{F_Z^{1975}}\right]$
			High energy and labor, high prices				
1975	1.172		1.084	1.081		0.0226	1.000
1975–1985		3.42			1.84		
1985	1.650		1.270	1.299		0.0255	1.533
1985–2000		2.67			1.84		
2000	2.464		1.440	1.711		0.0292	2.625
2000–2010		2.30			1.82		
2010	3.100		1.510	2.053		0.0310	3.539
1975–2010		2.78%			1.83%		
			High energy and labor, low prices				
1975	1.180		1.084	1.089		0.0159	1.000
1975–1985		3.45			1.86		
1985	1.666		1.270	1.312		0.0161	1.228
1985–2000		2.69			1.86		
2000	2.495		1.440	1.733		0.0171	1.812
2000–2010		2.30			1.84		
2010	3.145		1.510	2.083		0.0173	2.218
1975–2000		2.80%			1.85%		
			Low energy and labor, high prices				
1975	1.172		1.084	1.081		0.0227	1.000
1975–1985		3.42			1.84		
1985	1.650		1.270	1.299		0.0256	1.519
1985–2000		2.54			1.84		
2000	2.416		1.412	1.711		0.0293	2.607
2000–2010		2.08			1.82		
2010	2.975		1.449	2.053		0.0311	3.511
1975–2000		2.66%			1.83%		
			Low energy and labor, low prices				
1975	1.180		1.084	1.089		0.0159	1.000
1975–1985		3.45			1.86		
1985	1.666		1.270	1.312		0.0160	1.218
1985–2000		2.56			1.85		
2000	2.446		1.412	1.732		0.0172	1.578
2000–2010		2.10			1.85		
2010	3.018		1.449	2.083		0.0173	2.230
1975–2000		2.68%			1.85%		

*Normalized to 1.0 for 1971.

economic growth for these scenarios ranges from 2.66 to 2.80 percent for the 1975–2010 period.

Conclusions

In view of the assumptions and the analyses in the earlier parts of this study and the check of the interdependence of the results with price and income elasticities and a simple economic growth model, we conclude the following:

(1) Future long-term average annual U.S. economic growth in terms of real GNP is not likely to exceed 2.5–3.0 percent even with the most optimistic assumptions about average productivity. This compares to an average annual rate of growth of 3.4 percent for the past 35 years.

(2) Future long-term growth in U.S. energy demands is not likely to exceed the 101–126 q range by the year 2000 if average energy price increases are 2.3–4.3 percent annually and are gradual and expected.

(3) If the projected economic growth and energy-demand scenarios are realized, the projected annual growth in per capita GNP will range from 2.4 to 2.6 percent compared to a past growth rate of 1.8 percent. The projected annual growth in per capita energy use will range from 1.0 to 1.7 percent compared to an average growth rate of 1.4 percent for the past 35 years.

(4) Other energy-demand scenarios are possible, but those developed here require a shift in energy carrier from a current energy use of 28 percent in the form of electricity to approximately 50 percent electricity by the year 2000.

APPENDIX A:
A ONE-SECTOR MODEL OF ENERGY AND GNP

Introduction

The model developed here is an extension of the so-called constant elasticity of substitution (CES) models that have been used in econometric analysis. As modified in this paper, the model relates labor force, capital requirements, technological change, and energy to gross national product (GNP). An explicit relationship between energy use and economic growth is chosen, and the resulting model is capable of estimating the effect of future energy prices on GNP. The discussion first sets the development of the model in context with other similar efforts. The model is developed, tested, and used to check the consistency of estimates for future values of labor, GNP, and energy prices.

There are many techniques employed by economists to attack the problem of determining long-run growth in GNP. The traditional approach is to consider the value of goods and services produced (GNP) to be dependent on the factors of production employed. When dealing with such a highly aggregated variable as the GNP,[124] economists use highly aggregated categories of inputs. It is often the case that all primary factor inputs are included in either of the two categories, capital or labor. For most models, the labor force is measured in man-hours and the capital stock is calculated in dollars. This implies that the GNP actually produced can be written as a function of the stocks of labor and capital employed such that

$$Y = F(K, L)$$

where Y stands for the GNP, K for capital, and L for labor.

A general relationship for GNP is of rather limited use in predicting the future. For prediction purposes, a specific functional form must be chosen. One popular form is the constant elasticity of substitution production function (CES),[125] whose equation is

$$Y = a[bK^{\rho} + (1 - b)L^{\rho}]^{1/\rho}$$

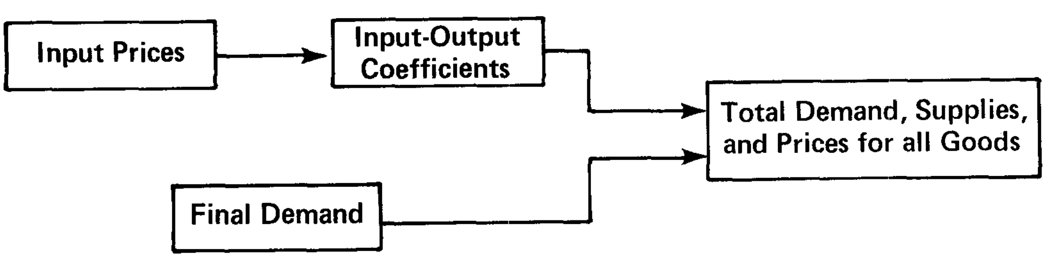
with a, b, and ρ parameters to be estimated. This function is called the CES production function because of its special property. Not only is it continuous, smooth, and homogeneous of degree 1, but the rate at which capital and labor can be substituted for one another (with output unchanged) is a constant. This particular function is of relatively little value in determining energy's impact on the GNP, since energy never enters explicitly into the function. A more sophisticated analytic framework is necessary to assess energy's impact on the GNP.

Energy and GNP Models

In 1974, Edward Hudson and Dale Jorgenson introduced a sophisticated analytic model designed to answer questions concerning the supply and demand for energy.[126] However, their approach to the energy-GNP problem not only employs a different methodology but also asks somewhat different questions than required in this analysis. The method employed here is simpler than the Hudson-Jorgenson methodology and is concerned with determining the impact of changing energy supplies and technologies on GNP. The Hudson-Jorgenson model asks almost reverse questions since, in effect, it generates a GNP independent of energy considerations and then asks why energy prices, supplies, and demands will bring about equilibrium under varying energy taxed and nontaxed scenarios.

The Hudson-Jorgenson model integrates two modeling levels; on one level, an elaborate input-output model which has nine sectors (five of which are energy related—coal mining, crude petroleum and natural gas, petroleum refining, electric utilities, and gas utilities) is employed. Whereas traditional input-output modeling takes the input-output coefficients as exogenously given constants, the Hudson-Jorgenson model determines these coefficients endogenously.

Hudson and Jorgenson use Samuelson's nonsubstitution theorem[127] to show that, for given factor input prices (specifically the wage rate for labor, the rental rate for capital, and input prices), output prices and input-output coefficients can be determined. Once these parameters are obtained, it is necessary only to determine the composition of final demands to obtain gross outputs for all sectors.



A crucial step in the Hudson-Jorgenson model is to obtain input prices and final demands. A second-level model, the macroeconomic growth model, is required to obtain these. The Hudson-Jorgenson macromodel is basically an elaborate two-sector neoclassic growth model which uses the supplies of labor and capital to determine the GNP, and a set of final demand equations to determine the investment and consumption components of the GNP. Investment is then added to and depreciation subtracted from the next period's stock of available capital. The macromodel then determines the level and aggregate composition of final demand as well as the input prices for labor and capital when it clears these factor markets.

With this elaborate framework, the model is able to make predictions concerning the demand for energy and to conclude that substantial conservation will result if energy is taxed. This model, however, is not well suited for determining the impact of a decreased supply of energy on the underlying growth rate of the aggregate economy (since the Hudson-Jorgenson macromodel never uses energy as an argument in determining the macroeconomic production possibilities frontier).

Anne Carter has used a different approach to develop estimates of energy's impact on the GNP growth rate.[128] Carter employs "turnpike" theory[129] to develop a dynamic input-output framework, and estimates maximum potential growth rates for the U.S. economy in the year 1980 under varying assumed technologies. Compared with the base year "Von Neumann growth rate" of 3.54 percent, she finds that increasing input requirements for electric energy generation will reduce the estimated rate of GNP growth to 3.32 percent. She also estimates the rate of GNP growth if coal gasification were introduced as a new technology, and finds that annual GNP growth rates fall to 3.06 percent.

Carter's method not only allows her to make predictions of direct impacts for evolving energy technologies on GNP growth rates but also allows examination of indirect impacts from these technological changes on other sectors of the economy. However, the analysis focuses directly on particular technologies with laborers never explicitly considered; as a consequence, her results form an upper bound on possible GNP growth rates.

The Hudson-Jorgenson and Carter methodologies are two recent, rather elaborate attempts to explicitly assess energy's economic impacts using and extending the tools of input-output analysis. Both studies stand in sharp contrast to the relative simplicity of this paper's one-sector energy and GNP model. In fact, the one-sector model has simplicity as its principal virtue.

The model incorporates energy directly into the aggregate production function with labor and capital, and represents a methodology for assessing the impact of energy availability and technology on GNP.

The One-Sector Model

The model proposed in this paper is one in which energy is introduced in a straightforward fashion. A simple macroeconomic model is developed in the general form

$$Y = F(L, K, E, t) \qquad (1)$$

where Y is the GNP, L stands for employed labor force, K is the capital stock, t is the period of time which determines the state of the technology, and E is energy.

This function has several important properties. First, all factors of production (L, K, and E) are assumed to be productive such that if more of any one of them became available, a larger GNP could be produced. Since the marginal product of a factor is defined to be the change in output from a one-unit change in the input, all products are said to have positive marginal products. This may be written in equation form as

$$F_L = \frac{\partial F}{\partial L} > 0 \qquad F_K = \frac{\partial F}{\partial K} > 0 \qquad F_E = \frac{\partial F}{\partial E} > 0$$

Notice that this relationship has some other implications as well. Since all factors are assumed to have positive marginal products, one factor can always be substituted for another without changing the total output. The same GNP is possible with fewer laborers if more capital is made available.

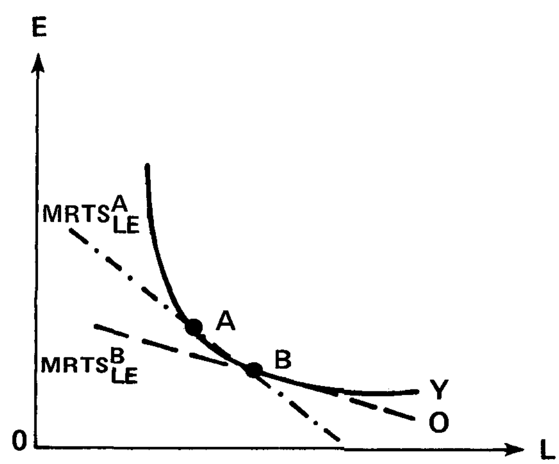
An isoquant for the function is defined to be the locus of all points (L, K, E) which yield the same total GNP. One can deduce from the assumption of positive marginal productivity that all isoquants have a negative slope. The slope of an isoquant, called the marginal rate of technical substitution (MRTS), indicates the rate at which one input can be substituted for another with total output unchanged. Thus the MRTS between labor and capital is

$$\text{MRTS}_{LK} = -\frac{F_L}{F_K}$$

while the MRTS between labor and energy is

$$\text{MRTS}_{LE} = -\frac{F_L}{F_E}$$

Note that the slope of the isoquant depends on exactly where the MRTS is evaluated. More labor is substituted for a unit of energy at point B than at point A in Figure 9. Isoquants are assumed not only to have negative slopes but also to



be convex to the origin. This implies that if the GNP is held constant, then as energy is substituted for more and more units of labor, greater amounts of energy are needed for each additional unit of labor replaced. Hence the slope of the isoquant becomes steeper as one moves along the isoquant from B and A.

In general, it seems reasonable to assume that some of all inputs are necessary to produce any output, since it is difficult to imagine any GNP (as we know it) being produced if no laborers are used, if the laborers have no tools with which to work, or if no energy is available. If this assumption is correct, then isoquants can never touch an axis.

The final property attributed to the function in equation (1) is that it is homogeneous of degree 1 in L, K, and E. Thus doubling the stock of capital, number of laborers, and available energy will exactly double the GNP, or

$$\lambda F(L, K, E) = F(\lambda L, \lambda K, \lambda E)$$

This property implies that the function can be written in the form of the Euler equation, which states that

$$F(L, K, E) = LF_L + KF_K + EF_E$$

The Use of an Energy Deflator

There are many alternative functional forms that possess all the appropriate properties. The problem is finding one which also fits the historic record. The form that has been chosen for examination in this paper is termed the energy deflator form of the CES production function, which can be written as

$$Y = ae^{rt} \frac{[bL^{\rho} + (1 - b)K^{\rho}]^{1/\rho} \cdot E/c}{[bL^{\rho} + (1 - b)K^{\rho}]^{1/\rho} + E/c} \tag{2}$$

This may also be expressed as[130]

$$Y = H \frac{JZ}{J + Z} \tag{2'}$$

where

$$H = ae^{rt} \qquad J = [bL^{\rho} + (1 - b)K^{\rho}]^{1/\rho} \qquad Z = \frac{E}{c}$$

Note that the function J is the familiar constant elasticity of substitution or CES production function, originally developed by Arrow, Chenery, Minkas, and Salow[130] and used to model historic growth patterns for nonagricultural production. The function H, which multiplies the CES production function, produces a technology subject to Hicks neutral technological change. This type of technological change augments all factors of production, favoring none. (This form was found to fit historic data better than the factor-augmenting forms of either Harrod neutral or Salow neutral technological change.)

Note that the energy deflator production function may also be written as

$$Y = HJ\left(\frac{Z}{J + Z}\right) = HJ\left[\frac{1}{1 + c(J/E)}\right] \tag{1'}$$

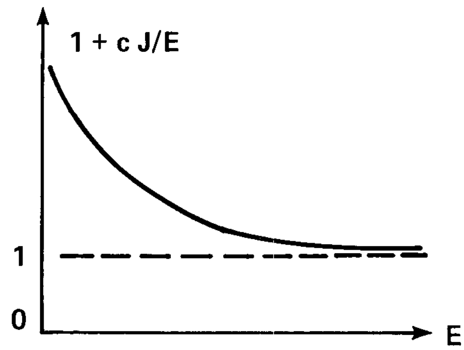
This production function would be exactly the same as traditional aggregate production functions were it not for the term

$$\frac{1}{1 + c(J/E)}$$

which is the energy deflator. For given c, K, L, and t, the value of HJ is set. As more energy is used, the value of $c(J/E)$ decreases and the GNP increases. Energy acts then to either augment or retard the GNP, and it does so in such a way that it either augments or reduces the productivity of both capital and labor. This, of course, says little more than that the marginal product of energy is positive. If $E/c = Z$ is defined to be the effective energy supply, the marginal product of energy can be calculated by partially differentiating equation (2) with respect to Z, which gives

$$F_Z = \left(\frac{Y}{Z}\right)\left(\frac{J}{J + Z}\right) \tag{3}$$

The energy deflator can be viewed graphically as shown in Figure 10. For given amounts of labor and capital, the energy deflator can take on values ranging from 1 to infinity. As energy becomes extremely abundant, the energy deflator falls to 1 and the production function for GNP becomes the standard form $Y = HJ$. However, if energy were extremely scarce, the energy deflator would approach infinity and the GNP would approach zero. In this case, energy is a critical factor. Obviously, the more energy there is available, the larger the GNP; although there are limits to the amount GNP can be increased using energy alone.



New Energy Technologies

Estimates for the parameters of a, b, c, r, and ρ are made using historic data over the period 1929-1973. Once these parameters are obtained, the model takes values of L, K, E, and t and generates values for the GNP. The only problem is, of course, that the future may not be like the past. Perhaps as liquids and gases are depleted the same energy-to-GNP ratio would result from more roundabout processes. Capital and labor may be diverted from GNP-producing activities to the production of an intermediate product such as synthetic fuels from coal. This diversion of resources to energy production will have its costs and can be modeled in this analysis through a change in the parameter c.

Before discussing the methodology by which c may be varied in response to changes in technology, it is important to note that if the markets for factor inputs L, K, and E are competitive, then the price paid for each factor of production will be equal to the value of its marginal product. As a consequence, F_L, F_K, and F_E may be interpreted as the price of one unit of labor, capital, and energy, respectively. For example, energy's price is given by

$$F_Z = \frac{JY}{(Z + J)Z}$$

If a new technology for producing energy were suddenly introduced, it would affect the GNP. For example, current production of oil and natural gas uses a relatively efficient technology, one in which these energy supplies are obtained directly from natural sources. When natural sources are depleted, however, a different technology for obtaining energy will be necessary. One way that the economy might replace the natural liquids and gases is to produce synthetic liquids and gases from coal. Clearly, this alternative will require that more capital and labor be diverted to the energy sector. This may be modeled by an increase in the value of the energy deflator via an increase in the value of c. As one energy technology replaces another, the technology coefficient c must also be changed.

Determining exactly how much to vary c requires that the efficiencies of the two processes first be compared. For example, 38 q of energy from oil and gas was produced in 1967 at an average price of \$0.40 per million Btu. Substitute synthetic liquids and gases might cost \$2.00 per million Btu, an increase of 500 percent. Since energy's price is assumed to equal the value of energy's marginal product in a competitive economy, equation (3) can be differentiated to give

$$\frac{1}{F_Z}\frac{\partial F_Z}{\partial c} = \frac{1}{c}\frac{2}{(1 + J/Z)} \tag{4}$$

This expression can be rearranged to obtain a more useful form as follows:

$$\Delta c = ½\, c\left(1 + \frac{J}{Z}\right)\frac{\Delta F_Z}{F_Z} \tag{5}$$

In this form, the change in energy costs, $\Delta F_Z/F_Z$, is related directly to the change in the energy technology coefficient Δc.

The following example is also useful in illustrating the application of these equations. Assume that

$$J = E = H = 1$$

It is known that energy's share of the GNP, $F_Z Z/Y$, has been approximately 1.5 percent for some period of years. This may be written as

$$0.015 = \frac{F_Z Z}{Y} = \frac{J}{J + Z}$$

starting with equation (3). As a consequence, values for Z and c may be directly calculated to be $Z = 65.67$ and $c = 0.0152$, since $Z = E/c$ and $E = 1$.

The introduction of synthetic liquids and gases increases energy's price by 500 percent so that $\Delta F_Z/F_Z = 5$. With equation (5), the amount by which c must now be changed to accommodate this change in technology may be calculated as follows:

$$\begin{aligned}\Delta c &= ½\, c\left(1 + \frac{J}{Z}\right)\frac{\Delta F_Z}{F_Z}\\ &= (0.5)\,(0.0152)\,(1 + 0.0152)\,(5)\\ &= 0.0386\end{aligned}$$

Therefore, the value of c must be increased by 0.0386 or from 0.0152 to 0.0538. This, in turn, alters the value of Z to 18.56.

The value of GNP may now be calculated for the two cases with $Y = H[JZ/(J + Z)]$, $H = J = 1$ in this example, and $Y = Z/(Z + 1)$. The initial value of Y was 0.985, and, after the introduction of synthetic liquids and gases, Y became approximately 0.95, a decrease of 3.5 percent. It is interesting to note that energy's share of the GNP has also changed from 0.015 to 0.051, an increase of 240 percent.

Energy's Historic Role in Determining GNP

Energy's future relationship to GNP may be quite different from that in the past, but nevertheless an understanding of energy's future impacts must be rooted in an understanding of its historic role. This is especially important in light of the methodology developed in the last section to model energy's future impact on GNP. The past relationships may be examined both at a general level, without regard to a specific production function, and with the aid of the energy deflator production function. Together the two methods should yield not only a set of parameters for equation (2) but also a basic understanding of how energy influences the GNP.

Every homogeneous production function of degree 1 (with labor, capital, and energy) and Hicks neutral technological change can be written in the form

$$Y = ae^{rt}\,F(L, K, E) \tag{6}$$

Logarithmically differentiating with respect to time,

$$\frac{\dot{Y}}{Y} = r + \frac{F_L L}{F}\frac{\dot{L}}{L} + \frac{F_E E}{F}\frac{\dot{E}}{E} + \frac{F_K K}{F}\frac{\dot{K}}{K} \tag{7}$$

or

$$\frac{\dot{Y}}{Y} = r + \alpha_1 \frac{\dot{L}}{L} + \alpha_2 \frac{\dot{E}}{E} + (1 - \alpha_1 - \alpha_2)\frac{\dot{K}}{K}$$

where the coefficients α_1, α_2, and $(1 - \alpha_1 - \alpha_2)$ are the output elasticities of labor, energy, and capital, respectively. In a competitive economy they also represent the relative shares for the respective factors.

To assess energy's contribution to economic growth, time series for both energy and energy's factor share are obtained. The former is taken from "United States Energy Through the Year 2000,"[131] while the latter is obtained from Jack Faucett Associates' compilation for the Energy Policy Project.[132]

Labor's share of the GNP is obtained by dividing total labor compensation by the GNP. Energy's share of the GNP is calculated from value added in the coal mining and oil and natural gas producing sectors of the economy. It is important to note that returns to hydroelectric and nuclear power sectors are not available, although they are either nonexistent or insignificant in most years. This tends to slightly underestimate energy's factor reward. On the other hand, all value-added amounts less payments to labor in the primary energy industries are included as returns to energy. Hence, to the extent that capital's contribution is underestimated, energy's contribution is overestimated.

In the time series given in Table 50, energy's contribution to growth, $\alpha_2(\dot{E}/E)$, is calculated, as well as the rate of GNP growth, $\dot{Y}/Y$. In column (6), the ratio $\alpha_2(\dot{E}/E)/(\dot{Y}/Y)$ is calculated to obtain a measure of the fraction of total GNP growth that can be explained by energy's growth. On two occasions, in 1949 and 1954, the two moved in opposite directions, with a maximum ratio of only 11.1 percent. In fact, on the average, over the period 1948-1971, energy accounts for only 0.575 percent of GNP growth. The inescapable conclusion is that energy has been relatively unimportant in explaining economic growth in the past. Energy's role seems to have been a rather passive one, available when needed.

Although energy may have played a passive role historically, it will play an increasingly active role in the future. As cheap energy becomes scarce, either less energy will be available at historic prices or the price will increase as more expensive supply sources come on line. The higher energy prices will encourage energy conservation, which, in turn, will tend to reduce GNP. The more expensive energy sources will require more capital and labor to produce each unit of energy, and other factors of production will be diverted from the production of GNP to the production of an intermediate energy form.

Estimating Parameters

As demonstrated in the previous section, energy's contribution to the historic GNP was small. This implies that the value of c must also be extremely small. As a first approximation, equation (2) is given by the usual CES function with Hicks neutral technological change.

$$Y = ae^{rt}\,[bL^{\rho} + (1 - b)K^{\rho}]^{1/\rho} \tag{8}$$

TABLE 50

(1) Year	(2) α_2	(3) $\dot{E}/E$	(4) $\alpha_2(\dot{E}/E)$	(5) $\dot{Y}/Y$	(6) $\frac{\alpha_2(\dot{E}/E)}{\dot{Y}/Y}$
1948	0.0165	0.0269	0.00044	0.04059	0.011
1949	0.0152	−0.0734	−0.00112	0.00613	−0.183
1950	0.0141	0.0764	0.00108	0.08358	0.013
1951	0.0146	0.0791	0.00115	0.07748	0.015
1952	0.0144	−0.0082	−0.00012	0.03745	0.003
1953	0.0145	0.0297	0.00043	0.03819	0.011
1954	0.0155	−0.0352	−0.00055	−0.01311	−0.042
1955	0.0160	0.0895	0.00143	0.06480	0.022
1956	0.0165	0.0491	0.00081	0.02115	0.038
1957	0.0168	0.0000	0.00000	0.01793	0.000
1958	0.0155	0.0000	0.00000	−0.00206	0.000
1959	0.0143	0.0330	0.00047	0.05843	0.008
1960	0.0138	0.0342	0.00047	0.02251	0.021
1961	0.0138	0.0156	0.00022	0.02480	0.009
1962	0.0132	0.0453	0.00060	0.05636	0.011
1963	0.0125	0.0393	0.00049	0.03878	0.013
1964	0.0116	0.0378	0.00044	0.05126	0.009
1965	0.0110	0.0402	0.00044	0.05721	0.008
1966	0.0102	0.0565	0.00058	0.05779	0.010
1967	0.0100	0.0331	0.00033	0.02685	0.012
1968	0.0100	0.0567	0.00057	0.04283	0.013
1969	0.0094	0.0521	0.00049	0.02534	0.019
1970	0.0100	0.0363	0.00036	0.00325	0.111
1971	0.0094	0.0191	0.00018	0.02950	0.006
Average	0.013224				0.00575

or merely $Y = HJ$. Equation (8) will be used to obtain a first approximation for the parameters a, b, r, and ρ. Given these parameters, energy's historic factor shares may be used to fix the parameter c, since multiplying energy's marginal product by Z/Y gives

$$\frac{F_Z Z}{Y} = \frac{[bL^\rho + (1-b)K^\rho]^{1/\rho}}{[bL^\rho + (1-b)K^\rho]^{1/\rho} + E/C} \tag{9}$$

This allows c to be determined from the data using values of b and ρ obtained from equation (8).

The basic historic data used to estimate the parameters in the model are shown in Table 51. The GNP is given in billions of 1958 dollars in the July 1976 issue of the "Survey of Current Business" ("SCB"), Table 1.2.[133] Labor is the number of full-time equivalent employees from Table 6.4 of the "SCB."[134] The capital time series is the gross capital stock series from the paper by Masgrave in the March 1974 issue of the "SCB."[135] Using the historic data, the annual savings rates, depreciation rates, and indices for GNP, capital, and labor are calculated (see Table 52). The savings rate s is defined by the quotient of investment and GNP. The capital stock in Table 51 is the gross stock on December 31. The growth in capital stock during a year is equal to investment minus depreciation. Using the capital stock and investment, depreciation and the depreciation rate have also been calculated. (The depreciation rate is the depreciation divided by the average capital stock—the July 1 value.) Table 52 contains indices for GNP, capital, and labor which are normalized to 1.0 in 1971. The indices are plotted in Figure 11.

During the depression and World War II, the savings rate was low and the investment was about equal to the depreciation, so there was no growth in the

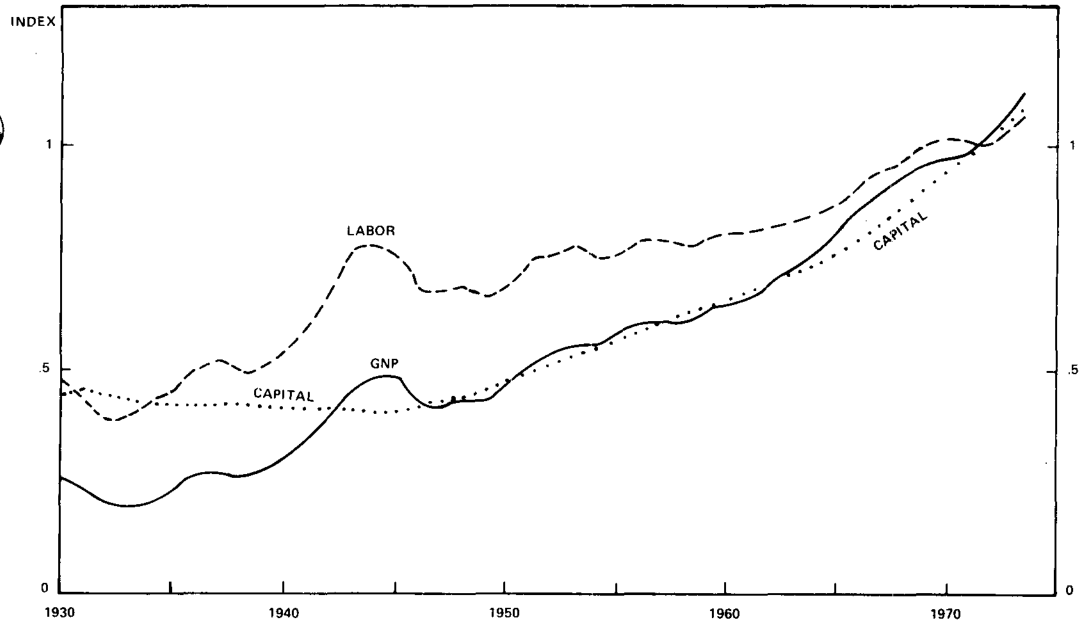
TABLE 51. Historic Data

Year	GNP	Investment	Labor	Capital
1929	203.6	26.5	35896.0	436.2
1930	183.5	21.7	33769.0	442.3
1931	169.3	14.1	30690.0	441.0
1932	144.2	8.2	27215.0	433.2
1933	141.5	7.6	27681.0	424.1
1934	154.3	9.2	30905.0	417.1
1935	169.5	11.5	32263.0	412.3
1936	193.0	15.8	35413.0	411.8
1937	203.2	18.8	36662.0	413.9
1938	192.9	13.7	34945.0	410.6
1939	209.4	15.3	36339.0	408.0
1940	227.2	18.9	38336.0	408.5
1941	263.7	22.2	43022.0	412.1
1942	297.8	12.5	48045.0	407.9
1943	337.1	10.0	54211.0	401.0
1944	361.3	13.4	55361.0	397.5
1945	355.2	19.8	53642.0	400.0
1946	312.6	30.2	47481.0	410.8
1947	309.9	36.2	47506.0	427.8
1948	323.7	38.0	48589.0	447.2
1949	324.1	34.5	47290.0	461.8
1950	355.3	37.5	49059.0	480.9
1951	383.4	39.6	53181.0	500.6
1952	395.1	38.3	54396.0	518.1
1953	412.8	40.7	55364.0	536.3
1954	407.0	39.6	53585.0	553.5
1955	438.0	43.9	54864.0	572.7
1956	446.1	47.3	56193.0	595.5
1957	452.5	47.4	56435.0	615.9
1958	447.3	41.6	54845.0	630.3
1959	475.9	44.1	56202.0	645.2
1960	487.7	47.1	57098.0	663.5
1961	497.2	45.5	56938.0	680.1
1962	529.8	49.7	58463.0	699.9
1963	551.0	51.9	59333.0	720.0
1964	581.1	57.8	60642.0	745.1
1965	617.8	66.3	62856.0	778.1
1966	658.1	74.1	66114.0	817.8
1967	675.2	73.2	67913.0	855.3
1968	706.6	75.6	69832.0	894.5
1969	725.6	80.1	71803.0	936.6
1970	722.5	77.2	71587.0	973.4
1971	746.3	76.7	71170.0	1006.8
1972	792.5	83.7	72794.0	1045.1
1973	839.2	94.4	75948.0	1090.2

TABLE 52. Savings, Depreciation, GNP, Capital, and Labor Indices

Year	Savings	Depreciation	Rate	GNP	Capital	Labor
1929	13.0157	14.9	3.4619	0.2728	0.4347	0.5044
1930	11.8256	15.6	3.5515	0.2459	0.4436	0.4745
1931	8.3284	15.4	3.4869	0.2269	0.4461	0.4312
1932	5.6865	16.0	3.6605	0.1932	0.4415	0.3824
1933	5.3710	16.7	3.8960	0.1896	0.4329	0.3889
1934	5.9624	16.2	3.8516	0.2068	0.4248	0.4342
1935	6.7847	16.3	3.9306	0.2271	0.4188	0.4533
1936	8.1865	16.3	3.9558	0.2586	0.4162	0.4976
1937	9.2520	16.7	4.0450	0.2723	0.4170	0.5151
1938	7.1021	17.0	4.1237	0.2585	0.4164	0.4910
1939	7.3066	17.9	4.3733	0.2806	0.4134	0.5106
1940	8.3187	18.4	4.5070	0.3044	0.4123	0.5387
1941	8.4187	18.6	4.5333	0.3533	0.4144	0.6045
1942	4.1975	16.7	4.0732	0.3990	0.4141	0.6751
1943	2.9665	16.9	4.1785	0.4517	0.4085	0.7617
1944	3.7088	16.9	4.2329	0.4841	0.4032	0.7779
1945	5.5743	17.3	4.3386	0.4759	0.4027	0.7537
1946	9.6609	19.4	4.7854	0.4189	0.4095	0.6671
1947	11.6812	19.2	4.5791	0.4152	0.4235	0.6675
1948	11.7393	18.6	4.2514	0.4337	0.4419	0.6827
1949	10.6449	19.9	4.3785	0.4343	0.4590	0.6645
1950	10.5545	18.4	3.9037	0.4761	0.4761	0.6893
1951	10.3286	19.9	4.0550	0.5137	0.4957	0.7472
1952	9.6937	20.8	4.0836	0.5294	0.5144	0.7643
1953	9.8595	22.5	4.2678	0.5531	0.5325	0.7779
1954	9.7297	22.4	4.1108	0.5454	0.5503	0.7529
1955	10.0228	24.7	4.3864	0.5869	0.5687	0.7709
1956	10.6030	24.5	4.1945	0.5977	0.5899	0.7896
1957	10.4751	27.0	4.4577	0.6063	0.6118	0.7930
1958	9.3002	27.2	4.3653	0.5994	0.6293	0.7706
1959	9.2666	29.2	4.5786	0.6377	0.6441	0.7897
1960	9.6576	28.8	4.4013	0.6535	0.6609	0.8023
1961	9.1512	28.9	4.3019	0.6662	0.6785	0.8000
1962	9.3809	29.9	4.3333	0.7099	0.6969	0.8215
1963	9.4192	31.8	4.4792	0.7383	0.7170	0.8337
1964	9.9466	32.7	4.4639	0.7786	0.7399	0.8521
1965	10.7316	33.3	4.3724	0.8278	0.7692	0.8832
1966	11.2597	34.4	4.3111	0.8818	0.8059	0.9290
1967	10.8412	35.7	4.2675	0.9047	0.8449	0.9542
1968	10.6991	36.4	4.1605	0.9468	0.8836	0.9812
1969	11.0391	38.0	4.1505	0.9723	0.9247	1.0089
1970	10.6851	40.4	4.2304	0.9681	0.9645	1.0059
1971	10.2774	43.3	4.3733	1.0000	1.0000	1.0000
1972	10.5615	45.4	4.4252	1.0619	1.0362	1.0228
1973	11.2488	49.3	4.6176	1.1245	1.0783	1.0671

capital. After World War II, the savings rate increased and capital grew at the same rate as the GNP. The depreciation rate has been remarkably constant over the whole period. (The maxima are 4.8 percent in 1946 and 4.6 percent in 1973. The



minima are 3.5 percent in 1929 and 3.9 percent in 1950.) The savings rate has been more volatile, but has been nearly constant in the postwar period. (The maximum was 11.7 percent in 1948 while the minimum was 9.2 percent in 1961.)

There are two available methods for estimating the parameters a, b, ρ, and r. The first is a two-stage process in which b and ρ are estimated using traditional least-squares procedures and then these values, in turn, are employed to obtain estimates for a and r. The second method is to estimate all four parameters simultaneously using nonlinear least-squares techniques. Both methods are employed in this analysis.

The two-stage estimation process begins by noting that labor's wage rate, w, and capital's rental rate, r, are equal to F_L and F_K, respectively, so that

$$\frac{wL}{rK} = \frac{F_L L}{F_K K} = \left(\frac{b}{1-b}\right)\left(\frac{K}{L}\right)^{\rho} \qquad (10)$$

from equation (8). Equation (10) may also be written as

$$\ln\left(\frac{wL}{rK}\right) = \ln\left(\frac{b}{1-b}\right) + \rho \ln\left(\frac{K}{L}\right) \qquad (11)$$

which is a form that is easily estimated using standard least-squares techniques.

By defining wL as compensation to employees and attributing the remainder of the GNP as returns to capital, rK is equal to GNP $- wL$. Table 1.10 of the July issue of the "SCB" may be used to obtain the necessary data for equation (11) over the period 1950-1973.[136]

Employing traditional least-squares techniques yields $b = 0.652$ and $\rho = -0.484$. Substituting these values into equation (8), one obtains

$$\ln \frac{Y}{(0.652L^{-0.484} + 0.348K^{-0.484})^{-2.066}} = \ln a + rt$$

A second least-squares estimation can be carried out to obtain values for a and r which are $a = 0.600$ and $r = 0.0119$.

Having estimated values for a, b, ρ, and r, using data from the period 1950-1973, the actual GNP over the period 1929-1949 can be compared to predicted values using the estimated parameters. This yields a maximum error of

−36 percent in 1933, while the maximum error for the period 1950-1973 was +6.3 percent in 1966.

When nonlinear least-squares techniques are employed to estimate a, b, ρ, and r simultaneously, their values change to $a = 0.233$, $b = 0.960$, $\rho = -1.256$, and $r = 0.0180$ (see Table 53). These estimates increase the accuracy of the model. The maximum error changes from −36 percent to −12.7 percent. The most-affected variables are b and ρ, whose values change dramatically.

Examination of Tables 53 and 54 shows that the predicted GNP is too high during periods of slow economic growth and too low during periods of rapid economic growth. A plausible explanation is that during a recession there will be excess capital stock, and employers will be reluctant to reduce their work forces. If the method of nonlinear least squares is used to determine the parameters with positive errors penalized by a factor of 10, the optimum solution is shown in Table 55. For this upper-bound model, the only period where the historic GNP is greater than the prediction is in the year 1929 and during the Vietnam War (1965-1966). However, the economy was close to full capacity during World War II, from 1963 to 1968, and for 1972-1973.

A "test" can be conducted to examine the model's validity. The parameters a, b, ρ, and r are estimated from 1929-1950 data and these parameters are then used to predict values for GNP over the period 1951-1973. There would seem to be no a priori reason to suspect that an especially good fit would result since the two periods are quite different. The period from 1929 to 1950 witnessed the great depression and World War II, in which there were large fluctuations in the labor force but there was an essentially constant capital stock. The period from 1951 to 1973 was characterized by smooth growth in labor force, capital stock, and GNP.

The predictions for the period 1951-1973 are compared to the actual data in Table 56. The maximum error is 6.8 percent in 1965 and the parameters are nearly the same as the parameters in Table 53. (ρ changes from −1.256 to −1.235, and r changes from 0.0180 to 0.0166.) Similarly, the model is estimated for the period 1950-1973 (see Table 57). The parameters in Table 57 are almost identical to the parameters in Table 53. These results are encouraging.

This model is finally used to evaluate the sources of historic economic growth. Since the production function is homogeneous of degree 1,

$$\frac{\Delta \text{GNP}}{\text{GNP}} = \alpha \frac{\Delta L}{L} + (1 - \alpha) \frac{\Delta K}{K} \tag{12}$$

where α is the output elasticity of labor, $F_L L/Y$, which for the CES production function is

$$\alpha = \frac{F_L L}{Y} = \frac{bL^\rho}{bL^\rho + (1 - b)K^\rho} \tag{13}$$

The output elasticity changes with time as L and K change. For example, for the parameter values given in Table 53, α is equal to 0.95 in 1929, decreases to 0.91 in 1944, and increases to 0.96 in 1971. For the parameter values given in Table 54, α is equal to 0.77 in 1929, 0.73 in 1944, and 0.78 in 1971. Thus the optimum fit suggests that, except for the contribution of technological change, growth in labor force is responsible for more than 90 percent of the growth in GNP. If a value of ρ similar to the one fitted to equation (8) is used, growth in labor force is responsible for 75 percent of the GNP's growth. It must be concluded from this analysis that GNP growth is due primarily to two factors, technological change and labor.

Only a determination of the value for the parameter c remains, and this determination can be accomplished using equation (9) and Table 50. During the period 1948-1971, the average factor share for energy is found to be 0.0132. For the base year, 1971, all variables are normalized to unity so that $L = K = E = 1$.

TABLE 53. 1929–1973, $\rho = -1.26$

Year	Historic GNP	Predicted GNP	% error
1929	0.2728	0.2382	12.7
1930	0.2459	0.2290	6.9
1931	0.2269	0.2128	6.2
1932	0.1932	0.1929	0.2
1933	0.1896	0.1995	–5.2
1934	0.2068	0.2257	–9.2
1935	0.2271	0.2393	–5.4
1936	0.2586	0.2663	–3.0
1937	0.2723	0.2802	–2.9
1938	0.2585	0.2726	–5.5
1939	0.2806	0.2880	–2.6
1940	0.3044	0.3084	–1.3
1941	0.3533	0.3502	0.9
1942	0.3990	0.3952	1.0
1943	0.4517	0.4494	0.5
1944	0.4841	0.4660	3.7
1945	0.4759	0.4609	3.2
1946	0.4189	0.4199	–0.2
1947	0.4152	0.4287	–3.2
1948	0.4337	0.4471	–3.1
1949	0.4343	0.4449	–2.4
1950	0.4761	0.4699	1.3
1951	0.5137	0.5174	–0.7
1952	0.5294	0.5393	–1.9
1953	0.5531	0.5595	–1.2
1954	0.5454	0.5536	–1.5
1955	0.5869	0.5774	1.6
1956	0.5977	0.6026	–0.8
1957	0.6063	0.6173	–1.8
1958	0.5994	0.6127	–2.2
1959	0.6377	0.6392	–0.2
1960	0.6535	0.6615	–1.2
1961	0.6662	0.6727	–1.0
1962	0.7099	0.7033	0.9
1963	0.7383	0.7272	1.5
1964	0.7786	0.7571	2.8
1965	0.8278	0.7992	3.5
1966	0.8818	0.8558	3.0
1967	0.9047	0.8959	1.0
1968	0.9468	0.9387	0.9
1969	0.9723	0.9836	–1.2
1970	0.9681	1.0004	–3.3
1971	1.0000	1.0144	–1.4
1972	1.0619	1.0570	0.5
1973	1.1245	1.1227	0.2

Parameters: $a = 1.0144, r = 0.018047654,$
$b = 0.9605, \rho = -1.2560447$

TABLE 54. 1929–1973, $\rho = 0.4$

Year	Historic GNP	Predicted GNP	% error
1929	0.2728	0.2563	6.0
1930	0.2459	0.2497	–1.5
1931	0.2269	0.2359	–4.0
1932	0.1932	0.2177	–12.6
1933	0.1896	0.2232	–17.7
1934	0.2068	0.2460	–19.0
1935	0.2271	0.2576	–13.4
1936	0.2586	0.2806	–8.5
1937	0.2723	0.2929	–7.6
1938	0.2585	0.2868	–11.0
1939	0.2806	0.2997	–6.8
1940	0.3044	0.3169	–4.1
1941	0.3533	0.3516	0.5
1942	0.3990	0.3878	2.8
1943	0.4517	0.4289	5.0
1944	0.4841	0.4410	8.9
1945	0.4759	0.4377	8.0
1946	0.4189	0.4084	2.5
1947	0.4152	0.4188	–0.8
1948	0.4337	0.4374	–0.8
1949	0.4343	0.4397	–1.3
1950	0.4761	0.4635	2.7
1951	0.5137	0.5053	1.6
1952	0.5294	0.5271	0.4
1953	0.5531	0.5473	1.0
1954	0.5454	0.5471	–0.3
1955	0.5869	0.5705	2.8
1956	0.5977	0.5955	0.4
1957	0.6063	0.6124	–1.0
1958	0.5994	0.6131	–2.3
1959	0.6377	0.6381	–0.1
1960	0.6535	0.6602	–1.0
1961	0.6662	0.6736	–1.1
1962	0.7099	0.7027	1.0
1963	0.7383	0.7270	1.5
1964	0.7786	0.7566	2.8
1965	0.8278	0.7973	3.7
1966	0.8818	0.8513	3.5
1967	0.9047	0.8927	1.3
1968	0.9468	0.9364	1.1
1969	0.9723	0.9822	–1.0
1970	0.9681	1.0053	–3.8
1971	1.0000	1.0251	–2.5
1972	1.0619	1.0684	–0.6
1973	1.1245	1.1319	–0.7

Parameters: $a = 1.025, r = 0.015893869,$
$b = 0.7755, \rho = -0.4$

TABLE 55. 1929–1973, Full Capacity

Year	Historic GNP	Predicted GNP	% error
1929	0.2728	0.2668	2.2
1930	0.2459	0.2566	–4.4
1931	0.2269	0.2386	–5.2
1932	0.1932	0.2164	–12.0
1933	0.1896	0.2231	–17.7
1934	0.2068	0.2509	–21.4
1935	0.2271	0.2650	–16.7
1936	0.2586	0.2932	–13.4
1937	0.2723	0.3075	–12.9
1938	0.2585	0.2989	–15.6
1939	0.2806	0.3146	–12.1
1940	0.3044	0.3354	–10.2
1941	0.3533	0.3783	–7.1
1942	0.3990	0.4240	–6.3
1943	0.4517	0.4780	–5.8
1944	0.4841	0.4936	–2.0
1945	0.4759	0.4879	–2.5
1946	0.4189	0.4463	–6.6
1947	0.4152	0.4554	–9.7
1948	0.4337	0.4742	–9.3
1949	0.4343	0.4721	–8.7
1950	0.4761	0.4975	–4.5
1951	0.5137	0.5455	–6.2
1952	0.5294	0.5677	–7.2
1953	0.5531	0.5880	–6.3
1954	0.5454	0.5820	–6.7
1955	0.5869	0.6059	–3.2
1956	0.5977	0.6311	–5.6
1957	0.6063	0.6458	–6.5
1958	0.5994	0.6408	–6.9
1959	0.6377	0.6670	–4.6
1960	0.6535	0.6889	–5.4
1961	0.6662	0.6996	–5.0
1962	0.7099	0.7298	–2.8
1963	0.7383	0.7532	–2.0
1964	0.7786	0.7826	–0.5
1965	0.8278	0.8243	0.4
1966	0.8818	0.8805	0.2
1967	0.9047	0.9203	–1.7
1968	0.9468	0.9625	–1.7
1969	0.9723	1.0068	–3.5
1970	0.9681	1.0230	–5.7
1971	1.0000	1.0362	–3.6
1972	1.0619	1.0776	–1.5
1973	1.1245	1.1420	–1.6

Parameters: $a = 1.0358, r = 0.015743994,$
$b = 0.9321, \rho = 1.2034883$

TABLE 56. 1929–1973, Historic and Predicted

Year	Historic GNP	Predicted GNP	% error
1929	0.2728	0.2426	11.1
1930	0.2459	0.2328	5.3
1931	0.2269	0.2159	4.8
1932	0.1932	0.1953	–1.1
1933	0.1896	0.2018	–6.4
1934	0.2068	0.2280	–10.3
1935	0.2271	0.2415	–6.3
1936	0.2586	0.2685	–3.8
1937	0.2723	0.2822	–3.6
1938	0.2585	0.2740	–6.0
1939	0.2806	0.2891	–3.0
1940	0.3044	0.3093	–1.6
1941	0.3533	0.3509	0.7
1942	0.3990	0.3959	0.8
1943	0.4517	0.4501	0.4
1944	0.4841	0.4662	3.7
1945	0.4759	0.4603	3.3
1946	0.4189	0.4181	0.2
1947	0.4152	0.4261	–2.6
1948	0.4337	0.4437	–2.3
1949	0.4343	0.4406	–1.5
1950	0.4761	0.4647	2.4
1951	0.5137	0.5111	0.5
1952	0.5294	0.5319	–0.5
1953	0.5531	0.5509	0.4
1954	0.5454	0.5440	0.2
1955	0.5869	0.5666	3.5
1956	0.5977	0.5904	1.2
1957	0.6063	0.6037	0.4
1958	0.5994	0.5981	0.2
1959	0.6377	0.6231	2.3
1960	0.6535	0.6439	1.5
1961	0.6662	0.6536	1.9
1962	0.7099	0.6824	3.9
1963	0.7383	0.7045	4.6
1964	0.7786	0.7324	5.9
1965	0.8278	0.7719	6.8
1966	0.8818	0.8254	6.4
1967	0.9047	0.8627	4.6
1968	0.9468	0.9025	4.7
1969	0.9723	0.9441	2.9
1970	0.9681	0.9587	1.0
1971	1.0000	0.9705	3.0
1972	1.0619	1.0096	4.9
1973	1.1245	1.0709	4.8

Parameters: $a = 0.9703, r = 0.016575427,$
$b = 0.9652, \rho = -1.2352493$

TABLE 57. 1973–1929

Year	Historic GNP	Predicted GNP	% error
1973	1.1245	1.1238	0.1
1972	1.0619	1.0578	0.4
1971	1.0000	1.0151	–1.5
1970	0.9681	1.0011	–3.4
1969	0.9723	0.9843	–1.2
1968	0.9468	0.9393	0.8
1967	0.9047	0.8964	0.9
1966	0.8818	0.8562	2.9
1965	0.8278	0.7994	3.4
1964	0.7786	0.7572	2.8
1963	0.7383	0.7272	1.5
1962	0.7099	0.7032	0.9
1961	0.6662	0.6724	–0.9
1960	0.6535	0.6613	–1.2
1959	0.6377	0.6389	–0.2
1958	0.5994	0.6122	–2.2
1957	0.6063	0.6170	–1.8
1956	0.5977	0.6023	–0.8
1955	0.5869	0.5771	1.7
1954	0.5454	0.5532	–1.4
1953	0.5531	0.5593	–1.1
1952	0.5294	0.5391	–1.8
1951	0.5137	0.5171	–0.7
1950	0.4761	0.4694	1.4
1949	0.4343	0.4443	–2.3
1948	0.4337	0.4467	–3.0
1947	0.4152	0.4283	–3.1
1946	0.4189	0.4195	–0.2
1945	0.4759	0.4610	3.1
1944	0.4841	0.4661	3.7
1943	0.4517	0.4493	0.5
1942	0.3990	0.3946	1.1
1941	0.3533	0.3492	1.2
1940	0.3044	0.3073	–0.9
1939	0.2806	0.2868	–2.2
1938	0.2585	0.2713	–5.0
1937	0.2723	0.2790	–2.5
1936	0.2586	0.2650	–2.5
1935	0.2271	0.2380	–4.8
1934	0.2068	0.2243	–8.5
1933	0.1896	0.1981	–4.5
1932	0.1932	0.1915	0.9
1931	0.2269	0.2113	6.8
1930	0.2459	0.2275	7.5
1929	0.2728	0.2367	13.2

Parameters: $a = 1.0140$, $r = 0.018233101$,
$b = 0.9653$, $\rho = -1.2561550$

Substitution of these values into equation (9) yields $c = 0.0134$.

Forecasting energy's impact on future GNP requires not only values for the parameters a, b, r, and ρ but also projections for the values L, K, and E. The variable K is obtained using the identity

$$\Delta K = sY - \delta K$$

where s is the savings rate, δ is the rate of depreciation—both assumed to be constant—and ΔK is the increase in the capital stock from one period to the next.

The savings rate is defined as the quotient of gross investment and GNP, while the growth in capital stock during a year is gross investment minus depreciation. Table 52 contains computed values for these parameters for the period 1929-1973. For these projections, the depreciation rate is fixed at 4.77 percent and the savings rate at 10.55 percent. The exogenous estimates for the labor force and energy supply are developed in earlier parts of this report. Other estimates of future values could also be used.

The value of c is determined for each year and becomes a parameter. The energy supply, labor force, and capital stock then interact to determine the exact price for that period. In essence, fixing the value of c and the supply of energy determines the supply side of the model, while the scarcity of energy relative to labor and capital determines the demand side. It is assumed that energy is always paid the value of its marginal product, the resulting price of energy is then merely $\partial F/\partial Z$. The estimates for future energy prices were used to determine the value of the parameter c.

Summary

The low-energy scenario projects a rise in the real price of energy over the period 1975-2010. The low energy prices are used in conjunction with both high and low projections for energy and labor force growth rates. Both low-price scenarios use values of c which correspond to an average rate of growth of 2.3 percent over the period. This more rapid rate of increase errs on the high-price side, and as such is expected to cause a small additional burden on society. Table 49 (page 000) reveals that prices have a minimal impact on GNP.

Another set of prices, the high energy prices, are added to form a high price scenario. Again, both high and low labor force – energy-demand cases are paired with this set of prices. This set of energy prices increases as rapidly as oil prices (which are projected to rise at the rate of 4.3 percent from 1975 to 1985) while U.S. prices "catch up" to world oil prices, and thereafter increase at a rate of 3 percent annually. The high prices actually used in this paper rise at a rate of 4.3 percent between 1975 and 1985 but rise at the rate of 3.3 percent thereafter, a faster rate than predicted earlier.

The results of the four cases—high energy and labor force growth with high prices, high energy and labor force growth with low prices, low energy and labor force growth with high prices, and low energy and labor force growth with low prices—are summarized in Table 58, and a close examination is very illuminating. Some major conclusions are worth special discussion. *Prices seem to have only minor impact on GNP.* High prices differ from low prices by 312 percent by the year 2010; yet in neither case does this reduce the GNP by as much as 1.5 percent! Prices seem to have a similar impotent impact on labor productivity, which continues to increase at a rate of approximately 1.85 percent in all cases. In fact, labor's average productivity decreases by only 1.4 percent as a result of high energy prices, and not at all as a result of smaller labor forces and energy supplies.

Energy's share of the GNP rises from approximately 1.32 (the average for 1948-1971) to 1.73 percent in 2010 when prices are low, an increase of 31 percent. When high prices are used, energy's share of the GNP jumps to 3.1 percent in 2010, an increase of 135 percent. It is interesting to note that the GNP predictions for 2010 are the same within 5 percent. This result also holds with respect to rates of economic growth, which range from 2.66 to 2.78 percent.

The projections of labor productivity seem to be below those used in earlier parts of the study. As a consequence, it seems that earlier predictions of the GNP are somewhat generous. This also implies that earlier parts of this paper may actually have overestimated the demand for energy. Decreased energy supplies and increased energy prices seem to have only a minor impact on economic growth if they are not sudden and unexpected.

The one-sector model seems to suggest that the results of earlier parts of this paper are reasonable, but, if anything, energy demands in the future may be overstated.

APPENDIX B: ELASTICITIES

In this appendix we explain in detail how the price elasticities in the fourth section were obtained. There are basically two methods for obtaining price elasticities: either from a historic analysis of prices and demands, taking into account other factors that may have influenced these prices and demands, or from a cross-sectional analysis comparing prices and demands from different regions in the same time period. In our analysis we have developed a base scenario (without energy conservation or price increases) as a reference case in order to perform cross-sectional analysis by comparing both our high and low scenarios with the reference case for the year 2010. We obtain all of our elasticities by comparison with this base case.

The general elasticity equation we have used is

$$\begin{bmatrix} \hat{q}_1 \\ \hat{q}_2 \\ \cdot \\ \cdot \\ \cdot \\ \hat{q}_n \end{bmatrix} = \left[\begin{array}{cccc|c} \epsilon_{11} & \epsilon_{12} & \cdots & \epsilon_{1n} & \eta_1 \\ \epsilon_{21} & \epsilon_{22} & \cdots & \epsilon_{2n} & \eta_2 \\ \cdot & \cdot & & & \cdot \\ \cdot & \cdot & & & \cdot \\ \cdot & \cdot & & & \cdot \\ \epsilon_{n1} & \epsilon_{n2} & \cdots & \epsilon_{nn} & \eta_n \end{array}\right] \begin{bmatrix} \hat{p}_1 \\ \hat{p}_2 \\ \cdot \\ \cdot \\ \cdot \\ \overline{\hat{y}} \end{bmatrix} \quad (1)$$

where $\hat{q}_i = \frac{\Delta q}{q}$ = percentage change in per capita quantity

$\hat{p}_i = \frac{\Delta p}{p}$ = percentage change in prices

$\hat{y} = \frac{\Delta y}{y}$ = percentage change in per capita income

ϵ_{ii} = own-elasticity = percentage change in quantity demanded of the "ith" fuel type divided by the percentage change in price of the "jth" fuel type

$\epsilon_{ij}(i \neq j)$ = cross-elasticities = percentage change in quantity demanded of the "ith" fuel type divided by the percentage change in price of the "jth" fuel type

η_i = income-elasticity = percentage change in quantity demanded of the "ith" fuel type divided by the percentage change in per capita income

where the energy carriers of electricity, gas, oil, and coal are considered in our study. We use equation (1) in calculating own-elasticities for the residential, transportation, and commercial sectors for both our low and high scenarios. For the industrial sector, in both scenarios, we have calculated an aggregate energy price elasticity for that sector, so that equation (1) reduces to

$$[\hat{q}] = [\epsilon \mid \eta] \begin{bmatrix} \hat{p} \\ \hline \hat{y} \end{bmatrix} \quad (2)$$

where η refers to the output elasticities of demand.

In order to solve for own-elasticities, we computed the quantities of $\hat{q}_i$, $\hat{p}_{12}$, and $\hat{y}$, and we assumed specific values for the cross- and income-elasticities, $\epsilon_{ij}(i \neq j)$ and η_i, respectively. For the commercial and residential sectors, we have used cross-elasticities developed by Chern at ORNL, which are shown in Table 58.

TABLE 58. Cross-Elasticities

	Residential and commercial			
	Elect.	**Gas**	**Oil**	**Coal**
Electricity	–	0.02*	0.29	0.0
Gas	0.92	–	0.51	0.0
Oil	0.22	0.81	–	0.0
Coal	0.0	0.0	0.0	–

*In order to make gas and electricity substitutes rather than complements, we replaced Chern's estimates with our own.

For the transportation sector we have assumed the cross-elasticities are all equal to zero, thereby implying no substitution between petroleum and other fuels. Income elasticities for all sectors have been obtained from FEA's PIES model (see Table 59).

TABLE 59. Income Elasticities

	Elect.	Gas	Oil	Coal
Residential	1.1	2.4	1.0	0.0
Commercial	1.6	2.4	1.0	0.0
Industrial	1.0	1.0	1.0	1.0
Transportation	0.0	0.0	1.0	0.0

By substitution of values of $\hat{q}_i$, $\hat{p}_i$, $\hat{y}$, $\epsilon_{ij}(i{\neq}j)$, and η_i into equation (1) or (2), it is just a matter of simple algebra to solve for the own-elasticities ϵ_{ii}.

As an example, consider the commercial sector of the low scenario. The quantity of electricity demanded is 10.3 compared with 21.3 for the base case. Taking into account a population of 250 million in the low scenario in comparison with 264 million for the base case, we compute $\hat{q}_1 = 0.648$. Similarly, we compute the other $\hat{q}_i$, the $\hat{p}_i$, and the $\hat{y}$. By substituting these values into equation (1), along with the cross-elasticities of Chern and FEA's income elasticities, we find

$$\begin{bmatrix} 0.648 \\ -0.054 \\ 0.0 \\ 0.0 \end{bmatrix} = \left[\begin{array}{cccc|c} \epsilon_{11} & 0.02 & 0.29 & 0.0 & 1.6 \\ 0.92 & \epsilon_{22} & 0.51 & 0.0 & 2.4 \\ 0.22 & 0.81 & \epsilon_{33} & 0.0 & 1.0 \\ 0.0 & 0.0 & 0.0 & \epsilon_{44} & 0.0 \end{array}\right] \left[\begin{array}{c} -0.667 \\ -0.667 \\ -0.667 \\ -0.667 \\ \hline -0.038 \end{array}\right]$$

Solving for own-elasticities, we obtain

$$\begin{bmatrix} \epsilon_{11} \\ \epsilon_{22} \\ \epsilon_{33} \\ \epsilon_{44} \end{bmatrix} = \frac{-1}{0.667} \left\{ \left(\begin{bmatrix} 0.648 \\ -0.054 \\ 0.0 \\ 0.0 \end{bmatrix} \left[\begin{array}{cccc|c} 0 & 0.02 & 0.29 & 0 & 1.6 \\ 0.92 & 0 & 0.51 & 0 & 2.4 \\ 0.22 & 0.81 & 0 & 0 & 1.0 \\ 0 & 0 & 0 & 0 & 0.0 \end{array}\right] \right) \left[\begin{array}{c} -0.667 \\ -0.667 \\ -0.667 \\ -0.667 \\ \hline -0.038 \end{array}\right] \right\}$$

$$= \begin{bmatrix} -1.190 \\ -1.213 \\ -0.973 \\ 0.0 \end{bmatrix}$$

in agreement with Table 47 in the last section of this report.

As another example, consider the industrial sector for the low scenario. In this sector we computed an aggregate energy price elasticity and we used equation (2). The total energy demanded in the low scenario is 61.3, including four units of geothermal, compared with a total energy of 89.9 for the base case. Taking into account population, we obtain $\hat{q} = 0.326$. In order to obtain $\hat{p}$, we calculated average prices with respect to electricity, oil, gas, and coal by summing their prices weighted by their respective proportions. The average price of fuel for the industrial sector for the low scenario is $3.60, compared with $1.57 for the base scenario. Therefore, $\hat{p}$ is calculated to be −0.785. η is assumed to be 1.0, which is consistent with the FEA values, and again $\hat{y} = 0.038$. Substituting these values in equation (2), we obtain

$$0.326 = \epsilon(-0.785) + 0.038$$

$$-0.367 = \epsilon$$

in agreement with Table 47. The other calculations are similarly done.

APPENDIX C: REFERENCES

1. Edison Electric Institute, "Economic Growth in the Future," Executive Summary, EEI Publication No. 75-32, p. 10, New York (June 1975).
2. E. F. Denison, *Accounting for United States Economic Growth, 1929-1969,* Brookings Institution, Washington, D. C. (1974).
3. See reference 1.
4. U. S. Department of Commerce, Bureau of the Census, "Census of Population: 1970, Vol. I, U. S. Summary," U. S. Government Printing Office, Washington, D. C. (1973).
5. U. S. Department of Commerce, Bureau of the Census, "Population Estimates and Projections," Series P-25, No. 541, p. 1, U. S. Government Printing Office, Washington, D. C. (1975).
6. C. F. Westoff, "The Decline of Unplanned Births in the United States," *Science,* Vol. 191, No. 4222, p. 38 (January 9, 1976). Also, interview with Robert T. Dennis, Executive Director, Zero Population Growth, Inc., Washington, D. C.
7. D. W. Jorgenson and H. S. Houthakker, "Energy Resources and Economic Growth" (draft), final report to the Energy Policy Project, p. II-12, Ford Foundation, Data Resources, Inc., Lexington, Mass. (1973).
8. "Economic Report of the President," pp. 114-116, Council of Economic Advisers, U. S. Government Printing Office, Washington, D. C. (1976).
9. See reference 2.
10. L. Munday, Vice-President of Research and Development, American College Testing Program, Iowa City, Ia., as given in a February 1976 seminar at George Washington University, Washington, D. C.

11. See reference 8, pp. 41-47.
12. P. W. McCracken in a statement before the U. S. House of Representatives Committee on Ways and Means (January 29, 1975). Basic data are from the Departments of Commerce and Labor.
13. B. Bosworth, J. S. Duesenberry, and A. S. Carron, *Capital Needs in the Seventies,* Brookings Institution, Washington, D. C. (1975).
14. New York Stock Exchange, "The Capital Needs and Savings Potential of the U. S. Economy: Projections Through 1985," New York (September 1974).
15. Organization for Economic Cooperation and Development, *National Accounts of OECD Countries, 1960-71,* OECD, Paris (1973).
16. U. S. Department of Commerce, Bureau of Economic Analysis, "A Study of Fixed Capital Requirements of the U. S. Business Economy, 1971-1980," National Technical Information Service Report No. PB 248 690, Washington, D. C. (February 1976).
17. A. Carter, "Energy, Environment and Economic Growth," *Bell Journal of Economics and Management Science,* Vol. 5, No. 2, p. 578 (Autumn 1974).
18. A. V. Kneese and C. L. Schultz, *Pollution, Prices and Public Policy,* Brookings Institution, Washington, D. C. (1975).
19. National Commission on Water Quality, "Issues and Findings," pp. I-15 through I-19, Washington, D. C. (November 1975).
20. F. Segel, Department of Commerce, Bureau of Economic Analysis, supplied the following figures: total fixed investment in 1974 was $111 billion; $3.3 billion of this was capital outlays for air pollution control, $1.8 billion for water, and $400 million for solid waste.
21. Informal communication with U. S. Department of Commerce.
22. Joint Economic Committee of the Congress, "Annual Report" (draft), U. S. Government Printing Office, Washington, D. C. (March 1976).
23. G. Parsky, "Capital Investment and the Need for a New Policy," WS-524, pp. 5-7, Department of the Treasury, Washington, D. C. (December 1975).
24. Federal Energy Administration, "Project Independence Report," p. 282, U. S. Government Printing Office, Washington, D. C. (November 1974).
25. National Petroleum Council, *U. S. Energy Outlook,* Washington, D. C. (December 1972). Average of four supply cases was $380 billion.
26. National Academy of Engineering Task Force on Energy, *U. S. Energy Prospects: An Engineering Viewpoint,* Washington, D. C. (1974).
27. Costs from an Arthur D. Little, Inc. study were quoted by Secretary of the Treasury William E. Simon (May 7, 1975) in his testimony before the Finance Committee of the U. S. Senate. See Treasury Department release WS-294.
28. See reference 27.
29. Energy Research and Development Administration, Division of International Security Affairs, "New Energy Technology Coefficients and Dynamic Energy Models," ERDA-3(MTR-6810), Vol. I, p. 3, Table III, Mitre Corporation Research, Washington, D. C. (January 1975).
30. U. S. Department of Labor, Bureau of Labor Statistics, "Structure of the U. S. Economy, 1980-85," *BLS Bulletin No. 1831,* Washington, D. C. (March 1975).
31. U. S. Department of Labor, Bureau of Labor Statistics, "The U. S. Economy in 1985," *BLS Bulletin No. 1809,* Washington, D. C. (1974).
32. See reference 31.
33. See reference 8, p. 202.
34. W. G. Dupree, Jr., and J. S. Corsentino, "United States Energy Through the Year 2000" (revised), p. 6, Bureau of Mines, U. S. Department of the Interior, Washington, D. C. (1975).
35. J. D. Parent, "Some Comments on Energy Consumption and GNP," unpublished paper prepared at the Institute for Gas Technology, Chicago (May 1974).
36. See reference 34 (numbers changed from 1972 dollars to 1975 dollars).
37. See reference 8, pp. 86-88.
38. "The Nation's Energy Future," report to the President of the United States, submitted by Dixy Lee Ray, WASH-1281, U. S. Government Printing Office, Washington, D. C. (December 1, 1973).
39. "Creating Energy Choices for the Future," Vol. 1: The Plan, ERDA-48, U. S. Government Printing Office, Washington, D. C. (June 30, 1975).
40. Ford Foundation Energy Policy Project, *A Time to Choose: America's Energy Future,* Ballinger Publishing Company, Cambridge, Mass. (1974).

41. H. C. Wolfe, series editor, *Efficient Use of Energy,* AIP Conference Proceedings No. 25, American Institute of Physics, New York (August 1975).
42. "Potential for Energy Conservation in the United States," Part I: 1974-1978 (September 10, 1974), Part II: 1979-1985 (August 6, 1975), National Petroleum Council, Washington, D. C.
43. J. R. Burroughs, The Dow Chemical Company, Midland, Mich., "The Technical Aspects of the Conservation of Energy for Industrial Processes," report to the Federal Power Commission National Power Survey, Technical Advisory Committee on Conservation of Energy, Position Paper No. 17 (May 1, 1973).
44. R. S. Carlsmith, Principal Investigator, "Energy Conservation Studies Progress Report—December 31, 1974," Report No. ORNL-NSF-EP-84, Oak Ridge National Laboratory, Oak Ridge, Tenn. (March 1975).
45. E. Hirst, "Energy Use for Food in the United States," Report No. ORNL-NSF-EP-57, Oak Ridge National Laboratory, Oak Ridge, Tenn. (October 1973).
46. T. D. Anderson et al., "An Assessment of Industrial Energy Options Based on Coal and Nuclear Systems," Report No. ORNL-4995, Oak Ridge National Laboratory, Oak Ridge, Tenn. (July 1975).
47. "Energy Conservation in the Manufacturing Sector, 1954-1990," sponsored by the Council on Environmental Quality, contained in the Federal Energy Administration's Project Independence Blueprint Final Task Force Report No. 4118-00048, U. S. Government Printing Office, Washington, D. C. (1974).
48. R. L. Goen et al., "Comparison Between West Germany and the United States," Stanford Research Institute Report No. SRI EGU 3519. Federal Energy Administration Report No. FEA-D-75-590. National Technical Information Service Report No. PB-245 652.
49. See reference 40, pp. 45-79.
50. D. Hayes, "Energy: The Case for Conservation," Worldwatch Institute Paper No. 4, Washington, D. C. (January 1976).
51. B. Hannon, "Energy Conservation and the Future," *Science,* Vol. 189, No. 4197, p. 95 (July 11, 1975).
52. "Making Everyone Unhappy," *Time,* p. 34 (January 5, 1976).
53. Energy Policy and Conservation Act, Public Law 94-163, 94th Congress, U. S. Government Printing Office, Washington, D. C. (December 22, 1975).
54. See reference 53.
55. Federal Energy Administration, "National Energy Outlook," Report No. FEA-N-75/713, p. 15, U. S. Government Printing Office, Washington, D. C. (February 1976). Price and income elasticities of demand under trends of increasing prices are not fully known because of limited experiences. Projections of future demand generally anticipate significantly reduced rates of energy growth because of higher prices.
56. Data furnished by Helen Tomasini, American Telephone and Telegraph Company, New York (March 9, 1976).
57. Federal Highway Administration, "Highway Statistics, 1972," U. S. Government Printing Office, Washington, D. C. (1973).
58. Federal Highway Administration, "Highway Statistics, 1974" (draft). Data are for the 1964-1974 decade, Table VM-1, to be published. For 1964 data, see U. S. Bureau of Roads, "Highway Statistics, 1964," U. S. Government Printing Office, Washington, D. C. (1966).
59. O. L. Culberson, "The Consumption of Electricity in the United States," Report No. ORNL-NSF-EP-5, Oak Ridge National Laboratory, Oak Ridge, Tenn. (June 1971).
60. Ford Foundation Washington Center for Metropolitan Studies, "Life-style and Energy Household Survey, 1972-1973," cited in *A Time to Choose: America's Energy Future,* p. 122, Ballinger Publishing Company, Cambridge, Mass. (1974).
61. Private communication with James A. McMahon, Chief of Analysis Branch, Tennessee Valley Authority, Chattanooga, Tenn. (March 1976).
62. See reference 51.
63. Opinion Research Corporation, "Report to Management," *Public Opinion Index,* Vol. 33, No. 16, p. 2 (August 1975).
64. G. H. Moore and J. N. Hedges, "Trends in Labor and Leisure," *Monthly Labor Review,* Vol. 94, No. 2, p. 5 (February 1971).
65. D. Ricardo, *Principles of Political Economy and Taxation,* p. 264, J. P. Dent and Sons, London (1911).

66. See reference 51.
67. See reference 34.
68. Center for Advanced Computation, "Energy Intensity Ranked Sector Table," Document No. 128 (Technical Memorandum 23), University of Illinois (1971).
69. Press release, Bureau of Mines, U. S. Department of the Interior (March 1976).
70. Stanford Research Institute, "Patterns of Energy Consumption in the United States," Menlo Park, Calif. (1972).
71. L. H. Crump and C. L. Readling, "Fuel and Energy Data: United States by States and Regions—1972," Information Circular 8647, Bureau of Mines, U. S. Department of the Interior, Washington, D. C. (1974).
72. B. Reed, "U. S. Regional Energy Consumption for 1971," unpublished IEA report (January 1975).
73. M. E. Fejer and D. H. Larson, "Study of Industrial Uses of Energy Relative to Environmental Effects," Institute of Gas Technology, Chicago (July 1974).
74. "Fuels and Electric Energy Consumed," 1972 Census of Manufactures, Special Report Series MC72(SR)-6, U. S. Bureau of the Census, Washington, D. C. (July 1973).
75. See reference 42.
76. See reference 41.
77. Federal Energy Administration, "Part 9: Price, Monthly Energy Reviews," National Energy Information Center, Washington, D. C. (1976).
78. Arthur D. Little, Inc., "The Potential for Energy Conservation in the Residential and Commercial Sectors," draft report to Council on Environmental Quality (July 1974).
79. J. C. Moyers, "The Value of Thermal Insulation in Residential Construction: Economics and the Conservation of Energy," Oak Ridge National Laboratory, Oak Ridge, Tenn. (December 1971).
80. H. C. Fischer, "The Annual Cycle Energy System," Energy Division Paper, Oak Ridge National Laboratory, Oak Ridge, Tenn. (1975).
81. J. A. McMahon, Chief of Analysis Branch, Tennessee Valley Authority, private communication (March 1976).
82. Residential/Commercial Task Group, "Potential for Energy Conservation in the United States: Residential/Commercial," National Petroleum Council, Washington, D. C. (1975).
83. See reference 53.
84. Defined as Nonfreight Trucking, Jack Faucett Associates, Inc., "Project Independence and Energy Conservation in Transportation Sector," Council on Environmental Quality, Washington, D. C. (July 1974).
85. See reference 84.
86. See reference 69 and previous annual releases.
87. See reference 47.
88. See reference 43.
89. Automation in the services sector and in process control for manufacturing is the key to the future high productivity assumed in the earlier sections of this report. (This is in agreement with the opinion of economic growth experts, Richard Damian, U. S. Department of Commerce, private communication.)
90. Report to Congress on Petrochemicals, Office of Economic Impact, Federal Administration in response to Public Law 93-275, Section 23 (1975).
91. "A National Plan for Energy Research Development and Demonstration: Creating Energy Choices for the Future 1976," Vol. I: The Plan, ERDA Report Stock No. 052-010-00478-6, U. S. Government Printing Office, Washington, D. C. (1976).
92. W. G. Dupree, Jr., and J. S. Corsentino, "United States Energy Through the Year 2000" (revised), Bureau of Mines, U. S. Department of the Interior, Washington, D. C. (December 1975).
93. See reference 1.
94. See reference 40.
95. W. S. Chern, "Energy Demand and Interfuel Substitution in the Combined Residential and Commercial Sector," p. 17, Oak Ridge National Laboratory, Oak Ridge, Tenn. (June 1976).
96. Federal Energy Administration, "1976 National Energy Outlook," Federal Energy Administration, Washington, D. C. (1976).
97. H. S. Houthakker and L. D. Taylor, *Consumer Demand in the United States,* 2nd ed., Harvard University Press, Cambridge, Mass. (1970).

98. J. W. Wilson, "Residential Demand for Electricity," *Quarterly Review of Economics & Business,* Vol. 11, No. 1, p. 7 (Spring 1971).
99. T. D. Mount, L. D. Chapman, and T. J. Tyrrell, "Electricity Demand in the United States: An Econometric Analysis," Report No. ORNL-NSF-9, Oak Ridge National Laboratory, Oak Ridge, Tenn. (July 1973).
100. K. P. Anderson, "Residential Energy Use: An Econometric Analysis," Report No. R-1297-NSF, The Rand Corporation, Santa Monica, Calif. (October 1973).
101. R. A. Lyman, "Price Elasticities in the Electric Power Industry," Department of Economics, University of Arizona (October 1973).
102. H. S. Houthakker, P. K. Verlager, and D. P. Sheehan, "Dynamic Demand Analysis for Gasoline and Residential Electricity," Data Resources, Inc., Lexington, Mass. (1973).
103. L. D. Taylor, G. R. Blattenberger, and P. K. Verlager, "The Residential Demand for Energy," report to the Electric Power Research Institute (preliminary draft), Department of Economics, University of Arizona (January 1976).
104. N. D. Uri, "A Dynamic Demand Analysis for Electrical Energy by Class of Consumer," Working Paper 34, Bureau of Labor Statistics, Washington, D. C. (January 1975).
105. E. R. Berndt and D. O. Wood, "Technology, Prices and the Derived Demand for Energy," *The Review of Economics and Statistics,* Vol. 57, No. 3, p. 259 (August 1975).
106. Federal Energy Administration Interagency Task Force on Coal, "Project Independence Blueprint Final Task Force Report," Stock No. 4118-00015, Washington, D. C. (1974).
107. M. B. Zimmerman, "Long-Run Mineral Supply: The Case of Coal in the United States," review of Ph.D. thesis at MIT by Richard L. Gordon, Electric Power Research Institute, Research Project 335-1, Vol. 1 (February 1976).
108. J. G. Asbury et al., "Price and Availability of Western Coal in the Midwestern Electric Utility Market 1974-1982," Argonne National Laboratory, Argonne, Ill. (October 1974). Distributed by National Technological Information Service, U. S. Department of Commerce, Washington, D. C.
109. See reference 8, pp. 30-32.
110. "Minerals and Materials—A Monthly Survey," Table 2, p. 11, Bureau of Mines, U. S. Department of the Interior, Washington, D. C. (April 1976).
111. See reference 95.
112. See reference 96.
113. See reference 97.
114. See reference 98.
115. See reference 99.
116. See reference 100.
117. See reference 101.
118. See reference 102.
119. See reference 103.
120. See reference 104.
121. See reference 96.
122. See reference 105.
123. K. Arrow, H. B. Chenery, B. Minkas, and R. M. Salow, "Capital-Labor Substitution and Economic Efficiency," *Review of Economics and Statistics,* Vol. 43, p. 228 (August 1961). The original statement of the properties of the CES production function.
124. The GNP is defined to be the dollar value of all new final goods and services produced in a given year, and as such is the sum of quantities of goods and services multiplied by their respective market prices, or

$$\text{GNP} = \sum_{i=1}^{n} p_i q_i$$

125. The elasticity of substitution is defined to be O_{KL}, where

$$O_{KL} = \frac{d(K/L)}{d(W/r)} \frac{W/r}{K/L}$$

where W is the price of L and r the price of K. It can also be shown that for a CES production function $O_{KL} = 1/(1-P)$.

126. E. A. Hudson and D. Jorgenson, "U. S. Energy Policy and Economic Growth, 1975-2000," *Bell Journal of Economics and Management Science,* Vol. 5, No. 2, p. 461 (Autumn 1974).
127. P. A. Samuelson, "Nonsubstitution Theorems," in U. Stiglitz, ed., *The Collected Scientific Papers of Paul A. Samuelson,* Vol. 1, pp. 513-536, MIT Press, Cambridge, Mass.
128. See reference 17, pp. 578-592.
129. The existence of turnpike theorems was originally conjectured in Chapter 12 of *Linear Programming and Economic Analysis* by R. Dorfman, P. A. Samuelson, and R. M. Solow, The RAND Series, McGraw-Hill, New York (1958). Also see E. Burmeister and A. R. Dobell, *Mathematical Theories of Economic Growth,* pp. 311-351, Macmillan, New York (1970).
130. See reference 123, pp. 225-249.
131. See reference 92.
132. Jack Faucett Associates, "Data Development for the I-O Energy Model, Final Report," submitted to the Energy Policy Project (May 1973).
133. "Survey of Current Business," Table 1.2, U. S. Department of Commerce, Washington, D. C. (July 1974). "U. S. National Income and Product Accounts, 1964-1969," Table 1.2, U. S. Department of Commerce, Washington, D. C. (July 1973). "The National Income and Product Accounts of the United States, 1929-1965, Statistical Tables, A Supplement to the Survey of Current Business," Table 1.2, U. S. Department of Commerce, Washington, D. C. (August 1966).
134. See reference 133, Table 6.4.
135. See reference 133, Table 1.10.
136. See reference 133.