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DIVISION OF ENERGY AND ECONOMIC ANALYSIS
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ABSTRACT

This report summarizes a detailed projection of the growth and structure of the U.S. energy and economic systems for the period 1980 to 2000. The projection originates through use of a combined model system that simulates energy and economic activity under a comprehensive set of assumptions. These assumptions cover a range of demographic, economic, and energy conditions that define the circumstances and constraints influencing the directions of private and public decisions. Accordingly, many of the provisions of current public policy are included among these inputs. The framework employed in this analysis is provided by the linked energy-economy model system of Brookhaven National Laboratory (BNL) and Dale W. Jorgenson Associates (DJA). This projection provides a point of reference for the quantitative analysis of proposed policy measures, research directions, and possible energy and economic contingencies.

EXECUTIVE SUMMARY

This report presents a detailed projection of the growth and structure of the U.S. energy and economic systems for the period 1980 to 2000. The analytic basis for this projection is the linked energy-economy model system of Brookhaven National Laboratory (BNL) and Dale W. Jorgenson Associates (DJA). This combined model system simulates energy and economic activity under a comprehensive set of assumptions, including demographic, economic, and energy conditions and constraints, with many of the provisions of current public policy included as inputs. When solved on the basis of these assumptions, this system provides information on economic growth and changes in the labor force, employment patterns, and economic structure, as well as energy information showing changes in energy fuel flows, petroleum imports, and new technologies involving energy supply and conversion devices.

The projection presented in this report shows that after a period of relatively slow growth in the early 1980s, GNP grows somewhat more rapidly through the mid-1990s and at a sharply increased rate thereafter (see Table E.1). This growth path is driven largely by the available labor force, productivity improvements, and expected moderation in energy price increases. The importance of the foreign trade sector increases steadily throughout the projection period, but somewhat below historical rates, as the U.S. faces increasing competition in world markets. The relative importance of government expenditures declines throughout the projection period. Tax incentives that favor saving and investment stimulate capital formation and result in continuing improvements in the growth of output per worker.

The relative prices of energy and labor as inputs to production are projected to rise more rapidly than those of capital and materials, providing additional stimuli to increase energy and labor productivity. For outputs, the relative prices of energy and energy-intensive goods and services rise more rapidly, on average, than do those of the more services-oriented sectors of the economy. Consistent with this relative price shift, final spending moves away from energy and energy-intensive goods and services toward the outputs of the service industries.

Production becomes increasingly more capital intensive and less labor intensive. Growth in the energy intensity of production (measured in Btu) declines. However, energy use in production shifts away from fuels toward a

Table E.1
Summary of Economic and Energy Projection: Average Annual Growth Rates, Percent Per Year

	1980-1985	1985-1990	1990-1995	1995-2000
Economic Summary:				
Real GNP	2.7	2.8	2.8	3.2
Real government purchases	2.4	2.2	1.8	1.7
Real investment	5.7	3.4	4.0	2.6
Relative prices				
Energy	13.3	10.6	9.7	9.0
Capital	8.2	6.2	5.8	5.1
Labor	10.0	8.9	8.6	8.3
Constant dollar capital-output ratio	0.4	0.8	0.5	0.9
Constant dollar labor-output ratio	-1.1	-1.3	-1.7	-1.7
Energy per unit of capital	1.0	-0.9	-0.8	-1.3
Energy-GNP ratio	-1.2	-1.6	-1.5	-1.7
Energy Summary:				
Primary energy	1.4	1.1	1.2	1.4
Energy imports	3.4	-2.5	-1.7	-5.4
Renewable energy sources	2.1	2.7	4.2	5.7
Liquid fuel use (including synthetics)	-0.3	-1.5	-0.8	-0.9
Gaseous fuel use (including synthetics)	-1.2	0.1	-0.4	0.1
Coal use	5.8	4.5	3.9	3.3
Aggregate delivered energy use	1.0	0.8	1.1	1.3

greater use of electricity. Overall, the restructuring of spending, input, and output patterns permits the energy intensity of the economy to decline substantially and steadily over time.

Primary energy usage continues to grow, but at relatively low rates, through the end of the century, reaching just over 100 quads by the year 2000. U.S. dependence on oil imports declines significantly; however, oil and gas imports account for 10 percent of our primary energy needs in 2000. The use of renewable energy sources (hydropower, geothermal, wind, solar, and biomass) increases fairly rapidly, but from a relatively small base, and these sources provide 10 percent of the resource requirements by the end of the century. While the use of liquid and gaseous fuels declines somewhat, their contribution to primary energy requirements falls significantly, from about 70 percent in 1980 to 47 percent in 2000. This results in increased dependence on coal, electricity, and renewable energy sources.

Over the forecast period, delivered energy use by the residential, commercial, and transportation sectors is slowed considerably, as these sectors take advantage of the many conservation options available to help mitigate the rising costs of energy. Industrial energy use continues to grow as the demand for petrochemical feedstocks continues to grow. In addition, the long lead times required for process changes and the slow turnover of the long-lived capital stock in this sector result in a much slower response to higher energy prices over the next 20 years.

Overall, the energy future can be characterized as one of slow evolution, with the U.S. dependence on liquid and gaseous fuels (both domestic and imported) slowly decreasing as the system shifts to more reliable and available energy forms (coal and renewables). The efficiency of energy use improves for all forms as the economic system substitutes relatively less expensive inputs (capital and materials) for relatively more expensive inputs (labor and energy).

The extent to which these trends can be accelerated through energy policies and research and development is somewhat limited. However, it is clear from this projection that several areas could use additional stimuli to aid their transition to less expensive, more reliable energy forms. The transportation sector continues to be almost completely dependent on liquid fuels. The efficiency of energy use throughout the system increases slowly, but is constrained as much by the vintage nature and relatively long lifetimes of the energy utilizing capital stock as by the efficiencies of the new devices. Basic research in areas concerning heat transfer, material sciences, and friction might enhance the efficiency of future conversion and end-use devices.

This projection provides a consistent aggregate projection of the U.S. energy and economic systems through the year 2000. The interrelationships and interactions between the two systems are many, and the evolution and direction of one cannot be separated from that of the other. The design and analysis of possible energy policies, contingencies, or research programs must be done against the backdrop of a consistent set of energy and economic information. Only then can the relative merits of possible actions be assessed correctly to ensure that the particular strategy chosen yields the best combination of benefits relative to the cost incurred.

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1 INTRODUCTION

This report summarizes a detailed projection of the growth and structure of the U.S. energy and economic systems for the period 1980 to 2000. The projection originates through use of a combined model system that simulates energy and economic activity under a comprehensive set of assumptions. These assumptions cover a range of demographic, economic, and energy conditions that define the circumstances and constraints influencing the directions of private and public decisions. Accordingly, many aspects of public policy evident in the spring of 1981 are included among these inputs. The framework employed in this analysis is provided by the linked energy-economy model system of Brookhaven National Laboratory (BNL) and Dale W. Jorgenson Associates (DJA). This system, when solved on the basis of the specified assumptions, generates a projection of future energy and economic conditions.

This projection provides information on several important variables and trends, including the following:

- economic growth
- evolving economic structure
- labor force and employment
- energy input
- patterns of energy use
- role of petroleum imports
- role of new technology energy supplies
- role of new technology energy conversion devices

Many problems arise in the design and implementation of energy (and economic) policies, and there is continual controversy over the components and direction of future policies. In formulating and proposing new policy and research directions, it is important to examine the relative merits of each possible strategy to ensure that the particular action yields the greatest combination of economic, environmental, and security benefits relative to the costs incurred. This projection provides a point of reference for the quantitative analysis of proposed policy measures, research directions, and possible energy and economic contingencies.

2 MODELING APPROACH

The approach used in this study incorporates three integrated models which represent the national energy system structure, the domestic economy, and their interactions. The three models are discussed briefly below, and then the integration framework is described.

2.1 THE DYNAMIC GENERAL EQUILIBRIUM MODEL

The Dale W. Jorgenson Associate's Dynamic General Equilibrium Model (DGEM) is a simulation model of the structure and growth of the U.S. economy.[1,2] It combines a model of macroeconomic growth with a multisector input-output model based on flexible coefficients. For each year, it models economic activity on a sectoral basis and integrates the results into a consistent whole. There are nine producing sectors of which five are energy-related. New technology energy supply, conversion, and end-use activities are included explicitly under five categories. Inputs into production and final demand purchases are provided by the nine main producing sectors. In addition, there are three sources of inputs to the economy (capital, labor, and competitive imports) and four categories of final demand for goods and services (personal consumption expenditures, investment, government purchases and exports). These activities are organized into an accounting framework which covers transactions between each of the twelve supplying sectors and each of the eighteen purchasing sectors.

Simulations from DGEM reflect the patterns of desired expenditure that are consistent with what is achievable from production, i.e., supply possibilities of the economy. The resulting projection has the following features:

- final demand expenditure on each type of good or service that reflects income, prices, and other determinants;
- levels of real economic activity that are feasible in terms of the supply and demand position of each sector and, therefore, of the economy;
- a supply position that reflects patterns of inputs and productivities in each sector and, through time, the availability of these inputs and resources to the economy;
- economic growth as a sequence of one-period equilibria giving demand, supply, and the relative price for each commodity and factor.

2.2 THE TIME-STEPPED ENERGY SYSTEM OPTIMIZATION MODEL

Brookhaven National Laboratory's Time-stepped Energy System Optimization Model (TESOM) is a detailed technological model of the U.S. energy supply, conversion, and end-use demands based on Brookhaven's Reference Energy System.[3,4] The model solution satisfies a set of exogenously determined energy service demands (e.g., space heat or motive power) over the residential, commercial, industrial, and transportation sectors of the economy.

The model includes detail on end-use devices for each energy demand category, specified by technology and fuel type. Hence, it allows substitution of a variety of fuels to satisfy the specified demands. A market penetration algorithm[4] prevents overly optimistic implementation of new technologies within the model. In addition, assumptions regarding primary resource availabilities may be included. Resource prices are represented either as short-run or long-run supply curves, or as fixed prices for each time period.

Formulated as a series of cost minimization linear programming models stepped over time, TESOM represents the dynamics of energy prices, technological developments, and service demands as well as the static picture of the energy system structure at discrete time intervals.

2.3 THE INPUT-OUTPUT MODEL

Developed jointly by BNL and the University of Illinois, the input-output model is a 110-sector representation of the interindustry structure of the U.S. economy.[5] It is disaggregated into 20 energy sectors and 90 non-energy sectors, with the output of the energy sectors specified in Btu rather than dollar values. Twelve of the energy sectors are energy supplies, and the remaining eight are energy demand categories.

Final demands for all 110 sectors are transformed into required total output for each sector, given the structure of interindustry demands. The input-output model provides energy service demand values, as well as a highly disaggregated set of output levels for the energy and nonenergy supply sectors.

2.4 MODEL INTEGRATION

The three models are aligned with consistent sets of information regarding the energy system and the economy.[6,7] Energy prices, technological data, and import levels (all results of TESOM) are inputs to the DGEM model. Energy demands and economic conditions from DGEM are included as inputs to the input-output model. Coefficients relating the energy supply and demand sectors in the I-O are determined from TESOM results. Finally, the I-O energy service demands are disaggregated to match the energy services which are inputs to TESOM.

3 ASSUMPTIONS

3.1 DEMOGRAPHIC AND ECONOMIC

In developing a projection of this type, i.e., a reference projection, DGEM requires input information on future demographic trends, rates of unemployment and domestic price inflation, government expenditure and revenue policies, and export patterns. (For alternatives to a reference projection, inflation and government revenue positions vary endogenously while adjustments in government purchases and/or deficits and the economy's export patterns are specified as part of the analysis; generally, only population and the unemployment rate remain fixed at their reference values.)

The Census Bureau's Series II population projections (fertility rate of 2.1) form the basis for the demographic trends incorporated into this projection[8] (see Table 3.1). The rate of population growth under the Series II assumptions shows a steady decline toward, although not reaching, zero. The annual population growth over the 1972-80 period averaged 0.9 percent; thus, the Series II projection embodies slightly higher growth during the eighties than was observed over much of the seventies. Of more importance, however, is the changing age structure of the population. Growth of the working-age population (ages 16-65) slows dramatically through the middle nineties. This has significant implications for the allowable growth in the civilian labor force and, therefore, for the overall rate of productivity advance (both of

Table 3.1
Demographic Projections (Millions)

	1980	1985	1990	1995	2000
Population	222.5	232.9	243.5	252.8	260.4
Population, 16 and over	168.3	177.6	185.1	191.1	199.3
Population, 16-65	143.4	150.3	155.3	159.7	167.5
Number of households	80.8	87.9	95.5	103.2	110.8
Annual Average Percent Growth Rates		1980-1985	1985-1990	1990-1995	1995-2000
Population		0.9	0.9	0.8	0.6
Population, 16 and over		1.1	0.8	0.6	0.8
Population, 16-65		0.9	0.7	0.6	1.0
Number of households		1.7	1.7	1.6	1.4

which are endogenous to the projection). From 1972 through 1980, growth of the working-age population was almost double that of the population as a whole -- 1.5 percent per annum versus 0.8 percent. Spurred by significant changes in relative prices (e.g., energy and materials), this permitted a rapid expansion in the civilian labor force without a commensurate increase in real compensation and was one of the contributors to the observed deterioration in the rate of growth in productivity. This productivity effect was made worse by the employment growth being strongest in the seemingly least productive industries and occupations within the economy. In the Series II projection, slower growth in the working-age population suggests that such a pattern is unlikely to recur with similar intensity. Finally, household formation is projected to continue the trends toward smaller families and more single-person households, but the rate of reduction in persons per household is expected to be less precipitous than during the seventies.

The rate of unemployment is assumed to follow a cyclical pattern along a steadily declining long-run trend. The long-run reduction is conditional on the labor-market tightening that would result naturally from slower growth of the working-age population. The cyclical pattern around such a trend is based on recent empirical evidence in which the Presidential-election cycle and significant changes in relative prices play prominent roles. The inflationary pressures within the economy are expected to abate gradually over the remainder of the century. The process of reducing inflation begins slowly and becomes progressively more effective through time. One reason for this is the longer-term (post-1985) moderation in energy price increases assumed for this projection (discussed below). Another reason is that the economic consequences of slower growth in the working-age population are likely to encourage improvements in productivity growth, which, in turn, favorably affect unit production costs and thus aid in reducing inflation. Finally, changes in government fiscal, monetary, and regulatory policies are directed, with increasing success, toward ameliorating inflation and its consequences. The unemployment and inflation projections are summarized in Table 3.2.

Table 3.2
Projected Trends in the Unemployment Rate and Domestic Price Inflation

	Unemployment Rate (%)			
	1980-1985	1985-1990	1990-1995	1995-2000
Average	7.0	6.7	6.3	6.1
High	7.4	7.0	6.4	6.2
Low	6.5	6.3	6.0	5.9

Rate of Change in GNP Price Deflator (%/yr)	
1980-1981	9.5
1981-1982	9.0
1982-1985	8.5
1985-1990	7.3
1990-1995	6.6
1995-2000	6.2

Input information regarding the level and growth of government purchases reflects the directional changes made in public policy in recent months. In particular, a slowing in the rate of growth of non-defense spending is projected for all levels of government, curtailment being sharpest at the federal level as cuts in the federal budget must accomodate both reductions in total expenditure growth and significant increases in defense spending. State and local purchases show, at least initially, more modest growth reductions. In part, this presumes the successful transfer of programmatic and managerial responsibilities from federal to state and local jurisdictions. However, in keeping with the current political views on government spending, it also reflects the continuation of a trend begun in the middle seventies. These budgetary changes are projected to have a significant impact on the government component of the National Income and Product Accounts (NIPA), as illustrated in Table 3.3.

Government transfers and tax revenues are projected to rise approximately in line with the economy as a whole. This, coupled with slower growth in government expenditures, alters the trend in budget deficits so that a smaller portion of total private saving need be absorbed by government.

Table 3.3
Projected Trends in Government Purchases:
National Income and Product Accounts (Billions of 1972 Dollars)

	Federal				
	Defense	Non-defense	Total	State/Local	Total
1980	71.0	37.4	108.4	181.7	290.1
1985	86.9	39.1	126.0	200.6	326.6
1990	107.8	40.9	148.7	216.1	364.8
1995	128.0	43.0	171.0	227.1	398.1
2000	148.4	45.2	193.6	238.7	432.3

Private investment and the process of capital formation are favored by this change alone. However, a significant change is projected also for the structure of taxation. For the most part, changes in taxes on labor income are estimated to be neutral. Increases in certain federal, state, and local taxes on labor income are compensated by reductions in federal personal income tax rates. The tax reductions that do occur are directed toward stimulating increased saving and investment by businesses and households. The combination of structural changes in government transfer programs, slower growth in government purchases, and new tax incentives favoring the capital input encourage investment and improve productivity growth at the expense of current consumption and leisure.

The final economic assumption concerns the future growth of real exports. In each decade since 1950, U.S. export growth has accelerated; the export share of real GNP has increased from 4.4 to 10.9 percent during these thirty years. Over the fifties and sixties, U.S. producers benefited from increasing incomes abroad, a relatively stable currency, increasing diversity and innovation in their output mixes, and comparative advantages in production secured through productivity improvements and technological change. In the seventies, exchange rate adjustments accounted for a significant portion of the accelerated growth. The major U.S. devaluation of the early 1970s stimulated export growth. But, the trade consequences of large price changes in the world oil market are of most importance. Here, U.S. exporters benefited not only from the large new markets created in the oil-producing countries but also from the fact that world oil trade was conducted in U.S. dollars. As other oil importing nations sought to finance their petroleum imports by increasing exports and/or reducing net capital outflows, the supply of dollars increased relative to other currencies. This rapidly led to movements in exchange rates. Export volumes were increased substantially as exchange rate adjustments favored the U.S. In addition, growth remained relatively strong for our industrialized trading partners, and revenues to oil and other resource-producing nations continued to increase. For the remainder of the century, export growth is expected to be an important component of the overall growth in final spending and output (Table 3.4). However, the level of growth is projected to be reduced significantly relative to historical experience. This results from the following considerations. First, price shocks to the world oil market are assumed not to recur. Second, adjustments in exchange rates and international trade patterns in response to previous price shocks have occurred already, so that future growth in world oil prices is relatively easily accommodated. Third, future growth in the economies of our major trading partners is expected to slow somewhat compared with that in the 1970s. Finally, except for exporters of agricultural products, U.S. exporters are expected to face increased competition from foreign export producers and accelerated import substitution within importing countries.

Table 3.4
Projected Trends in Real Exports (Billions of 1972 Dollars)

Year	Real Exports	Annual Growth
1980	161.6	
1985	190.0	3.3
1990	221.6	3.1
1995	260.4	3.3
2000	314.0	3.8

3.2 ENERGY ASSUMPTIONS

In addition to the demographic and economic conditions, TESOM and DGEM depend on important assumptions affecting the future development of the nation's energy system. The projection allows for the effects of policy initiatives and actions that currently are legislated or announced and under control of the Executive Branch. The most important of these considerations incude oil price decontrol and the windfall profits tax, the provisions of the Natural Gas Policy Act, conservation and renewable tax credits for businesses and households (expiring in 1985), the stated objectives for the Synthetic Fuels Corporation, and features of the Power Plant and Industrial Fuel Use and Public Utility Regulatory Policies Acts. The analysis also incorporates price projections for domestic and imported energy resources; costs for selected electric generation, synthetic fuel, and end-use technologies; production patterns for domestic oil and gas; and market penetration rates (expressed as "optimistic" upper bounds) for specific sources of energy supply conversion.

Energy price assumptions are presented in Tables 3.5 and 3.6 in standard units and per million Btu, respectively. The world oil price is assumed to grow from $34 per barrel in 1980 to almost $64 per barrel in 2000 (1980$). Full decontrol of domestic oil prices occurs in 1981, and the decontrol assumption includes the provisions of the Crude Oil Windfall Profits Tax of 1978. These oil-price assumptions conform to those of the Mid-Price Scenario for the NEP III analysis currently being conducted by DOE's office of Policy, Planning, and Analysis (PPA). Domestic and world oil prices are assumed to converge in 1985 at $40.04 per barrel. Shale crude prices are also tied to the world oil price, since it is assumed that substantial marketing of shale oil will not occur until the price is competitive.

Table 3.5
Energy Resource Prices (1980 $/Standard Unit)

	1980	1985	1990	1995	2000
Refiner acquisition cost:					
Domestic crude oil ($/bbl)	24.19	40.04	47.32	55.51	63.69
Imported crude oil ($/bbl)	34.00	40.04	47.32	55.51	63.69
Domestic nat. gas (wellhead) ($/thousand ft^3)	1.52	3.69	4.46	5.36	6.27
Imported nat. gas (pipeline) ($/thousand ft^3)	4.44	5.99	7.08	8.30	9.53
Liquid nat. gas ($/thousand ft^3)	4.69	6.35	7.50	8.79	10.09
Coal (minemouth) ($/short ton)	25.31	28.03	31.19	34.58	38.42

Table 3.6
Energy Resource Prices (1980 $\$/10^6$ Btu)

	1980	1985	1990	1995	2000
Refiner acquisition cost:					
Domestic oil	4.17	6.91	8.16	9.57	10.98
Imported oil	5.85	6.91	8.16	9.57	10.98
Shale oil	5.85	6.91	8.16	9.57	10.98
Domestic nat. gas (wellhead)	1.49	3.61	4.37	5.25	6.14
Imported nat. gas (pipeline)	4.35	5.87	6.93	8.13	9.33
Unconventional gas	4.35	5.87	6.93	8.13	9.33
Alaskan gas	4.35	5.87	6.93	8.13	9.33
Liquid nat. gas	4.59	6.22	7.35	8.61	9.88
Coal (minemouth)	1.12	1.24	1.38	1.53	1.70
Nuclear fuel	0.75	0.82	0.93	1.04	1.15
Wood and biomass	1.05	1.38	1.47	1.63	1.80

Domestic natural gas prices are consistent with on-going analysis within PPA. These prices are based on PPA's best estimate for world oil prices and an analysis of price patterns under decontrol, and take into account the many long-term contracts which will limit natural gas price increases through this century. Partial decontrol of natural gas prices occurs in 1985 in accordance with the Natural Gas Policy Act. Growth in wellhead gas prices averages 8.0 percent annually through 1984 and rises sharply in 1985 as many categories of natural gas become fully deregulated. After 1985, domestic gas prices grow at slightly faster rates than do oil prices but do not reach "Btu parity" by 2000. Imported natural gas, Alaskan gas, and LNG prices were determined by studying the relationship between the recent rise in world oil prices and the dramatic increases in the costs of pipeline gas and LNG. Because these prices now approach the world oil price, imported natural gas and Alaskan gas prices were set at 15 percent below the world oil price and LNG at 10 percent below for the years 1985 through 2000.

The coal prices used are slightly higher than current PPA estimates. Previous BNL estimates have been based on the assumption that rising oil prices would have a greater effect on coal prices. The Data Resources, Inc., Energy Review for Spring 1981 also forecasts coal prices at a substantially higher level, using oil price assumptions very close to those being used here.[9] For the current TESOM case, the coal resource price for 2000 was set at $1.70 per million Btu (1980 dollars), and prices for the intervening years were determined by using an even growth path from 1980 prices. Growth in the price of nuclear fuel reflects the adequacy of relatively low-cost uranium supplies given the slower growth of nuclear capacity in the future power generation mix. Nuclear fuel prices for 1980 to 2000 are based on mid-price nuclear fuel processing cost assumptions reported by DOE.[10]

Wood and biomass are priced to reflect the negligible cost of the 1 to 2 quads of waste wood energy now used annually by the pulp and paper industry. The price to each sector is adjusted by markups to take into account the differences in quality, preparation, and transportation costs to deliver the fuel to each sector. The highest markup is to the residential and commercial sector, which is set to reflect the average price of cordwood used for home heating. Wood and biomass resource prices increase at a slightly faster rate than coal prices.

Domestic oil and gas production levels, summarized in Table 3.7, were obtained from a report by the General Accounting Office.[11] Slight revisions were made in the gas estimates for 1986 to 1990 to reflect more favorable gas supply conditions following decontrol.

Table 3.7
U.S. Production of Oil and Gas

Year	Petroleum and Natural Gas Liquids (Million bbl/day)	Natural Gas (Trillion cu ft)
1980	10.2	19.0
1985	8.9	17.1
1990	8.0	17.9
1995	8.0	16.8
2000	8.5	16.6

Note: Liquids production includes Lower-48 and Alaska, onshore and offshore, and enhanced recovery.
Gas production includes Lower-48 and Alaska.

The final set of energy assumptions relate to the levels of implementation of selected energy technologies. Nuclear capacity is estimated to expand from 55.2 gigawatts electric (GWe) in 1980 to 166 GWe by the year 2000. This growth, though large, merely reflects the scheduled completion of all nuclear power plants currently envisioned.[12]

4 ECONOMIC STRUCTURE AND GROWTH

4.1 OVERVIEW OF ENERGY AND MACROECONOMIC PERFORMANCE

The U.S. economy and its use of energy are projected to show continued growth over the period encompassed by this analysis. A summary of the principal characteristics of this growth appears in Table 4.1. The rate of economic growth increases gradually over the remainder of the century. Real GNP growth averages 2.9 percent per annum from 1980 to 2000. Though not achieving the 3.8 percent annual rate experienced from 1950 to 1973, economic performance is improved materially over that observed during the post-embargo period, 1973 to 1980, when real growth averaged only 2.4 percent annually.

Table 4.1
Overview of Energy and the Economy

	1980	1985	1990	1995	2000
Population	222.2	232.9	243.5	252.8	260.4
Real GNP	2628.8	2997.7	3441.7	3946.0	4612.0
Real personal disposal income	1825.2	2092.3	2420.9	2820.1	3406.4
Primary energy	78.0	83.5	88.4	94.0	100.7
Civilian labor force	104.8	113.2	120.2	125.4	133.0
Unemployment rate	7.2	7.1	6.6	6.2	6.2
GNP price deflator	1.774	2.704	3.846	5.303	7.175
Energy-GNP ratio	29.7	27.9	25.7	23.8	21.8
Average annual Growth rates					
Population		0.9	0.9	0.8	0.6
Real GNP		2.7	2.8	2.8	3.2
Real personal disposable income		2.8	3.0	3.1	3.8
Primary energy		1.4	1.1	1.3	1.4
Employment		1.6	1.3	0.9	1.2
Gross labor productivity		1.1	1.5	1.8	2.0
GNP price		8.8	7.3	6.6	6.2
Energy-GNP ratio		-1.2	-1.6	-1.5	-1.7

Units: Population and Civilian labor force in millions of persons.
Real GNP and Real personal disposable income in billions of 1980 dollars.
Primary energy in quadrillion Btu.
Unemployment rate in percent.
GNP price deflator based on 1972 = 1.0.
Energy-GNP ratio in thousands of Btu per 1980 dollar.
Growth rates in percent.

This economic growth can be expressed in terms of increased labor input and increases in gross labor productivity. Population growth is already below previous trends and is forecast to continue to decline in the future. However, labor force expansion and employment growth reflect the trend of the working-age population, which exhibits a very different time pattern. Expansion of the labor force slows steadily through the mid-1990s in accordance with slower growth in the working-age population. Although male and female participation rates (especially the latter) rise throughout the projection horizon, the increases are not sufficient to offset the age-structure effects of population growth. Thus, employment growth steadily declines: from 1980 to 1985, employment increases from 97 million to 105 million, an average annual rate of 1.6 percent; employment grows to 112 million by 1990 and 117 million by 1995 or by 1.3 and 0.9 percent annually over the respective five-year intervals. Part of the inability of the economy to recover to pre-embargo rates of growth is explained by this slowing in labor force expansion and employment growth. In addition, this deceleration is most rapid during the period 1990 to 1995, so that employment considerations constrain economic recovery from the energy price increases occurring in the previous decade, i.e., relatively high oil price growth in 1980 to 1985 and gas price decontrol in 1985. But this trend is reversed after 1995. Toward the end of the century, there is a sharp increase in the growth of the working-age population. This, combined with modest increases in participation rates, stimulates employment. Employment reaches 12 million by 2000, expanding at a 1.2 percent annual rate from 1995 onward. Employment growth thus contributes to increasing economic growth as the end of the century is approached.

Increases in gross labor productivity account for the portion of real growth not due to increases in labor input. The projected increase in output per worker is in the range of 1.1 to 2.0 percent per annum. This is well below the sustained rate of productivity advance observed over the period 1950 to 1973, i.e., 2.2 percent annually. Slower productivity growth is partially due to the assumed continuing increases in the relative prices of energy. From 1973 to 1980, a period encompassing two major energy price shocks, productivity growth averaged only 0.3 percent per year. This poor performance is not expected to recur. Indeed, productivity growth increases in each five-year interval to 2000, reaching approximately historic levels. However, improvements in the rate of productivity advance are slowed by continuing increases in real energy prices through the mid-1980s. Because oil and gas price decontrol and relatively high oil price growth impose a productivity cost on the economy, it is not until the late 1980s and the 1990s that substantive improvements in productivity growth materialize. Nevertheless, projected productivity growth will continue to make a significant contribution to overall economic growth. Through the mid-eighties, employment growth makes a larger contribution to overall economic growth. After 1985, with employment growth increasingly slowed, productivity improvements make the larger contribution. From 1995 onward, when real GNP growth is increased sharply, continuing productivity growth is augmented by accelerated labor force expansion.

The projected increases in gross labor productivity include the effects of increased labor efficiency, more capital per worker, improved capital efficiency, and changes in the sectoral mix of production. Increases in capital per worker are particularly important in advancing labor productivity. From the figures on input composition given below (Table 4.5), the ratio of capital input to labor input, or average capital per worker, is estimated to increase by almost 53 percent between 1980 and 2000, an average annual increase of 2.1 percent. This trend reflects, among other things, the relative price implications of both the changing population age structure and the favored tax treatment afforded to future capital accumulation.

Energy growth exhibits the most marked change from previous trends. Growth of 3.7 percent annually prior to 1973 gives way to future annual growth of 1.3 percent from 1980 to 2000. Future energy growth is more rapid than the 0.2 percent annual rate observed since 1973, but the large and sudden price changes of the past are not repeated in the future (except for natural gas price decontrol in 1985). The projected patterns of energy growth reflect lagged responses to price and regulatory changes occurring in the 1970s and over the forecast period 1980 to 2000. Though fluctuations in energy growth do appear, the economy's use of energy becomes systematically and progressively more efficient through time.

A common measure of the aggregate economic efficiency of energy use is provided by the ratio of primary energy input to the quantity of final output produced, i.e., the energy-GNP ratio. This ratio has shown a general downward trend over the last thirty years. From 1950 to 1973, it declined at an average annual rate of 0.1 percent annually, despite falling relative energy prices. From 1973 to 1980, substantial increases in real energy prices occurred, and the energy-GNP ratio fell at an average annual rate of 2.1 percent. For the future, the yearly rate of decline is projected to average 1.5 percent.

An alternative view of the economic efficiency of energy use is given by the ratio of energy input to capital input, or the energy efficiency of capital in production (Table 4.5 below). Energy per unit of capital is projected to fall by more than 9 percent from 1980 to 2000, an average annual decrease of 0.5 percent. Except for 1980 to 1985, the time pattern of these changes conforms to that of the energy-GNP ratio.

Reducing the energy intensity of the economy or, equivalently, increasing the gross economic efficiency of energy use depends on increases in the technical efficiency of energy conversion and end use, technical progress in the economy as a whole, and structural changes in spending, input, and output patterns. Changes in the time pattern of energy use are conditional on the mix of relative effects from these influences. For the 1980s the dominant cause of improved energy efficiency is the economy's adjustment to the rapid increase in world oil prices (1979 to 1985), deregulation of petroleum prices (1981), and partial decontrol of natural gas prices (1985). Energy policy measures initiated in the 1970s also contribute to the increased efficiency of energy use. For the 1990s, structural changes in spending, input, and output patterns (caused in part by rising energy prices), continuing increases in energy costs, and improving productivity conditions more equally account for reductions in the energy intensity of the economy. On balance, these energy changes indicate the flexibility or capacity for change within the economy that permits accommodation of more costly and less readily available energy supplies without corresponding reductions in the growth of real output and incomes.

4.2 DISPOSITION OF FINAL OUTPUTS

The increasing quantity of production permits a continuing increase in material standards of living and supports a sustained rise in the volume of expenditure. Real disposable income per capita, measured in 1972 dollars, increases from $4589 in 1980 to $7308 by 2000, an increase of 59.3 percent.

The total volume of purchases increases by 74.4 percent, from $1482 to $2600, over this same period (all prices in 1972 dollars). In Table 4.2, these expenditures are separated into purchases by consumers, businesses, governments, and the rest of the world. Personal consumption expenditure (PCE) is now and will remain the dominant use of production. Per capita consumption expenditure increases from $4204 in 1980 to $6544 by 2000, at an average annual rate of 2.2 percent.

Consumption's share of total output is in the range of 60.0 to 65.0 percent throughout the forecast. The PCE share lies in the lower portion of this range for much of 1980 to 2000, rising significantly only at the end of the century. This time pattern is the result of two important influences. First, consumption absorbs much of the impact of rising energy prices. PCE growth is slower than real GNP growth during the 1980s, reflecting the effects of relatively high oil price growth and natural gas price decontrol, and is faster than real GNP growth over the 1990s, when energy price growth is moderated. Second, and perhaps more important, changes in the tax

Table 4.2
Disposition of Total Final Output

	1980	1985	1990	1995	2000
Purchases (billion 1972 $)					
Consumption, C	934.2	1038.9	1207.6	1398.4	1704.2
Investment, I	204.5	270.4	320.1	389.3	442.0
Government, G	290.1	326.6	364.8	398.1	432.3
Exports, X	161.6	190.0	221.6	260.4	314.0
Imports, M	108.5	136.0	173.9	221.7	292.6
Petroleum imports	44.6	60.6	65.3	66.0	55.0
GNP	1481.9	1689.9	1940.2	2224.5	2599.9
Composition of Purchases (%)					
Consumption, C	63.0	61.5	62.2	62.9	65.6
Investment, I	13.8	16.0	16.5	17.5	17.0
Government, G	19.6	19.3	18.8	17.9	16.6
Exports, X	10.9	11.2	11.4	11.7	12.1
Imports, M	7.3	8.0	8.9	10.0	11.3
Petroleum imports	3.0	3.6	3.4	3.0	2.1
GNP	100.0	100.0	100.0	100.0	100.0

Note: GNP = C + I + G + (X - M)

structure serve to stimulate saving and investment at the expense of current consumption. The PCE share of real disposable income is projected to show a decline during 1980 to 2000, implying an increase in the propensity to save. On the use side, investment as a share of real GNP gradually increases, although with some cyclical variation. Investment averages 15 percent of GNP during 1980 to 1985 and 17 percent during 1995 to 2000.

In addition to the investment effects of tax changes, the fraction of total final output going to government is projected to fall from present levels of more than 19 percent to 17 percent by 2000. Reductions in the growth of government purchases permit a larger portion of private savings to be absorbed by business and household investment, i.e., the crowding out of private investment by ever-increasing government deficits is avoided under this set of assumptions. Finally, foreign trade is projected to continue to increase in importance over the remainder of the century. Exports become an increasingly important use of final output, even though export growth occurs at rates well below historical levels, and competitive imports increasingly substitute for domestically produced crude, intermediate, and finished products. Also, future petroleum demand and supply patterns are such that potential energy import problems are likely to remain well into the 1980s, diminishing only gradually toward the end of the century.

4.3 PATTERNS OF RELATIVE PRICE CHANGES

Prices of various goods and services increase at rates reflecting differential movements in production costs and input prices. In turn, the impacts on output prices of these movements in costs are influenced by productivity changes and by changes in input use patterns. Indeed, productivity improvements and input substitutions are the principal mechanisms providing partial compensation for the inflationary effects of increases in input prices. Table 4.3 presents the annual rates of change in the prices of each of the major categories of finished goods and services and in the prices of the primary inputs to production.

Energy prices are projected to increase more rapidly than all other input prices. These price changes reflect the rise in world oil prices, oil and gas price decontrol, and continuing cost increases in energy processing

Table 4.3
Output and Input Price Increases
(Average Annual Rates of Change in Percent)

	1980-1985	1985-1990	1990-1995	1995-2000
Final Output Prices				
Agriculture, nonfuel mining, construction	9.8	7.7	7.0	6.3
Nonenergy manufacturing	8.8	7.4	6.9	6.5
Transportation	8.0	7.0	6.7	6.6
Communications, trade, services	7.6	6.8	5.9	6.0
Energy	13.3	10.6	9.7	9.0
Average	8.8	7.3	6.6	6.2
Input Prices				
Capital	8.2	6.2	5.8	5.1
Labor	10.0	8.9	8.6	8.3

and conversion. Labor prices also are projected to continue to increase, but at a declining rate. For workers, a rising relative price of labor implies an increase in purchasing power and material standards of living; however, for producers, increasing relative labor prices raise production costs and provide an incentive for substitution away from the labor input. Therefore, during 1980 to 2000, both energy and labor prices increase relative to prices of other inputs, and capital and intermediate nonenergy materials can be expected to substitute for labor and energy. Since capital and materials prices increase at less rapid rates, the control of production costs, i.e., cost minimizing behavior, implies a restructuring of input patterns toward these factors.

A change in the relative price structure is projected also on the output side of the economy. Since energy input costs are rising most rapidly, prices of energy output show the most rapid annual rate of increase. Energy price increases average almost 3.2 percent more per year than do the measured increases in the overall price of finished goods and services. The prices for agriculture, nonfuel mining, construction, and nonenergy manufacturing also show faster than average rates of increase. These sectors use both labor and energy relatively intensively, and sectoral productivity improvements and capital-materials substitutions are unable to offset fully the cost impacts of the relative rise in these two input prices. This is not the case for the prices of communications, trade, and services. Here, projected productivity changes and increased use of capital and materials secure reductions in relative output prices, even though these sectors historically relied on intensive use of labor. A similar pattern is observed in transportation through 1990, but, after that, efficiency gains and input restructuring no longer contain cost increases so that transport prices, in relative terms, are slightly higher. Overall, there is a wide range of movement in relative prices, e.g., the spread in annual rates of change between energy and services is approximately 3.8 percentage points from 1980 to 2000. These differentials exert substantial influence on the emerging patterns of final spending, intermediate purchases, and sectoral production, i.e., the structure of economic growth.

4.4 STRUCTURE OF FINAL SPENDING

The composition of final demand spending is projected to change materially over time in response to changes in relative prices. Final demand spending covers personal consumption expenditure; investment; purchases of labor, materials and other items by governments; and exports. The composition of final demand is shown in Table 4.4 in terms of its allocation over the principal categories of goods and services: agriculture, nonfuel mining, and construction; nonenergy manufacturing; commercial transportation; communications, trade, and services; and energy. The structure of this spending reveals several systematic changes occurring through time.

Table 4.4
Composition of Real Final Demand
(Percent of Total Constant Dollar Final Demand)

	1980	1985	1990	1995	2000
Agriculture, nonfuel mining, construction	13.8	13.6	13.4	13.2	12.9
Nonenergy manufacturing	35.7	35.9	35.7	35.5	34.9
Transportation	3.5	3.5	3.5	3.6	3.7
Communications, trade, services	42.6	43.0	43.8	44.5	45.7
Energy	4.4	4.0	3.6	3.2	2.8
Total	100.0	100.0	100.0	100.0	100.0

The most striking change is the reduced role of energy in the volume of final spending. Energy falls continuously from 4.4 percent of total purchases in 1980 to 2.8 percent by 2000. (In current dollars, the share of energy increases because the relative quantity reduction is less than the relative price rise.) In part, this energy reduction is caused by compositional shifts within final spending. Investment and exports increase in relative importance, and energy purchases in these categories are minimal. However, most of the energy reduction occurs as government purchases are reduced and, more importantly, households adjust their expenditure patterns in response to increases in relative energy prices.

Agriculture, nonfuel mining, and construction also decline in relative importance from 14 percent of real final demand in 1980 to 13 percent in 2000. Here, reductions in the demands by households (as incomes and relative prices change) and by governments (due to budgetary restrictions) are partially compensated by the restructuring toward investment and exports. Investment involves relatively large purchases from the construction sector, and agricultural exports are projected to increase their comparative advantage in international trade.

The share of nonenergy manufacturing in total final spending is stable through the 1980s and declines only slightly during the 1990s. At first glance, this appears inconsistent with the relative price changes discussed above, but it has important causes. In the household sector, increases in relative energy prices are larger than those for manufactured goods. Consequently, there is limited substitution of these goods for energy, even though price increases to households are higher than average. In addition, manufacturing's share of total business purchases is relatively large so that the shift toward investment tends to stabilize its overall relative importance. The restructuring of government spending toward defense purchases, which are relatively intensive in manufactured goods and materials, has a similar effect. Finally, manufacturing continues to play an important role in international trade, despite increasing competition from foreign producers. On balance, these conditions partially offset the demand reductions that might be expected from considering relative price changes alone.

The remaining sectors (commercial transportation, communications, trade, and services) absorb an increasing fraction of total spending. Here, relative price considerations in the household sector are the dominant influence. Since the prices of these goods and services decline in relative terms, households redirect their expenditures toward the outputs of these sectors at the expense of other purchases. Also, export growth contributes to the increasing share for commercial transportation and the shift toward investment augments the price-induced rise in relative importance for the communications and trade industries.

4.5 STRUCTURE OF INPUTS TO PRODUCTION

The pattern of inputs used in domestic production also changes considerably over time. Table 4.5 shows the constant dollar proportions of total input for capital, labor, energy, and intermediate materials. Significant changes take place in the relative importance of each of these aggregate inputs: production becomes progressively more capital intensive and less labor intensive, thus continuing the long-run historical trend; the energy intensity of production increases from 1980 to 1985 but declines continuously thereafter; the relative importance of materials rises steadily throughout the projection horizon. Except for energy, these changes conform exactly to expectations regarding the effects of relative price changes for inputs (Table 4.3). However, changes in the composition and structure of final demand and total interindustry expenditure also are extremely important to the projected input patterns. Labor services input within total input

Table 4.5
Aggregate Input Patterns
(Share of Total Constant Dollar Inputs to Production)

	1980	1985	1990	1995	2000
Input Share for:					
Capital	0.140	0.143	0.149	0.153	0.160
Labor	0.276	0.261	0.244	0.224	0.206
Energy	0.057	0.062	0.061	0.061	0.059
Materials	0.526	0.534	0.546	0.563	0.575
Annual Percentage Growth Rates in:					
Capital per unit of labor		1.6	2.2	2.3	2.6
Energy per unit of capital		1.0	-0.9	-0.8	-1.3

declines by 25 percent from 1980 to 2000. Increasing inputs of capital and intermediate materials substitute for this labor. The capital-labor ratio increases by 53 percent, and the materials-labor ratio rises by 46 percent. This increase in the capital-labor ratio and gains in the materials efficiency of capital are major sources of the improvements in gross labor productivity. Further, the increasing relative importance of materials implies more specialization and indirectness in production, i.e., production becomes more intensive in purchased goods and services rather than primary economic inputs. This also contributes to advances in the labor productivity measure.

The energy intensity of production merits special discussion. As given by the constant dollar proportion of total input, energy rises from 5.7 to 6.2 percent between 1980 and 1985, and then declines only gradually to 5.9 percent by 2000. This appears to be inconsistent with both the pattern of rising relative input prices for energy (Table 4.3) and the declining levels of energy use, measured in physical units, within the economy (Tables 5.1 and 5.3 below). However, several important mechanisms underlie these energy changes. The energy inputs are measured in constant dollars per physical unit, i.e., Btu of purchased energy. In these terms, electricity is most expensive, followed, in descending order, by refined petroleum products, delivered gas, and coal. In terms of relative price increases within energy, gas prices rise most rapidly followed by petroleum, coal, and electricity prices.

For U.S. production as a whole, interfuel substitution possibilities are strongest for the combinations coal and oil, oil and gas, oil and electricity, and gas and electricity. Thus, with this pattern of relative energy price changes, a shift occurs in energy inputs away from oil and gas and toward electricity and, to a lesser degree, coal. Also, in response to changes in spending and interindustry expenditure patterns (Tables 4.4 and 4.6, respectively), a shift occurs in U.S. production toward the communications, trade, and services industries (Table 4.7 below). Here, gas-electricity substitution dominates other adjustment mechanisms, amplifying the overall shift toward electricity.

Finally, as discussed below and in previous sections, nonenergy imports are projected to increase in both absolute and relative importance throughout 1980 to 2000. It happens that import growth is the strongest in commercial transportation, for which there is virtually no alternative to petroleum, and in nonenergy manufacturing, which partially accounts for the limited coal substitution observed for total nonenergy production. These changes in the level and structure of imports also lead to relatively more electricity within total productive inputs. The time pattern of energy shares disguises a continuing and significant decline in physical units of energy input and a steady structural shift toward electricity in the overall fuel mix for production. Since electricity is most expensive in real terms, the dollar share of energy in total input rises initially and then falls gradually. (Note, too, the continuous decrease in energy's share of total final spending, implying that electricity demand growth in the household sector is diminished significantly). In the short run (1980 to 1985), reductions in the growth of energy use in production are not sufficient to prevent the rising energy share that results from restructuring; after 1985, reductions in energy growth more than compensate the share effects caused by restructuring.

Trends in the composition of intermediate purchases also reveal important changes within overall input patterns. Table 4.6 covers these structural details. Energy's share of total interindustry expenditure follows a pattern identical to that observed for energy's share of total inputs (for the reasons enumerated above). Within intermediate materials, there are

Table 4.6
Composition of Real Intermediate Purchases
(Percent of Total Constant Dollar Interindustry Expenditure)

	1980	1985	1990	1995	2000
Agriculture, nonfuel mining, construction	7.1	6.8	6.8	6.7	6.9
Nonenergy manufacturing	49.4	48.4	48.2	47.9	48.2
Transportation	5.5	5.5	5.6	5.7	5.8
Communications, trade, services	28.2	28.9	29.3	30.0	29.8
Energy	9.8	10.4	10.1	9.7	9.3
Total	100.0	100.0	100.0	100.0	100.0

general trends away from agriculture, nonfuel mining, construction, and manufacturing, accompanied by input restructuring toward transportation, and communications, trade, and services. As the economy becomes progressively more services oriented, production is more specialized and indirect, and, as relative prices change, input patterns shift toward greater reliance on purchased services rather than goods and materials.

4.6 STRUCTURE OF DOMESTIC PRODUCTION

The preceding two sections discussed the structure of economic growth from the perspective of demand. Here, total demand for each type of good or service depends on the quantities purchased by final users and by producers as inputs to production. The structural pattern of total demand is conditional on changes in final spending and interindustry input patterns. However, in achieving equilibrium, the supply position for each type of good or service is also important. Supply must equal demand, and supply is obtained from the combination of domestic production and competitive imports.

Table 4.7 shows the structure of domestic production for 1980 to 2000. Several differences emerge in comparing this pattern of outputs, i.e., domestic supply, with those for final spending and intermediate purchases, i.e., total demand. In agriculture, nonfuel mining, and construction, the trends for production and expenditure are virtually identical. Through time, the outputs from these sectors become slightly less important in final spending as inputs to production. A similar decrease occurs in the relative

Table 4.7
Composition of Real Domestic Output
(Percent of Total Constant Dollar Production in the U.S.)

	1980	1985	1990	1995	2000
Agriculture, nonfuel mining, construction	10.6	10.5	10.4	10.4	10.4
Nonenergy manufacturing	42.1	41.5	41.0	40.5	39.9
Transportation	4.3	4.2	4.2	4.2	4.2
Communications, trade, services	36.3	37.0	37.8	38.6	39.5
Energy	6.7	6.8	6.6	6.3	6.0
Total	100.0	100.0	100.0	100.0	100.0

importance of these sectors in total domestic output. These identical trends imply that the economy remains almost entirely self-sufficient in this output category for the remainder of the century, i.e., demand and domestic supply move in parallel. Further, the degree of self-sufficiency does not change significantly from 1980 to 2000, the import share of total supply increasing only from 1.8 to 2.4 percent.

In the communications, trade, and services industries similar supply trends are observed, but, the outputs become progressively more important over time. Both expenditure and production activities are redirected toward these sectors; the economy becomes increasingly more services oriented in demand and supply. Again, imports contribute only a small share of total supply as growth in domestic production keeps pace with demand growth. Imports account for less than 1.0 percent of total availability in 1980 and less than 2.0 percent in 2000.

Domestic supply and demand trends in the remaining sectors show different patterns. Energy's share of total domestic output is stable through the mid-1980s and declines only gradually thereafter. In production, the energy trends are not as pronounced as those observed for final spending and input purchases. From 1980 to 1985, slower growth in energy demand is accompanied by a shift away from oil and gas and toward electricity and coal. However, these changes are not sufficient to prevent an increase in oil and gas imports for this period. Consequently, energy's share of domestic production is stable. There is greater use of domestically produced coal and electricity but also increased reliance on energy imports. After 1985, the share of energy in total demand declines more rapidly than the share of energy in domestic production. This pattern reflects the increasing contribution of domestically produced energy (coal, electricity, synthetic fuels, renewables, etc.) and results in a declining role of imported energy in overall supply. Thus, there is not only a shift away from energy in response to price changes and spending adjustments, but also a gradual shift from imported toward domestic energy.

Demand trends in nonenergy manufacturing are marked by stability, both in final spending and as a productive input. Yet, there is a continuous decline in its relative importance within total domestic output. With demand shares approximately constant over time and a declining share of domestic supply in total availability, imports of manufactured goods increase in relative importance. In fact, the import share of total supply rises from 3.0 percent in 1980 to 7.6 percent by 2000.

Commercial transportation increases in relative importance within final spending and intermediate purchases. However, its share of total U.S. production is stable throughout the projection horizon. As in the case of manufacturing, this implies a significant increase in the use of imported transportation services; the domestic share of total supply falls from 94 percent to 87 percent over the twenty-year period ending in 2000.

The production trends in manufacturing and commercial transportation have important implications for future energy demand. Growth in energy use is slowed both in direct response to energy price increases and indirectly, through effects on the structures of final spending and intermediate purchases, i.e., less energy-intensive goods and services are demanded. But, both manufacturing and commercial transportation are relatively energy intensive, so that growth in energy demand is slowed further by importing energy in the embodied form of finished goods and services. This suggests that some portion of the energy import problem confronting the U.S. is exported to other producing nations.

4.7 SUMMARY OF THE MACROECONOMIC PROJECTION

The main characteristics of the U.S. economy over the remainder of the century can be summarized as follows:

- Real GNP growth is relatively low during the early 1980s, reflecting lower employment growth (compared with the 1970s), a continued low rate of productivity advance, and higher energy prices.
- Real GNP growth is higher and is stable over the period 1985 to 1995. The moderation of energy price increases and increasing productivity growth compensate for the continuing slower growth of the labor force.
- From 1995 onward, real GNP growth is sharply increased. Labor force expansion accelerates and augments the continuing productivity improvement.
- Productivity growth is of increasing importance over the entire projection horizon.

- Consumption remains the dominant use of final output, with investment, exports, and imports increasing in relative importance and government purchases declining in relative importance. Tax incentives that favor saving and investment and the reduction in the growth of government expenditure stimulate capital formation which, in turn, allows an increase in the capital intensity of production and continuing improvements in the growth of output per worker.
- Relative price structures are projected to change significantly. For inputs, the prices of energy and labor rise relatively more rapidly than do those for capital and materials. For outputs, the prices of energy and energy-intensive goods and services rise more rapidly, on average, than do those of the more services-oriented sectors of the economy.
- Within final spending, there is a structural shift away from energy and, gradually, from energy-intensive goods and services. Final spending is redirected toward the outputs of the services industries. These changes occur in response to relative price changes and changes in the disposition of final output, i.e., consumption, investment, etc.
- Production becomes increasingly more capital intensive and less labor intensive. Growth in energy use, measured in physical units, is slowed significantly, so that the energy intensity of production (Btu per dollar of total input) declines. There is, however, a restructuring of energy inputs to production toward relatively greater use of electricity. Also, the relative importance of materials, as an input to production, increases. This implies that production becomes more intensive in purchased goods and services rather than primary economic inputs. The increase in the capital-labor ratio and economic specialization (indirect production) are major sources of the improvements in gross labor productivity. Finally, as the economy becomes progressively more services oriented, input patterns within intermediate materials shift toward purchased services at the expense of goods and materials.
- Growth in domestic supply conforms to demand growth in all sectors except energy, manufacturing, and commercial transportation. In energy, total demand is increasingly satisfied by domestically

produced energy. For manufacturing and transportation, imports account for an increasing fraction of total availability. Thus, growth in energy demand is slowed not only by structural changes in final spending and intermediate purchases but also by shifting the production of energy-intensive goods and services to foreign producers and redirecting productive inputs to the domestic energy and, more importantly, the services industries.

- The restructuring of spending, input, and output patterns permits the energy intensity of the economy to decline substantially and steadily over time.

5 ENERGY SYSTEM DEVELOPMENT

5.1 DELIVERED ENERGY PRICES AND QUANTITIES

Average delivered prices for all fuels and electricity are shown in Table 5.1. Delivered prices in TESOM are a function of resource prices; fuel price markups by product type and sector; refining, cleaning, and transmission and distribution efficiencies; annualized capital costs; and operation and maintenance costs. Resource price assumptions are discussed in Section 3.2, above. Fuel price markups are based on historical data, and except for the coal, wood, and biomass markups, remain constant over time. Efficiencies for refining, cleaning, and transmission and distribution rise slowly over the period 1980 to 2000. Real capital costs are held constant over time (in constant dollars) except those for electricity generating plants and synthetic fuel processing plants, which increase at the rate of one percent annually. These factors tend to soften the impact of increasing resource prices on delivered energy prices. Thus, real delivered energy prices grow at rates lower than those of primary energy resources.

The reference projection shows that in the year 2000, oil products are still far more expensive than gas delivered to all consuming sectors. Oil rises from $7.07 per million Btu in 1980 to $12.92 in 2000 (all prices in constant 1980 dollars), while gas rises from $3.12 to $8.54. Wood and biomass remain a relative bargain, with an average delivered price of $2.25 in 2000. This average price remains low because of the substantial use of waste wood by the pulp and paper industry. The average delivered price for the direct use of coal rises to $2.07 in 2000, or about $46 per short ton.

Table 5.1
Delivered Energy Prices by Fuel Type (1980 $/Million Btu)

	1980	1985	1990	1995	2000
Coal (direct use)	1.51	1.63	1.76	1.90	2.07
Coke	3.20	3.28	3.42	3.57	3.74
Wood, biomass	1.38	1.76	1.89	2.08	2.25
Oil	7.07	9.19	10.39	11.73	12.92
Methanol		13.62	13.92	14.26	14.92
Gas	3.12	5.49	6.38	7.55	8.54
Lo-Btu gas		5.32	5.68	6.04	6.36
Electricity	17.61	18.72	18.79	19.04	19.51

Methanol, at $14.92 per million Btu in 2000, is more expensive than oil in all periods (although the gap narrows as the end of the century approaches).

The average price of electricity rises very slowly from $17.61 per million Btu in 1980 to $19.51 in 2000. This corresponds to delivered prices in 2000, in 1980 cents per kWh, of 7.1¢ to the residential and commercial sector, 6.0¢ to the industrial and feedstocks sector, and 6.3¢ to the transportation sector, or an average annual growth rate of only 0.5 percent. The slow rise can be explained in large part by the change in the mix of refined fuel inputs to electricity generation plants (see Section 5.2 below). The resource prices for these fuels (Table 3.6 above) show clearly the price differential between coal, nuclear fuel, and oil and gas products. As electric utilities turn away from oil and gas, because of both high price and limited availability, coal and nuclear capacity become more attractive, slowing the growth in delivered electricity prices.

Table 5.2 shows delivered fuel prices by sector of consumption, with fuels aggregated by type (solids, liquids, gases, and electricity) for each sector. As expected, solids are the least expensive source of energy,

Table 5.2
Delivered Energy Prices by Economic Sector (1980 $/Million Btu)

	1980	1985	1990	1995	2000
Residential/Commercial					
Coal, coke, wood, biomass	2.98	3.29	3.47	3.73	3.99
Oil, methanol	6.62	8.77	9.98	11.30	12.52
Gas, lo-Btu gas	3.53	5.91	6.82	8.01	9.02
Electricity	18.59	19.55	19.74	20.13	20.81
Industrial and Feedstocks					
Coal, coke, wood, biomass	1.83	2.00	2.09	2.20	2.32
Oil, methanol	5.99	8.25	9.60	11.05	12.40
Gas, lo-Btu gas	2.75	5.13	6.04	7.21	8.20
Electricity	16.20	17.35	17.21	17.32	17.60
Transportation					
Oil, methanol	7.64	9.70	10.80	12.07	13.18
Electricity	16.20	17.35	17.53	17.89	18.43

followed by gases, liquids, and electricity. Price differentials between sectors are determined by historical fuel markups, reflecting the differences in processing and service charges involved in delivering different grades and quantities of fuels to end users. Since residential and commercial users generally require a higher grade product and incur substantial handling charges, all fuel types in all time periods are more expensive to residential and commercial users than to industrial customers. Oil and methanol used by the transportation sector are more expensive than liquid fuels delivered to other sectors, again reflecting the quality of the product involved.

Total delivered energy use rises from 57 quads in 1980 to 70 quads in 2000, at an average annual growth rate of 1 percent. Delivered energy includes electricity used by all sectors, and losses in electricity generation account for most of the drop in quantity from primary to delivered energy.

The mix of delivered fuels used to satisfy demand requirements over the years 1980 to 2000 is shown in Table 5.3 and Figure 5.1. Throughout the projection period there is a steady increase in electrification of the energy system and a continuous movement away from oil and gas products. Although

Table 5.3
Delivered Energy Quantities by Fuel Type (Quadrillion Btu)

	1980	1985	1990	1995	2000
Coal	2.0	2.8	3.8	4.9	6.4
Coke	1.4	1.6	1.8	2.0	2.2
Wood, biomass	1.8	2.0	2.1	2.6	3.3
Oil	28.4	29.1	27.8	27.4	26.5
Methanol	0.0	<0.05	0.1	0.1	0.2
Gas	15.6	15.4	16.1	16.2	16.8
Lo-Btu gas	0.0	<0.05	0.1	0.1	0.2
Electricity	7.3	8.6	10.0	11.3	12.6
Waste Heat	0.0	0.0	0.2	0.4	0.6
Direct solar	<0.05	<0.05	0.2	0.4	0.9
Geothermal	0.0	0.0	<0.05	0.0	0.0
Total	56.6	59.6	62.0	65.4	69.7

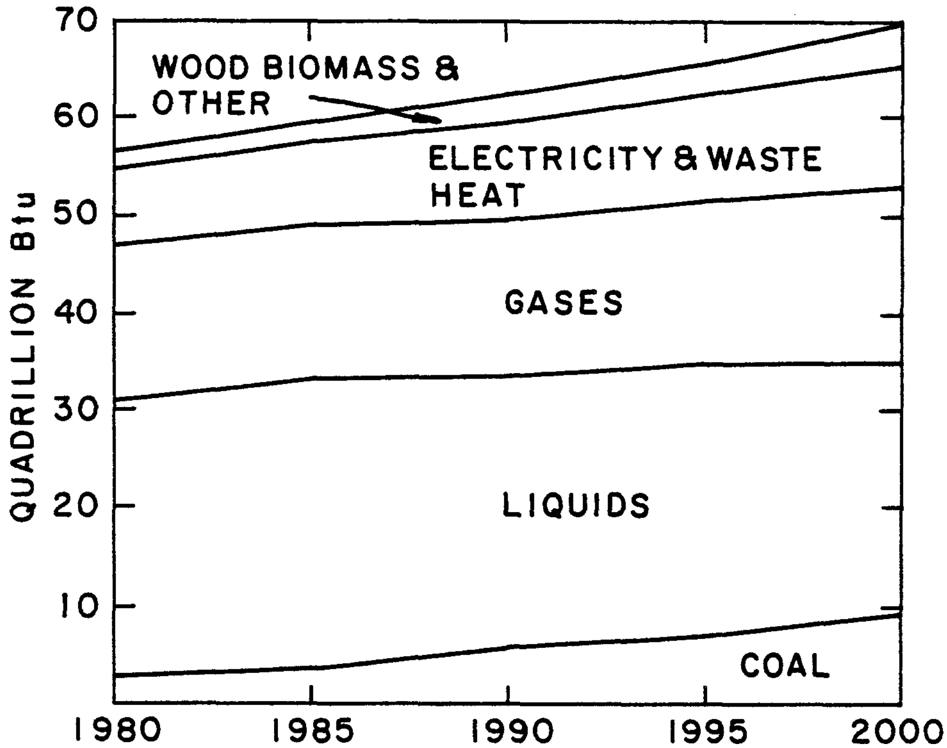

Figure 5.1. U. S. Delivered Energy Use.

electricity has the highest price of all delivered fuel types on a Btu basis, it can be used with almost 100 percent efficiency, while all other fuel types undergo significant Btu loss at the end-use device. Total direct use of oil increases slightly between 1980 and 1985, but declines in all years between 1985 and 2000 as the price continues to rise and as oil-using capital stock is slowly replaced. As a percentage of total delivered energy use, oil use declines in all years, falling from more than 50 percent in 1980 to 38 percent in 2000, as shown in Table 5.4.

Direct use of natural gas decreases slightly as the price jumps following decontrol in the period 1980 to 1985. However, since gas prices increase at a much slower rate than oil prices from 1985 to 2000, reaching a delivered price equal to only two-thirds the delivered cost of oil, direct use of gas increases slowly from 15 quads in 1985 to 17 quads in 2000. Gas usage maintains an approximately one-quarter share of delivered energy use over the 1985 to 2000 period.

Delivered coal consumption rises from 2 quads in 1985 to more than 6 quads in 2000, showing an increase in its share of total delivered energy from less than 4 percent to 9 percent. This does not include the significant increase in coal used for electricity generation (see below), mostly in the industrial sector, which replaces much of its oil and gas burning boiler capacity with more reliable coal-fired units.

Wood and biomass are projected to increase steadily in importance as direct usage rises from just under 2 quads in 1980 to over 3 quads in 2000, an annual growth rate of 3 percent. Most of this increase occurs in the industrial sector, where waste wood products are used heavily by the pulp and paper industry. Wood also increases in importance in the residential and commercial sector, where improved end-use device efficiencies make it somewhat more attractive as a fuel for space and water heating.

The direct heat category for delivered fuels includes waste heat, direct solar, and geothermal energy. Direct solar and geothermal do not enter into the reference projection until 1990. Total use of direct heat rises from 0.01 quads in 1980 to 1.5 quads in 2000, accounting for a rise from less than 0.01 percent of total delivered energy in 1980 to 2.2 percent in 2000. The largest part of this is direct solar, which represents 1.3 percent of all energy used in 2000. The direct use of geothermal remains negligible in all time periods, although significant geothermal energy is used for electricity generation.

Methanol enters the market slowly, and only 0.2 quads are used by the year 2000. Methanol is not projected to become very cost competitive during this reference period.

Table 5.4
Delivered Energy Usage Shares by Fuel Type (Percent)

	1980	1985	1990	1995	2000
Coal (including coke)	6.2	7.4	8.9	10.6	12.3
Wood, biomass	3.2	3.3	3.4	3.9	4.7
Oil	50.2	48.8	44.8	41.9	38.0
Methanol	0.0	<0.05	0.1	0.2	0.3
Gas	27.6	25.9	26.0	24.8	24.2
Lo-Btu gas	0.0	0.1	0.1	0.2	0.3
Electricity	12.8	14.4	16.1	17.2	18.0
Other renewables	<0.05	0.1	0.6	1.2	2.2
Total	100.0	100.0	100.0	100.0	100.0

Electricity usage increases from 7.3 quads in 1980 to 12.6 quads in 2000, rising from about 13 percent to 18 percent of total delivered energy use.

Table 5.4 shows that, despite all these changes in fuel flow patterns over the projection period, in 2000 oil products still have the largest share (38 percent) of all delivered energy. Oil is followed by gas plus lo-Btu gas at about 25 percent, electricity at 18 percent, and coal at 9 percent. Although the ratios have changed, the basic configuration is still the same as in 1980. This continued dependence on oil and gas products through the end of the century shows the difficulty with which the energy system adapts to new fuels and technologies even when compelled to do so by the rapid rise in the cost of conventional fuels.

Table 5.5 shows delivered energy quantities broken down by economic sector and fuel type. Usage shares for the residential and commercial, industrial and feedstocks, and transportation sectors are shown in Table 5.6.

In the residential and commercial sector, electricity rises greatly in use and replaces gas products as the primary fuel form by 2000. Electricity captures almost 43 percent of the market, and gases account for 38 percent. Liquids decline from 24 percent of usage in 1980 to 11 percent in 2000. Use of coal, wood, and biomass nearly doubles over this period, but still accounts for less than 5 percent of residential and commercial usage by 2000. The contribution of renewable solar and geothermal technologies approaches that of solids by the end of the projection period, rising from negligible usage in 1980, but despite these impressive gains renewables still make the smallest contribution to the residential and commercial sector.

The primary shift in delivered energy to industry and feedstocks is away from oil and, to a lesser degree, gas towards increased use of coal, wood, and biomass. The primary industrial fuel is natural gas in 1980, but it is replaced by solids in 2000, when solids account for about 32 percent of the market, and gases, 31 percent. Liquids decrease from almost 32 percent of the market in 1980 to only 20 percent in 2000. Electricity increases slowly from about 12 percent to almost 15 percent. Waste heat enters the market in 1990, and grows rapidly from 0.7 to 1.8 percent of total usage. Solar and geothermal, which make a tentative appearance in the industrial sector in 1985, rise to 0.6 percent of usage in 2000.

Table 5.5
Delivered Energy Quantities by Economic Sector and Fuel Type
(Quadrillion Btu)

	1980	1985	1990	1995	2000
Residential/Commercial					
Coal	0.2	0.2	0.2	0.3	0.3
Wood, biomass	0.2	0.3	0.3	0.4	0.5
Oil	3.9	3.7	3.1	2.2	1.9
Gas	7.4	7.2	7.1	6.7	6.6
Electricity	4.3	5.4	6.2	6.9	7.4
Direct solar	<0.05	<0.05	0.1	0.3	0.7
Subtotal	15.9	16.7	17.1	16.8	17.4
Industrial and Feedstocks					
Coal	1.9	2.6	3.5	4.6	6.0
Coke	1.4	1.6	1.8	2.0	2.2
Wood, biomass	1.6	1.7	1.8	2.2	2.8
Oil	7.4	7.6	7.1	7.1	6.8
Methanol	0.0	0.0	<0.05	<0.05	<0.05
Gas	8.2	8.3	9.1	9.5	10.2
Lo-Btu gas	0.0	<0.05	0.1	0.1	0.2
Electricity	2.9	3.2	3.6	4.3	5.0
Waste heat	0.0	0.0	0.2	0.4	0.6
Direct solar	0.0	<0.05	<0.05	0.1	0.2
Geothermal	0.0	0.0	<0.05	<0.05	<0.05
Subtotal	23.5	25.0	27.2	30.3	34.2
Transportation					
Oil	17.1	17.7	17.5	18.1	17.8
Methanol	0.0	<0.05	0.1	0.1	0.1
Electricity	0.1	0.1	0.1	0.1	0.1
Subtotal	17.2	17.8	17.7	18.2	18.1

The transportation sector is dominated almost entirely by oil products. Electricity, used almost entirely for electric rail, rises from 0.3 percent to only 0.8 percent by 2000. There is very limited opportunity for substitution in this sector as the price of oil products goes up, although there is substantial room for improvement in vehicle fuel use efficiency.

Table 5.6
Delivered Energy Usage Shares by Sector (Percent)

	1980	1985	1990	1995	2000
Residential/Commercial					
Solids	2.3	2.8	3.3	3.8	4.5
Liquids	24.4	22.1	18.3	13.4	10.8
Gases	46.4	42.8	41.2	40.1	38.0
Electricity	26.9	32.0	36.4	40.8	42.6
Solar, geothermal	<0.05	0.3	0.8	1.9	4.1
Subtotal	100.0	100.0	100.0	100.0	100.0
Industrial and Feedstocks					
Solids	20.9	23.7	26.1	29.0	32.3
Liquids	31.5	30.5	26.1	23.6	20.1
Gases	35.1	33.2	33.6	31.8	30.6
Electricity	12.5	12.6	13.4	14.1	14.6
Waste heat	0.0	0.0	0.7	1.2	1.8
Solar, geothermal	0.0	<0.05	0.1	0.3	0.6
Subtotal	100.0	100.0	100.0	100.0	100.0
Transportation					
Liquids	99.7	99.6	99.4	99.3	99.2
Electricity	0.3	0.4	0.6	0.7	0.8
Subtotal	100.0	100.0	100.0	100.0	100.0

Although oil remains the dominant delivered fuel throughout this scenario, the usage in each sector makes it clear that this is due largely to its lack of substitutability in the transportation sector. Oil use drops dramatically in all other sectors, and other substantial changes occur in sectoral fuel mix as coal and electricity usage become more attractive and as new capital stock enters the system.

5.2 ELECTRICITY GENERATED

Electricity generation between 1980 and 2000 is projected to grow at an annual average rate of 2.7 percent. Refined fuel inputs to generation plants increase from 25 quads in 1990 to 41 quads in 2000. As a percentage of total primary energy, refined fuel inputs to electricity generation plants grow continuously through the projection period, from 32 percent in 1980 to 41 percent in 2000. The largest percentage increases occur between 1980 and 1990, as the cost of primary energy rises sharply. Increased electrification of the energy system becomes desirable as the cost of delivered fossil fuels rises, since the mix of fuels used for generation can be altered to keep the price of electricity relatively stable.

Total generation of electricity grows from 8 quads in 1980 to almost 14 quads in 2000. The fuel mix used for generation (Table 5.7) is projected to change significantly over the base case period as oil and gas used in electric plants are displaced by coal, nuclear, and non-fossil fuels, which are more efficient and less expensive.

Electricity usage increases from 7.3 quads in 1980 to 12.6 quads in 2000, rising from about 13 percent to 18 percent of total delivered energy. Usage shares for refined fuel inputs to electricity generation are also shown

Table 5.7
Refined Fuel Inputs to Electricity Generation

	1980	1985	1990	1995	2000
Quadrillion Btu					
Coal	12.0	15.9	18.8	22.2	24.6
Oil	3.2	2.3	1.7	1.1	0.9
Gas	3.8	2.8	2.2	1.7	1.3
Nuclear	2.7	4.6	6.6	7.4	8.3
Hydroelectric	3.1	3.2	3.4	3.7	4.1
Photovoltaic	0.0	0.0	<0.05	<0.05	0.1
Geothermal	0.1	0.4	0.6	1.0	1.6
Solar thermal	0.0	0.0	<0.05	<0.05	0.1
Wind	0.0	<0.05	<0.05	0.1	0.3
Total	25.0	29.2	33.4	37.3	41.4
Percent Shares					
Coal	48.2	54.5	56.5	59.5	59.5
Oil	12.7	7.9	4.9	3.0	2.2
Gas	15.1	9.7	6.6	4.5	3.2
Nuclear	11.0	15.6	19.7	20.0	20.1
Hydroelectric	12.4	11.0	10.3	10.0	10.0
Other renewable	0.5	1.4	2.0	3.1	5.1
Total	100.0	100.0	100.0	100.0	100.0

in Table 5.7. Oil and gas usage are both projected to drop steadily and dramatically, while coal, nuclear, geothermal, and wind energy are projected to become increasingly feasible and economically desirable. Some oil- and gas-powered generation remains in the utility system because of the constraints of capital stock turnover.

Electricity generation by plant type is shown in Table 5.8. The total is 8 quads generated in 1980, equivalent to 2348 billion kWh, and is projected to rise to 4015 billion kWh by 2000.

Electricity generated from coal rises from 4 quads in 1980 to more than 8 quads in 2000. Its growth rate of almost 4 percent annually results in an increase of coal's share of total generation from about 50 percent in 1980 to 61 percent in 2000. Coal remains the primary fuel for electricity generation throughout the projection period, with central station coal steam electric plants producing most of the electricity. From 1990 onwards, these plants are joined by advanced coal electric plants, which produce 0.7 quads of electricity in 2000. The advanced coal plants include coal combined cycle, coal atmospheric fluidized bed combustion (FBC), and coal pressured FBC technologies. Electricity generation capacity for advanced coal plants increases from 13.9 megawatts in 1990 to 49.2 MW in 2000.

Table 5.8
Electricity Generation by Plant Type (Quadrillion Btu)

	1980	1985	1990	1995	2000
Coal	4.0	5.3	6.3	7.5	8.3
Oil	0.9	0.7	0.5	0.3	0.2
Gas	1.3	1.0	0.8	0.5	0.4
Nuclear	0.9	1.5	2.2	2.5	2.8
Hydroelectric	1.0	1.0	1.1	1.2	1.4
Other renewables	<0.05	0.1	0.1	0.2	0.4
Total	8.0	9.5	10.9	12.3	13.7

Nuclear generation increases from 0.9 quads in 1980 to 2.8 quads in 2000, and is done solely in light water reactor plants. Advanced nuclear technologies are not expected to be implemented during the projection period. Nuclear generation rises at an average annual rate of 6 percent, more than double the less than 3 percent annual rise in total electricity generation. As a percentage of total electricity generation, nuclear rises from about 11 percent in 1980 to almost 16 percent in 1985, followed by a jump to 20 percent in 1990. This trend slows considerably through the remainder of the century, as nuclear maintains this 20 percent share.

Electricity generated from oil and natural gas falls sharply throughout the projection period. While oil steam, gas turbine, and gas steam together account for 27 percent of generation in 1980, their total share falls to 5 percent in 2000, with only 0.7 quads generated. The decrease in the use of these fossil fuels is caused by government regulation, high resource prices, limited availabilities, and retirement of plants burning these fuels. For plants that remain, utilization factors decline steadily throughout the base case period. For gas steam plants, for example, the utilization factor drops from 0.5 in 1980 to 0.2 in 2000.

Generation from hydroelectric plants increases at an average annual rate of 1.6 percent during the projection period, rising from 1.0 quad in 1980 to 1.4 quads in 2000. As a percentage of total electricity generated, however, hydroelectric power declines from 12 percent to 10 percent in 2000. Although the cost of hydropower makes it very attractive, there is little growth potential for hydroelectric power through the end of this century.

Other renewable technologies, including photovoltaic, geothermal, solar thermal, and wind energy, increase rapidly from their negligible contribution in 1980 but still do not make a substantial contribution by 2000. The aggregate share of these technologies in total electric generation rises from 0.3 percent in 1980 to 3.3 percent in 2000. The primary contribution is made by geothermal, with 0.3 quads of generation in 2000.

Total capacity increases in all years throughout the projection period, with the largest increases occurring between 1980 and 1985. From about 600 MW in 1980, total electricity generation capacity rises to 1055 MW in 2000.

5.3 SYNTHETIC FUELS

Synthetic liquids and gases provide almost 5 quads of delivered energy by the year 2000. Synthetic liquids (including oil from shale) account for almost 5 percent of total liquids consumed in 2000, and synthetic gases (including unconventional gas) for more than 11 percent of total gases. Synthetic fuels first become available in 1985, but provide only about half a quad of energy. By 1990, synthetic fuel production rises to almost 2 quads, and it grows at an annual rate of almost 9 percent through 2000. The production levels for synthetic fuels are given in Table 5.9 in quads and in Table 5.10 in physical units.

5.4 PRIMARY ENERGY SUPPLIED

Total primary energy usage is projected to grow at an average annual rate of 1.3 percent, rising from 78 quads in 1980 to 101 quads by the end of the century. These figures exclude U.S. exports, and include biomass and waste wood, which are not always included in EIA accounting schemes. Primary energy usage for the projection period is shown in Table 5.11 and Figure 5.2. Usage shares are shown in Table 5.12.

Table 5.9
Synthetic Fuel Production Levels (Quadrillion Btu)

	1980	1985	1990	1995	2000
Synthetic Liquids					
Coal liquids	0.0	0.1	0.6	1.1	1.7
Coal methanol	0.0	<0.05	0.1	0.1	0.2
Shale oil	0.0	0.1	0.2	0.4	0.7
Subtotal	0.0	0.2	0.9	1.6	2.6
Synthetic Gases			0.1	0.2	0.4
High-Btu coal gas	0.0	0.0	0.1	0.1	0.2
Low-Btu coal gas	0.0	<0.05	0.1	0.1	0.2
Unconventional gas	0.0	0.3	0.8	1.1	1.3
Subtotal	0.0	0.3	1.0	1.5	2.0
Total	0.0	0.6	1.9	3.1	4.6

Table 5.10
Synthetic Fuel Production Levels:
Liquids (Millions of Barrels Per Day) and
Gases (Trillions of Cubic Feet Per Year)

	1980	1985	1990	1995	2000
Synthetic Liquids					
Coal liquid	0.0	0.1	0.3	0.5	0.8
Coal methanol	0.0	<0.05	0.0	0.0	0.1
Shale oil	0.0	<0.05	0.1	0.2	0.3
Subtotal	0.0	0.1	0.4	0.8	1.2
Synthetic Gases					
High-Btu coal gas	0.0	0.0	0.1	0.2	0.4
Low-Btu coal gas	0.0	<0.05	0.1	0.1	0.2
Unconventional gas	0.0	0.3	0.8	1.1	1.3
Subtotal	0.0	0.3	1.0	1.5	2.0

Table 5.11
Primary Energy Usage (Quadrillion Btu)

	1980	1985	1990	1995	2000
Nonrenewable					
Domestic oil	20.5	17.9	15.9	15.9	16.9
Imported oil	13.5	15.3	14.2	12.2	8.9
Shale oil	0.0	0.1	0.2	0.5	0.7
Domestic gas	19.7	17.3	16.8	15.1	14.5
Imported gas	0.9	1.7	0.8	1.4	1.4
Unconventional gas	0.0	0.3	0.9	1.2	1.4
Alaskan gas	0.0	0.0	0.8	1.0	1.2
Liquid natural gas	<0.05	<0.05	<0.05	0.1	0.1
Coal	15.6	20.7	25.8	31.3	36.8
Uranium	2.7	4.6	6.6	7.4	8.3
Subtotal	72.9	77.9	82.0	86.1	90.3
Renewable					
Wood and biomass	1.8	2.0	2.1	2.6	3.3
Hydroelectric	3.1	3.2	3.5	3.7	4.1
Geothermal	0.1	0.4	0.6	1.0	1.6
Solar	<0.05	<0.05	0.2	0.4	1.0
Wind	0.0	<0.05	<0.05	0.1	0.3
Subtotal	5.1	5.6	6.4	7.9	10.4
TOTAL	78.0	83.5	88.4	94.0	100.7
Imports	14.4	17.1	15.0	13.7	10.4

Note: Domestic crude production includes natural gas liquids.

Table 5.12
Primary Energy Usage Shares (Percent)

	1980	1985	1990	1995	2000
Nonrenewable					
Domestic oil	26.3	21.4	18.0	16.9	16.8
Imported oil	17.3	18.3	16.0	13.0	8.8
Shale oil	0.0	0.1	0.2	0.5	0.7
Domestic gas	25.2	20.7	19.0	16.1	14.4
Imported gas	1.2	2.1	0.9	1.5	1.4
Unconventional gas	0.0	0.4	1.0	1.3	1.4
Alaskan gas	0.0	0.0	0.9	1.1	1.2
Liquid natural gas	<0.05	<0.05	<0.05	0.1	0.1
Coal	20.0	24.8	29.2	33.3	36.6
Uranium	3.5	5.5	7.4	7.9	8.3
Subtotal	93.5	93.3	92.7	91.6	89.6
Renewable					
Wood and biomass	2.3	2.3	2.4	2.7	3.2
Hydroelectric	4.0	3.8	3.9	4.0	4.1
Geothermal	0.2	0.5	0.7	1.1	1.6
Solar	<0.05	0.1	0.2	0.5	1.0
Wind	0.0	<0.05	<0.05	0.1	0.3
Subtotal	6.5	6.7	7.3	8.4	10.4
Total	100.0	100.0	100.0	100.0	100.0
Imports	18.5	20.4	17.0	14.6	10.3

Note: Domestic crude production includes natural gas liquids.

Domestic oil production is projected to fall from present levels of 20.5 quads (9.7 MMBD) to 15.9 quads (7.5 MMBD) in 1995, and then to increase to 16.9 quads (8.0 MMBD) by the end of the century. The reversal in production trends after 1995 depends on the successful development of frontier areas in Alaska and the Lower-48 and on large-scale use of enhanced-recovery techniques. Price incentives to domestic producers from rising world oil prices and oil decontrol are expected only to compensate the rising cost of exploration, development, and production. Thus, output in the foreseeable future is in the range of 15 to 18 quads (7.0 to 9.0 MMBD), with some cyclical fluctuation as new opportunities are exploited.

Demand, over and above domestic supply, must be met by imported petroleum. (This import condition also applies to the demand-supply balance for natural gas). The reduction in total petroleum demand between 1980 and 1985

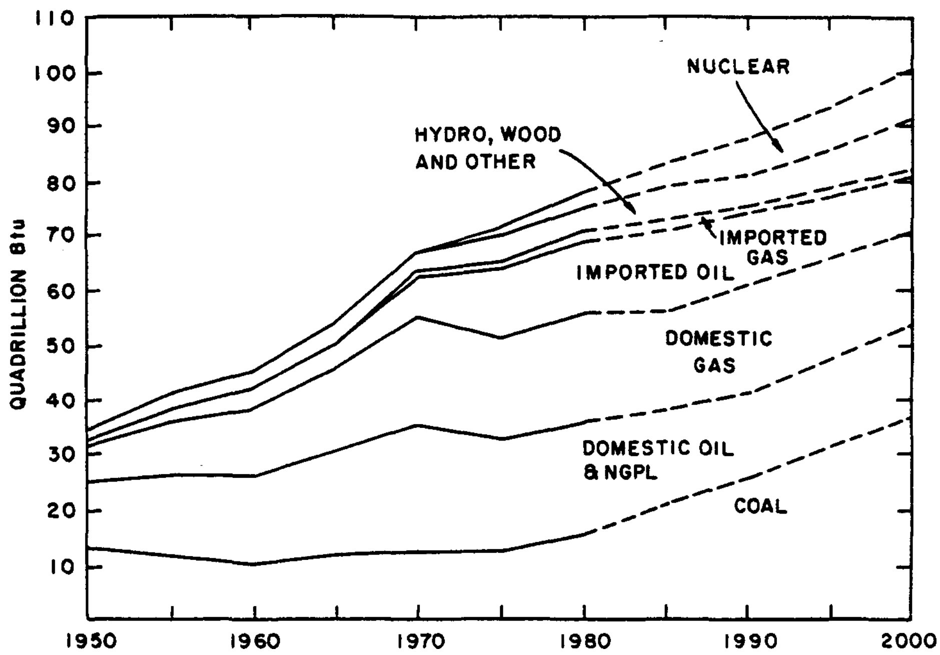

Figure 5.2. U.S. Primary Energy Use.

is not sufficient to reduce oil import requirements, given domestic production possibilities. Thus, oil imports increase slightly, from 13.5 quads (6.4 MMBD) in 1980 to 15.3 quads (7.3 MMBD) in 1985. From 1985 onward, oil import requirements steadily decline as demand contraction and supply expansion (from conventional and/or synthetic sources) occur. Oil imports reach levels of 14.2, 12.2, and 8.9 quads (6.7, 5.8, and 4.2 MMBD) in the years 1990, 1995, and 2000, respectively. Consequently, "oil vulnerability" continues to present a potential problem for the U.S. well into the 1990s.

Natural gas usage falls from 20.6 quads in 1980 to 18.6 quads in 2000. Most of this gas is domestically produced, with an increasing role played by unconventional gas and Alaskan gas by the end of the century. Natural gas (pipeline) and liquid natural gas are both imported in increasing quantities throughout the century, although their total usage share reaches only 1.5 percent of all primary energy by the end of the century. The largest drop in domestic natural gas usage follows decontrol in 1985, when price increases make it a less attractive energy source and also allow unconventional gas and Alaskan gas to enter the market competitively.

Coal usage increases dramatically, rising from about 16 quads (700 tons) in 1980 to almost 37 quads (1600 tons) in 2000. This growth takes place at a fairly even pace of 4.4 percent per year; by 2000, about two-thirds of this coal goes to electric generation. Coal's share of total primary energy rises from 20 to almost 37 percent by the end of the century, as its use for electric generation and synthetic fuels increases.

Nuclear fuel consumption rises sharply, from 2.7 quads in 1980 to 8.3 quads in 2000, to meet increased needs for electricity generation. This fuel is needed for plants currently under construction or planned to be in operation by 2000.

Non-fossil contributions to primary energy grow from 5.1 quads in 1980 to 10.4 quads in 2000. The largest non-fossil contributor in all time periods is hydroelectric power, followed by wood and biomass. Geothermal, solar, and wind energy make only small contributions, with a total usage share of 3.0 percent by 2000.

5.5 OIL IMPORTS AND TRADE

A relatively steady level of oil imports in conjunction with rising world oil prices means that the nominal bill for U.S. oil imports increases over time. Oil import payments are projected to increase from $79 billion in 1980 to $395 billion by 2000 (in current dollars). However, in the long run, oil imports will diminish as a percentage of total import payments (nominal and real) since the oil import quantity declines while other import quantities are projected to increase (see Table 4.2). From 1980 to 1985, the petroleum share of total imports increases from 41.4 to 44.6 percent. After 1985, when total imports rise from $136.0 billion to $292.6 billion (constant 1972 dollars) by 2000, petroleum's share steadily declines from 44.6 percent to 18.8 percent. But, exports must increase to sustain these overall import levels, regardless of the commodity mix within total imports. As discussed previously, exports are projected to rise continuously, from $161.6 billion to $314.0 billion (constant 1972 dollars), over the 1980 to 2000 period.

5.6 ENERGY SYSTEM EFFICIENCIES

Aggregate measures of efficiency for energy conversion and utilization are presented in Table 5.13, including those for primary resources to delivered fuels, for delivered fuels to energy services, and an overall

Table 5.13 Aggregate Energy Quantities and System Efficiencies				
		1980	1990	2000
Energy Quantities (quads)				
I	Total primary energy	78.0	88.4	100.7
II	Total delivered energy	56.6	62.0	69.7
III	Total energy service demands	32.6	39.5	49.0
Aggregate Efficiencies				
II/I	Average supply efficiency	0.73	0.70	0.69
III/II	Average demand efficiency	0.58	0.64	0.70
III/I	Average system efficiency	0.42	0.45	0.49

system-wide efficiency of energy services provided per unit of primary energy.

These efficiency indicators change over time as a result of the following:

- Projected improvements in efficiencies of conventional end-use devices and electricity generation.
- Introduction of new energy supply, conversion, and end-use technologies.
- Substitution of electricity, synthetic fuels, and renewable energy sources for oil.
- Changes in the structure of energy service demands over time.

The combined impacts of the increasing degree of electrification and the growth of synthetic fuels production accounts for the reduction in the amount of delivered energy obtained from each Btu of primary energy, as indicated by the declining average supply efficiency. These decreases in efficiency are offset by significant improvements in the average efficiencies of end-use devices. The replacement of vintage capital stocks and substitution for conventional fuels by those having relatively higher efficiencies at end-use conversion, such as electricity and solar, lead to a rising average demand efficiency over time. The average energy system efficiency is projected to increase at almost 1 percent per year from 1980 to 2000 as the U.S. moves from conventional liquid fuel dependency towards relatively less expensive and more efficient fuels and devices.

6 CONCLUSIONS AND POLICY IMPLICATIONS

The projection presented in this report, the BNL/DJA Long-Term Energy/Economy Reference Projection, provides a consistent long-run picture of the U.S. energy and economic systems. After a period of relatively slow growth in the early 1980s, GNP grows somewhat more rapidly through the mid-1990s and increases sharply thereafter (see Table 6.1). This growth path is largely driven by the available labor force, productivity improvements, and expected moderation in energy price increases. The importance of the foreign trade sector increases steadily throughout the projection period, but somewhat below historical rates, as the U.S. faces increasing competition in world markets. The relative importance of government expenditures declines throughout the projection period. Tax incentives that favor saving and investment stimulate capital formation and result in continuing improvements in the growth of output per worker.

The relative prices of energy and labor as inputs to production are projected to rise more rapidly than those of capital and materials, providing additional stimuli to increase energy and labor productivity. For outputs, the relative prices of energy and energy-intensive goods and services rise

Table 6.1
Summary of Economic Projection: Average Annual Growth Rates
(Percent per Year)

	1980–1985	1985–1990	1990–1995	1995–2000
Real GNP	2.7	2.8	2.8	3.2
Foreign trade				
Real exports	3.3	3.1	3.3	3.8
Real imports	4.6	4.9	5.0	5.7
Real government purchases	2.4	2.2	1.8	1.7
Real investment	5.7	3.4	4.0	2.6
Relative prices				
Energy	13.3	10.6	9.7	9.0
Labor	10.0	8.9	8.6	8.3
Capital	8.2	6.2	5.8	5.1
Nonenergy manufacturing	8.8	7.4	6.9	6.5
Communications, trade, and services	7.6	6.8	5.9	6.0
Constant dollar capital-output ratio	0.4	0.8	0.5	0.9
Constant dollar labor-output ratio	-1.1	-1.3	-1.7	-1.7
Capital per unit of labor	1.6	2.2	2.3	2.6
Energy per unit of capital	1.0	-0.9	-0.8	-1.3
Energy-GNP ratio	-1.2	-1.6	-1.5	-1.7

more rapidly, on average, than do those of the more services-oriented sectors of the economy. Consistent with this relative price shift, final spending moves away from energy and energy-intensive goods and services toward the outputs of the service industries.

Production becomes increasingly more capital intensive and less labor intensive. Growth in the energy intensity of production (measured in Btu) declines. However, energy use in production shifts away from fuels toward a greater use of electricity. Overall, the restructuring of spending, input, and output patterns permits the energy intensity of the economy to decline substantially and steadily over time.

Primary energy usage continues to grow, but at relatively low rates, through the end of the century, reaching just over 100 quads by the year 2000 (see Table 6.2). U.S. dependence on oil imports declines significantly; however, oil and gas imports account for 10 percent of our primary energy needs in the year 2000. The use of renewable energy sources (hydropower, geothermal, wind, solar, and biomass) increases fairly rapidly, but from a relatively small base, and these sources provide 10 percent of the resource requirements by the end of the century. While the use of liquid and gaseous fuels declines somewhat, their contribution to primary energy requirements falls significantly, from about 70 percent in 1980 to 47 percent in 2000. This results in increased dependence on coal, electricity, and renewable energy sources.

Table 6.2
Summary of Energy Projection: Average Annual Growth Rates
(Percent per Year)

	1980-1985	1985-1990	1990-1995	1995-2000
Primary energy	1.4	1.1	1.2	1.4
Energy imports	3.4	-2.5	-1.7	-5.4
Renewable energy sources	2.1	2.7	4.2	5.7
Liquid fuel use (including synthetics)	-0.3	-1.5	-0.8	-0.9
Gaseous fuel use (including synthetics)	-1.2	0.1	-0.4	0.1
Coal use	5.8	4.5	3.9	3.3
Electricity generation	3.4	2.9	2.4	2.2
Aggregate delivered energy use	1.0	0.8	1.1	1.3
Residential and commercial energy use	1.0	0.5	-0.4	0.6
Industrial and feedstocks energy use	1.3	1.7	2.2	2.4
Transportation energy use	0.7	-0.2	0.6	-0.2
Synthetic fuels	---	28.5	9.8	8.1

Over the forecast period, delivered energy use by the residential, commerical, and transportation sectors is slowed considerably, as these sectors take advantage of the many conservation options available to help mitigate the rising costs of energy. Industrial energy use continues to grow as the demand for petrochemical feedstocks continues to grow. In addition, the long lead times required for process changes and the slow turnover of the long-lived capital stock in this sector results in a much slower response to higher energy prices over the next 20 years.

Overall, the energy future can be characterized as one of slow evolution, with the U.S. dependence on liquid and gaseous fuels (both domestic and imported) slowly decreasing as the system shifts to more reliable and available energy forms (coal and renewables). The efficiency of energy use improves for all forms as the economic system substitutes relatively less expensive inputs (capital and materials) for the relatively more expensive inputs (labor and energy).

The extent to which these trends can be accelerated through energy policies and research and development is somewhat limited. However, it is clear from this projection that several areas could use additional stimuli to aid their transition to less expensive, more reliable energy forms. The transportation sector continues to be almost completely dependent on liquid fuels. The efficiency of energy use throughout the system increases slowly, but it is constrained as much by the vintage nature of the energy utilizing capital stock and its relatively long lifetimes, as by the efficiencies of the new devices. Research into basic science areas concerning heat transfer, materials sciences, and friction might enhance the efficiency of future conversion and end-use devices.

This projection provides a consistent aggregate projection of the U.S. energy and economic systems through the year 2000. The interrelationships and interactions between the two systems are many, and the evolution and direction of one cannot be separated from that of the other. The design and analysis of possible energy policies, contingencies, or research programs must be done against the backdrop of a consistent set of energy and economic information. Only then can the relative merits of possible actions be assessed correctly so as to ensure that the particular strategy chosen yields the best combination of benefits relative to the cost incurred.

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