Chapter III

U.S. Energy Consumption Patterns, 1952-82

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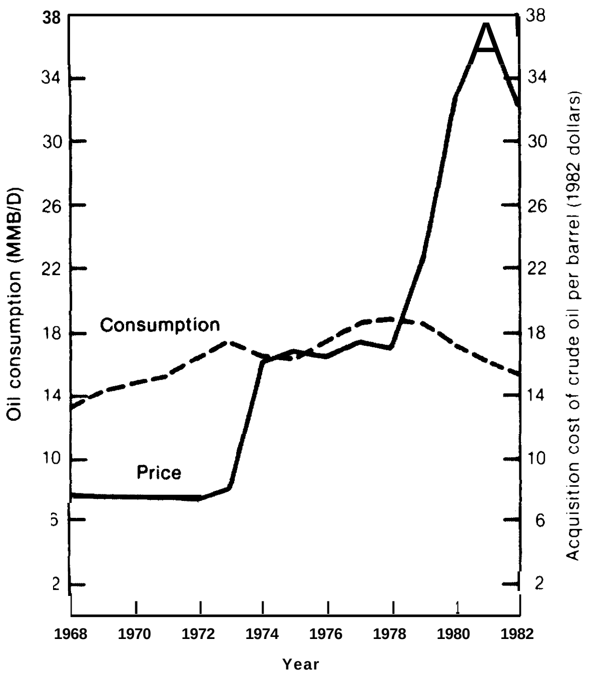
U.S. Energy Consumption Patterns, 1952=82

During the past decade, U.S. energy use changed considerably in response to a series of fuel supply shocks and reversals in energy supply/cost trends, By far, the most important fuel supply shocks involved oil imports. The first of two import disruptions occurred in 1973-74 as a result of the Arab-Israeli war. The second occurred in 1979-80 as a result of the Iranian revolution.

Both shocks had long-term effects on oil markets, effects that preview the expected consequences from a possible third disruption in the future. These effects on oil prices and total oil use over time are summarized in figure 6. As shown, average refiner acquisition prices more or less doubled during each disruption, and total oil use peaked.[1] Two years after the Arab oil embargo of 1973-74, total U.S. oil use had dropped to about 1 million barrels per day (MMB/D) below its 1973 peak. After the initial shock of the second oil disruption, total oil consumption declined for 4 years. In 1982, U.S. oil demand was more than 3 MMB/D below its all-time high of 18.8 MMB/D in 1978.

[1] The price of imported oil actually tripled during the 1973-74 curtailment, but the net effect on prices paid by refiners was reduced by the blending of imports with domestic production. Prior to 1973, domestic prices were much higher than import prices, and after 1973, domestic prices were temporarily held below international prices.

Figure 6.—Total Oil Consumption (MMB/D) and Price per Barrel (1982 dollars)



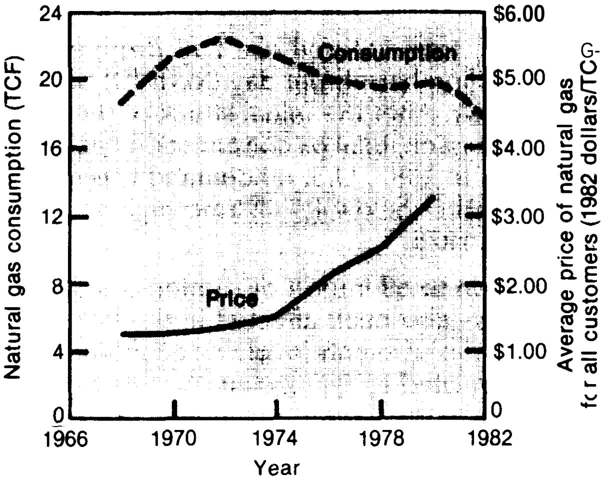
SOURCE: Energy Information Administration, 1962 *Annual Review of Energy*, Washington, DC, April 1963, pp. 67, 91.

In addition to oil import disruptions, U.S. energy use has also been affected in the last decade by a series of events involving economic adjustments related to energy supply/cost trends. These include the longest coal miners' strike in U.S. history; a reversal in natural gas production, which had been rising rapidly during the 1960s; a reversal in the cost of electricity, which had been declining for decades; the introduction of Federal and State environmental quality standards; and a dramatic shift in the financial cost of capital in 1979. Although the 1977-78 coal miners' strike, which lasted 109 days, may have had only temporary significance in terms of disrupting supplies, it boosted oil use during the period just prior to the Iranian revolution and thus increased oil demand at a crucial time. The other four economic adjustments deserve more attention because they continue to influence energy markets, as well as the potential flexibility of market responses to future oil import curtailments.

In 1972, domestic natural gas production hit a peak, after rising steadily since World War II (see fig. 7). The decline in total production resulted from a depletion of natural resources and from Federal price regulation, which held prices below the rising costs of producing gas from new reserves. At the same time, demand was expanding rapidly because gas is a good substitute for oil used in stationary heating applications, because gas can meet environmental emission standards at relatively low capital costs, and because the price of gas was held down by regulations while the price of oil rose sharply.

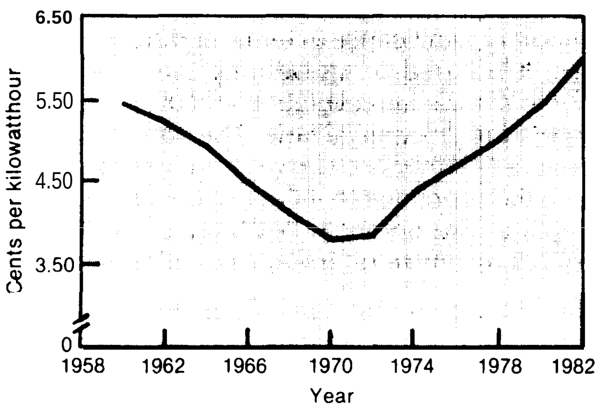
At about the same time that natural gas production peaked, the price of electricity sold by utilities bottomed out after decades of steady decline and began to rise during the 1970s (see fig. 8). This reversal resulted from several factors, in-

Figure 7.—Total Natural Gas Consumption (TCF/yr) and Average Price (1982 dollars/TCF)



SOURCE: Energy Information Administration, 1982 Annual Review *of* Energy, Washington, DC, April 1963, pp. 107, 117.

Figure 8.–Average Price of Electricity Sold by Electric Utilities, 1980-82



SOURCE: Energy Information Administration, 1982 *Annual Review of Energy,* Washington, DC, April 1963, p, 165.

eluding rising fuel costs, rising costs of meeting environmental regulations, and the rising cost of capital. In addition, during this period there were few technological advances to maintain or lower the capital cost per kilowatthour of generating capacity and/or to reduce the Btu input of fuel per kilowatthour of electricity produced.

Furthermore, the introduction of national environmental quality standards affected energy use during the past decade. The Clean Air Act and Amendments established a national system of air quality regulation, which included ambient air quality and prevention of significant deterioration standards. Partly because of these emissions standards and the uncertainty about future standards, many opportunities for switching to coal, which appeared economic on the basis of fuel costs alone, have not been pursued. Other reasons why switching to coal may not have been cost effective include the costs of conversion, handling equipment, transportation, and storage. Even today, coal still appears to be too bothersome and unreliable to handle and burn for any but the largest installations.

Finally, in 1979, a sharp increase in interest rates limited the growth potential for the entire economy and made it more difficult to reduce U.S. economic dependence on oil. Both of these economic limitations arose because the high cost of capital reduced the level of investment, decreased employment and worker productivity, and slowed improvements in energy efficiency and conversions to less expensive fuels. The high cost of capital particularly constrained growth in the electric utilities industry, which produces the most capital-intensive energy commodity, and made conversions from oil to coal extremely expensive.

This chapter discusses in detail how energy use patterns have changed during the past decade as a result of these developments, with particular emphasis given to oil and natural gas. Natural gas is examined in nearly as much detail as oil because it is an exceptionally good oil substitute for all stationary heat and power applications, provided the user can connect to a distribution pipeline.[2] Together, oil and gas are considered the premium fossil fuels.

[2] In fact, gas is the preferred fuel in many small burners, Such as those in the home, where it can be delivered by pipeline instead of by truck and where it burns more cleanly than oil. Furthermore, gas offers superior flame control in process heating and is the least costly source of hydrogen. However, as a gaseous fuel with a low-energy density per unit volume, it is inferior to oil as a transportation fuel because so little of it (measured in Btu) can be stored in a tank in between fillups.

ENERGY CONSUMPTION AND INTENSITY AVERAGED OVER THE ENTIRE U.S. ECONOMY[3]

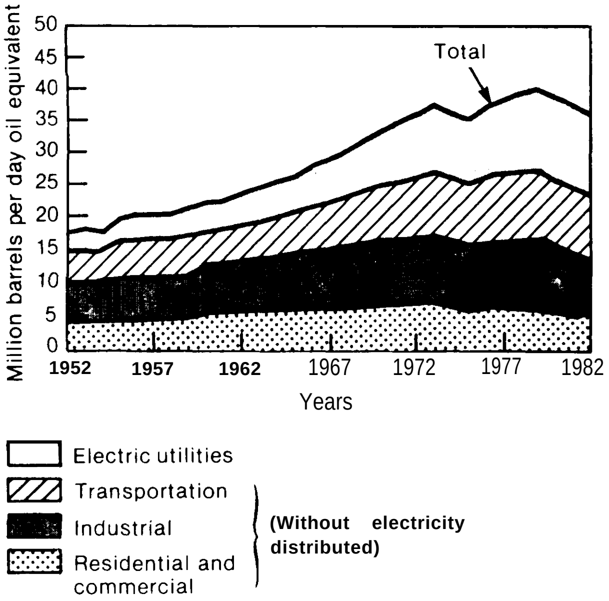
Prior to 1974, total U.S. energy use grew in step with the economy. Total energy use increased in every year for *20* years after 1952 except two, when minor declines occurred during economic recessions (1 *954* and 1958) *(see* fig. 9). The ratio of Btu per dollar of gross national product (GNP) stayed within a narrow band centered around *59,000 (see* fig. 10).

From 1952 to 1972, oil and natural gas accounted for nearly all (97 percent) of the increase in total energy use.[4] Until 1970, gas grew at a much higher rate than oil because of the rapid expansion of transmission and distribution lines built during World War II and because of the huge inventory of gas reserves discovered during oil exploration in the first four decades of this cent ury.

[3]The primary source of data for this and the next three sections is the 1982 Annual Review of *Energy,* EI A/DOE.

[4]The increased demand for coal for electricity production was more than offset by the decline in the direct use of coal in the industrial and transportation sectors.

Figure 9.–Consumption of Energy by End-Use Sector



SOURCE Energy Information Administration, 1982 Annual Review *of Energy,* Washington, DC, April 1983, p. 8

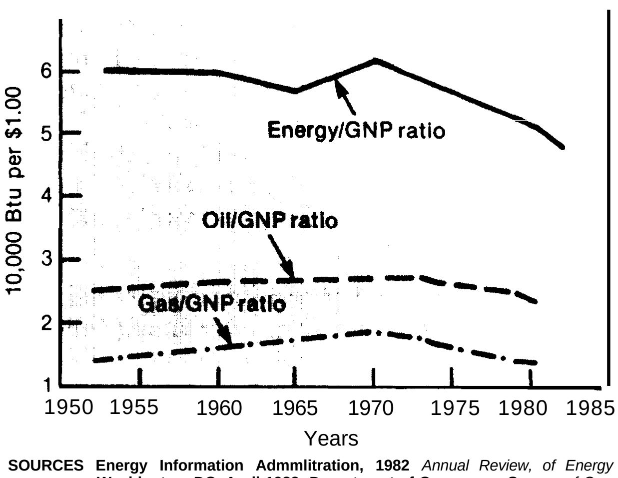
However, all of these trends changed in the early 1970s. Total energy use declined in 1974 and 1975 (see fig. 10). After 2 years of significant decline, total energy use bounced back in 1976 and 1977 and increased in 1979, reaching the most recent peak at just under 79 quadrillion Btu (quads).[5] Since then, total energy use has declined on the average by more than 2.7 percent per year through 1983.

Since 1973, oil and gas use has followed a similar pattern. The upward trend in oil use reversed itself after the Arab oil embargo of 1973-74. It should not be surprising that the upward and downward movements in total energy use and premium fossil fuel consumption would be similar, since the latter accounts for most of the total. It is also worth noting that the premium fuel share in total energy has steadily declined from a peak of 78 percent in 1972 to 67 percent in 1983.

Beginning in the early 1970s, a dramatic change occurred in the growth rates for oil and gas relative to the GNP. Before 1970, use of both premium fossil fuels grew more rapidly than the GNP, as shown in figure 11. Since 1973, both

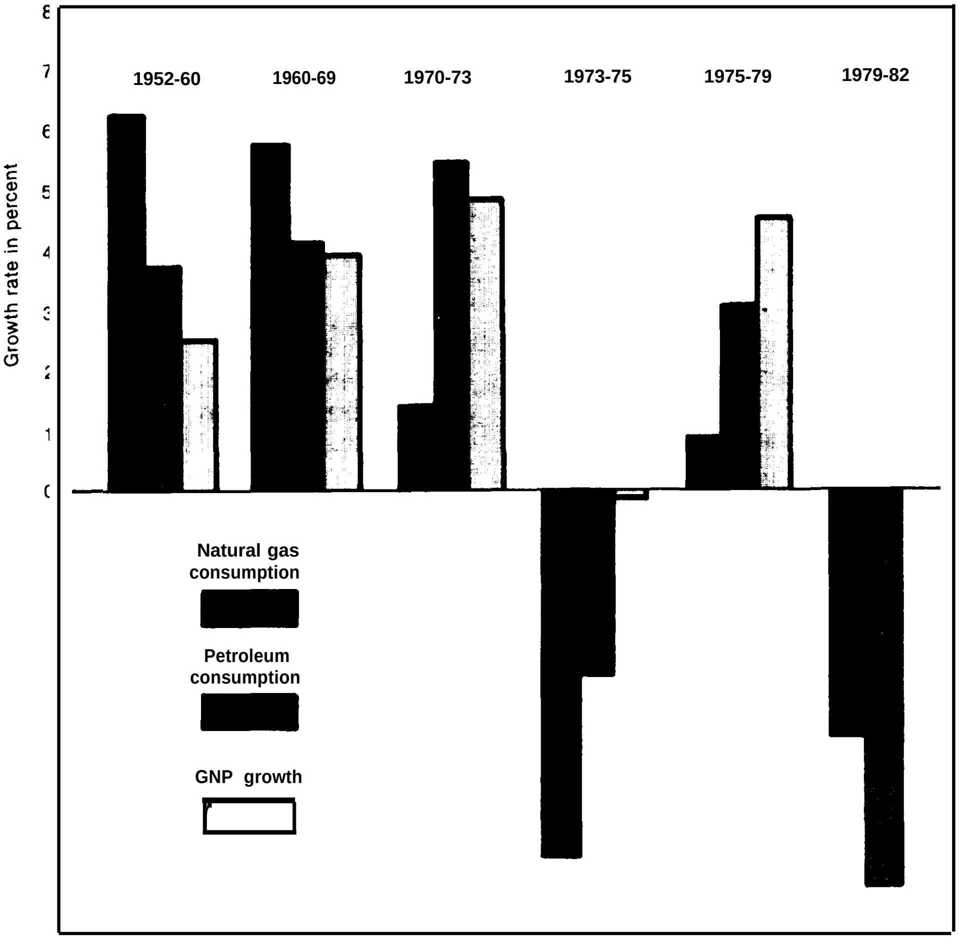
‘One quad = 1 quadrillion (1015, Btu.

Figure 10.—Energy Consumption-GNP Ratios, 1962-62



SOURCES Energy Information Admmlitration, 1982 *Annual Review, of Energy* Washington, DC, April 1983; Department of Commerce, Survey *of Current Business,* March 1984 Bureau of the Census, Statistical *Abstract of the United* States 1983, Washington, DC, 1983.

Figure 11.—Energy Use and GNP Growth Rate Trends, 1952-82



SOURCES: National Income and Product Accounts of the U.S. Department of Commerce, Bureau of Economic Analysis, September 1981; and Energy Information Administration, *I&Z Annual Review of Energy,* Washington, DC, April 1983.

rates have either grown more slowly or, when GNP decreased, declined more rapidly than the GNP. As measured by the ratio of fuel used to economic activity, oil peaked in 1973 at 27,000 Btu per dollar and declined steadily to 19,800 Btu per dollar in 1983. Natural gas peaked at 14,000 Btu per dollar in 1970 and declined to 11,300 Btu per dollar in 1983.

The major reason for these changes in fuel use was rapidly increasing prices, after taking general inflation into account. Figure 6 shows that since 1972, oil prices more than quadrupled and natural gas prices almost tripled. These enormous increases motivated all premium fossil fuel users to reduce their consumption. The price increases also gave domestic oil and gas producers strong new incentives to increase exploration and production. The domestic natural resource base has not increased significantly, however, and domestic oil production has declined since 1970, except for the addition of Alaskan oil. Domestic natural gas production also dropped below its 1973 peak, although the actual decline in production capacity is somewhat obscured by current uncertainties associated with Federal price regulation and possible deregulation.

ENERGY CONSUMPTION BY END-USE SECTOR

Using conventional energy accounts, total energy use can be divided into five sectors: 1) residential; 2) commercial; 3) industrial; 4) transportation; and 5) electric utilities. Residential and commercial energy use figures are often combined because data are not collected separately for all fuels. Fuel use data for electric utilities are also folded into total energy use by the other sectors because electricity is valued in the economy only as an intermediate input into the consuming/producing activities associated with the other four divisions. What is commonly called the industrial sector includes the activities of manufacturing, mining, construction, and agriculture,

Data are gathered for all five sectors, when possible, because each has a distinctive economic objective (e. g., residential, commercial, and industrial) or engages in a distinctive activity (e.g., transportation and electric utilities). Furthermore, with the exception of the transportation sector, each sector comprises a different group of decisionmakers with different economic problems. The combination of distinctive objectives and problems means that the sectors may follow trend lines distinct from one another as the economy grows and contracts over time.

All Fuel Products

When separated, electric utility fuel use displays by far the strongest growth trend, increasing by almost 500 percent and doubling its share over 30 years (see fig. 9). All sectors generally increased their energy use from 1952 to 1972, although industrial consumption declined somewhat during the recession years, particularly 1954 and 1958.

During the next 10 years (through 1982), residential/commercial energy use (excluding electricity) declined by about 20 percent, and industrial consumption declined by about 22 percent. Measured in terms of share in total fuel use, the residential/commercial sectors declined more than 3 percentage points during the last 10 years, compared to a 2-percentage-point decline during the 1952-72 period. The industrial sector share declined by 7 percentage points during the last 10 years, compared to a decline of 8 points during the previous 20 years. From 1972 to 1982, electric power generation increased its share by 8 percentage points and transportation increased its share by about 2 points.

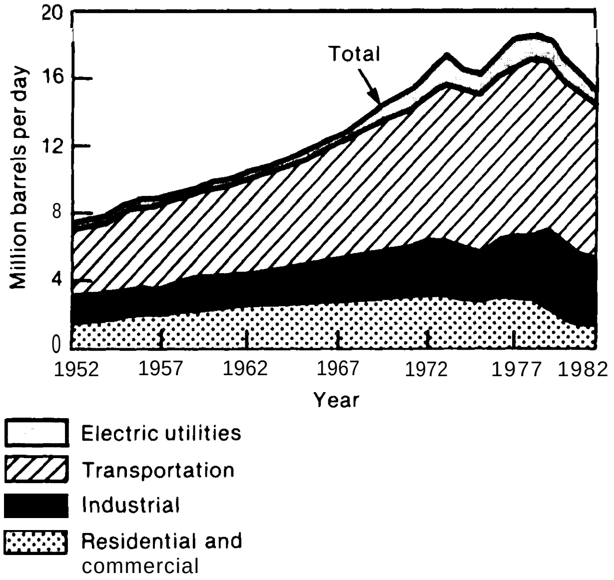
When electricity fuel use data are folded into totals (at 10,000 Btu per kilowatthour [kWh]) for the three end-use sectors, the trend for the residential/commercial share is reversed. Instead of declining during the 30-year period, the share rose steadily, and actual energy use stayed relatively stable after 1974. Electrification, in other words, was of major importance. In the industrial sector, the addition of electricity made only minor changes in both share and actual use trends. There was still a long-term, steady decline in the industrial share of total energy and a significant decline in actual consumption over the last 10 years. In fact, no long-term trend in shares of energy use by sector was reversed during the past decade of oil price inflation and other energy market turmoil.

Oil Consumption

As shown in figure 12, oil use in all four sectors grew steadily prior to 1973. The electric utilities sector experienced the most rapid increase, growing by an average annual rate of about 10 percent and more than tripling its share of total oil use over the 20-year reporting period. Oil use by the residential/commercial sector grew most slowly over the same period, showing an average annual growth rate of about 3.2 percent. Industrial sector oil use grew at about 3.7 percent per year, while transportation sector use grew at the rate of 4 percent annually.

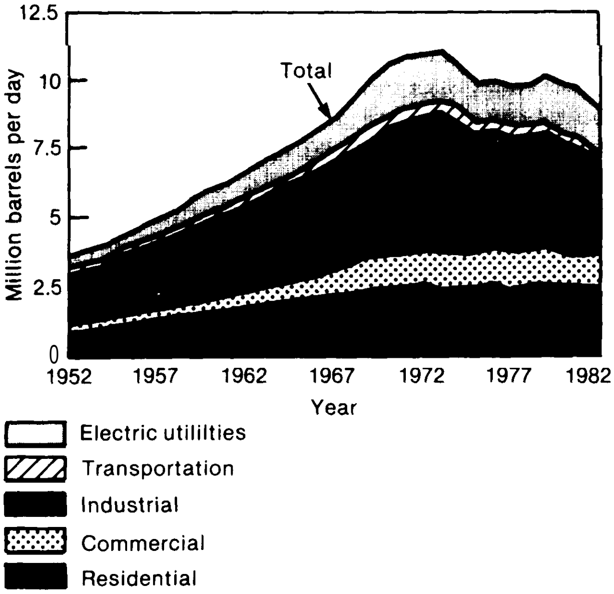
Since 1973, oil use has been shifting to the transportation sector. The industrial sector has maintained its share in total oil use in the last decade, principally because nonfuel use of oil—e.g., as a raw material—has grown, offsetting the decline in fuel applications. In contrast, the residential/commercial sector continued to lose its share of total oil use, and at a rate faster than that exhibited in the previous 20 years. Finally, after holding its total use and its share of total oil use

Figure 12.–Refined Petroleum Products Supplied to End= Use Sectors



SOURCE: Energy Information Administration, 1982 *Annual Review of Energy,* Washington, DC, April 1983, p. 66.

Figure 13.—Consumption of Natural Gas by End-Use Sector



SOURCE: Energy Information Administration, *1982 Annual Review of Energy,* Washington, DC, April 1983, p. 106.

constant until 1978, electric utilities have since lowered both sharply.

Natural Gas

Natural gas use data are available for all five end-use sectors. However, only four sectors show significant trends (see fig. 13). In the transportation sector, gas use has remained constant at 3 percent of the total since 1952 because it is used almost exclusively as a fuel for pipelines. The other four sectors steadily increased gas use until 1972. During the last decade natural gas use declined in all sectors, with the greatest decline occurring in the industrial sector.

In terms of natural gas shares over the 30-year period, the industrial sector had the largest drop, declining from 55 percent of the total to about 38 percent of total natural gas consumption, while the commercial sector experienced the largest gain, increasing its share from 7 to about 15 percent, The electric utilities sector also increased its share significantly, increasing from 12 to 18 percent of the total, and the residential sector increased its share by 4 percentage points to 29 percent.

These fuel share trends are the result of both market and regulatory forces, as mentioned above. Many industrial customers found that in the mid-1970s their gas supplies were unreliable and there was the threat that gas prices would rise sharply, due to resource depletion, regulatory actions, or both. During emergency shortage conditions (e.g., severe cold), residential/commercial customers were given priority, and Federal legislation called for industrial customers to pay more for gas in order to encourage fuel switching to coal (i.e., ''incremental pricing''). After 1979, industrial customers began switching back to gas from residual oil because oil prices increased, and gas supply conditions eased. This, however, did not show up as an increase in total gas consumption by industry because fuel conservation measures and slack demand for industrial products lowered total energy demand.

PETROLEUM PRODUCT MIX

Refineries convert crude oils into a variety of products. Although most of the products are fuels, crude oils can also be refined to produce petrochemicals—i e., feedstocks for the manufacture of a wide variety of plastics, synthetic fibers, paints and coatings, adhesives, piping, and the like.

Each of these products offers different opportunities for material substitution and conservation in its end-use applications. By examining the current product mix and its applications (next section), and how these have changed over time, the nature of U.S. economic dependence on oil can be described.

Out of at least 15 distinct product categories, the Energy Information Administration reports a 30-year consumption time series for six (see fig. 12 and table 3). The "other products" category includes kerosene, petrochemical feedstocks, lubricants, wax, petroleum coke, asphalt, road oil, still gas, natural gasoline, unfractionated stream, plant condensate, and miscellaneous other products. This category is a mixture of fuels and materials.

Before describing trends in greater detail for each of these product categories, it is important to note that production for all six increased during the 1952-72 period. A growing economy that required greater numbers of engines, greater quantities of heat and steam, and larger volumes of petroleum-based chemicals and synthetic materials was the primary force in driving oil use up,

Table 3.—EIA Petroleum Product Categories

	Percent of total liquids[a] used in 1982
1. Motor gasoline	41.5
2. Distillate fuel oil.	18.8
3. Residual fuel oil	13.0
4. Ethane and liquified gases.	**6.5**
5. Jet fuel	**6.8**
6. Other products	**13.4**
Total	100.0

[a]**Includes natural gas liquids and all products made from** crude oil.

SOURCE: Energy Information Administration, 1983 *Annual Review* **of** *Energy*, **Washington, DC, April 1983.**

However, consumption of all products slipped in 1974 and 1975 as a result of rapidly rising fuel prices. After the initial price shock wore off and as real prices declined, the economy began to grow again in the mid-197@ and product demand rose until 1979. **In the last 4 years, all but one product category —ethane and liquefied gases –declined as a result of price escalation, the economic recession, and the higher fuel efficiency of new cars. Each of the six major product categories is discussed** below.

Motor Gasoline

Gasoline is used almost exclusively in automobiles and light trucks. Since 1952, the share of gasoline in total oil use has stayed in the neighborhood of **40 percent. When real** oil prices were steady, growth in gasoline demand was relatively low, and when prices rose sharply in the last decade, consumption declined at a relatively slow pace. Since total oil consumption peaked in 1978, gasoline use has declined by a smaller percentage than four of the five other product categories. Perhaps a much sharper decline is imminent, as expected technological change would suggest (see ch. V). Because gasoline represents such a large portion of all petroleum products, however, even a small percentage decline translates into larger volume declines.

Distillate Fuel Oil

Distillate (#1 or #2) is used primarily for heat and mechanical motion (diesel). While #2 fuel oil and diesel are chemically distinct, they are generally considered as one fuel product because they come from the same boiling fraction in a barrel of crude oil and refineries can trade them off with little change in operations. Like gasoline, distillate has maintained over 30 years its share in total oil use, but its roughly 18-percent share is less than half that of the predominant product.

Residual Fuel Oil

The next largest single petroleum product category (measured by volume) is residual fuel oil (resid). As its name implies, it is the residuum, or bottom, of a barrel of crude, which remains after all other fractions have vaporized into the distillation column. Residual oil is generally too viscous to flow without preheating and special pumping. Therefore, its use is limited to large boilers. Residual fuel has been the only product category to lose its share of total petroleum use continually over the 30-year period, going from 21 percent in 1952 to 11 percent in 1982. Its most rapid share loss has occurred during the past 4 years, primarily because of the large decline in use by electric utilities. In general, this declining share has been the result of its relatively low end-use value, the availability of good fuel substitutes (e.g., coal and natural gas), and the increasing ability of refiners to crack large resid molecules into higher valued fractions, such as gasoline and distillate.

Ethane and Liquefied Gases

These relatively light hydrocarbons are used primarily as petrochemical feedstocks and secondarily for high-quality process and space heating, particularly in remote areas. Over the past 30 years, this category sharply increased its share in total oil use (from 4 to 10 percent) because both demand and supply conditions were favorable.

On the supply side, unlike other refined petroleum products, liquefied gases have an alternative source of supply in natural gas reserves. Since gas use expanded more rapidly than oil over this period, the potential supply of liquefied gases expanded at more than twice the rate of other petroleum products.

On the demand side, these light liquids are used primarily for chemical feedstocks, and demand for feedstocks has continued to be strong even during periods of sharply rising prices. The strength of this demand may be explained by the relatively rapid growth of the chemicals industry[6] and by the relatively low-cost share of feedstock materials in total petrochemical product cost leading to relatively low price elasticity for petrochemicals.

Jet Fuel

Jet fuel is the other product category that has sharply increased its share among all oil products over the last 30 years. However, this increase occurred entirely before 1973. Since then, its share has remained relatively steady. This category (slightly less than 7 percent of total product) is the least important of the five major products, as measured by volume consumed.

Other Petroleum Products

A diverse group of products are included in this category, making it difficult to generalize about end-use trends except to note that about 90 percent of the end uses are used in the industrial sector. The nonindustrial uses are primarily for kerosene for space heating and hot water and lubricants for transportation. Since the share of industrial activity in the economy has been steadily declining (see later section in this chapter), the share of this petroleum product group may tend to decline, as well. However, since 1952 this composite category has maintained its share in total oil consumption at around 13 percent. Although its share declined to about 12 percent in 1982, this appears to be the result of a temporary decline in industrial output associated with the deep recession in that year. The reasons for this share stability are the same as those for liquefied gases, given above.

[6] Measures of relative growth for the chemicals industry are rendered imprecise by relative price changes over such a long time period (30 years). However, two growth rate comparisons are available which nevertheless clearly show the strength of this industry. First, as reported by the Department of Commerce (*The National Income and Product Accounts* of the United States, 1929-76, Statistical Tables, pp. 229-233), income generated (current dollars) by "chemical and allied products" grew at an annual rate of 7 percent, while the economy grew at 6.7 percent. Of course, the relative difference would be much greater if inflation were removed. Second, from 1969-80, the growth in the Federal Reserve Board Index for the chemicals industry was 3.9 percent, while that for all manufacturers grew at 3,25 percent. (See *Industrial Production,* Annual, Board of Governors of the Federal Reserve System.)

THE COMBINATION OF OIL PRODUCT MIX AND FOUR DEMAND SECTORS

U.S. oil use can be further examined by integrating oil product mix and end-use sectors. Table 4 shows major petroleum products categories supplied to each end-use sector for 1982.

Residential and Commercial Sectors

Residential and small commercial building owners typically use distillate or liquefied petroleum gas for space and water heating because these fuels are very convenient to use in equipment of moderate cost. On the other hand, residual oil is used only in the largest boilers in very large apartment and commercial buildings. This fuel is less expensive, but handling is more difficult and costly. Since 1977, #2 distillate fuel oil use has declined greatly, and use of #6 residual fuel oil and liquefied gases has declined by an even greater percentage (see fig. 12). A sharply rising trend in electricity use by these two sectors indicates that a substantial amount of oil is being saved by the substitution of electricity, which now exceeds oil as a heating source. Natural gas is used also as an oil substitute in these sectors. However, its increased use as an oil substitute is being offset by the use of more energy-efficient technologies and equipment and other conservation measures.

Electric Utilities

Ninety-three percent of the petroleum used by utilities in 1982 was residual fuel burned in boilers. Over the past 30 years, utilities have sharply reduced oil use, primarily by substituting coal and nuclear power. Most recently, large reductions in the use of #6 residual fuel have occurred because actual demand for electricity has fallen far below estimates. When faced with excess capacity, utilities will shut down oil boilers first to maximize savings in fuel costs. If demand suddenly increases, however, oil use will climb to the extent that coal and nuclear generating capacity are not available.

Transportation

Gasoline, diesel, and jet fuel are the primary products used by the transportation sector. Gasoline accounts for the largest share—65 percent; diesel–l 5 percent; and jet fuel–11 percent. Two of the three most important fuels, gasoline and jet fuel, are used almost exclusively in the transportation sector. Furthermore, the amount of distillate burned as diesel fuel in transportation is about equal to all other uses of distillate combined, and much of the distillate used in indus-

Table 4.—Refined Petroleum Products Supplied to End-Use Sectors, by Type, 1982 (thousand B/D)

Fuel	Residential/ commercial	Industrial	Transportation	Electric utilities	Total[a]
Motor gasoline	50	70	6,420	0	6,540
Distillate fuel oil (#2)	700	620	1,310	40	2,670
—Hot water and steam					
—Engine					
—Other					
Residual fuel oil (#6)	170	460	440	640	1,720
—Hot water and steam					
—Marine fuel					
LPG	260	1,210	20	0	1,500
—Heat and hot water					
—Industrial feedstock					
Jet fuel	0	0	1,010	0	1,010
Other [b]	60	1,700	100	10	1,860

[a]Sum of the parts may not equal the total because of rounding.
[b]Includes (In order of importance) asphalt, other petroleum feed stocks, still gas, petroleum coke, lubricants, kerosene, special naphthas, aviation gasoline, wax, and road oil,

SOURCE: Energy Information Administration, *1983 Annual* Review *of Energy,* Washington, DC, April 1983, p 69 try is also diesel fuel for engines, such as in agricultural, mining, and construction equipment. In addition to these fuels, smaller amounts of residual fuel oil are used in marine ships.

Industrial

The mix of petroleum products used in the industrial sector is by far the most varied. The only major petroleum products not used in this sector are the two aviation fuels (jet fuel and aviation gasoline). The industrial sector is the major consumer of asphalt, lubricants, road oil, and the other products included in the "other" category.

Compared to the other three sectors, the industrial sector employs the most diverse, complex, and rapidly changing technologies, and these make it difficult to predict future consumption patterns. However, industrial users have options to adjust to higher oil prices that are not available or at least not as effective for the other demand sectors. These include shifting away from products that use more oil to products that use less, changing production processes in order to switch fuels or to use oil more efficiently, and substituting skilled labor and control technology in order to maximize fuel efficiency. In lieu of an extensive description of fuel use technology in specific industries, behavior of this second most important oil-consuming sector is described first in terms of time trends in energy intensity and second in terms of historical analysis, which suggests the effect of petroleum price inflation on product mix.

INDUSTRIAL SECTOR ENERGY INTENSITY

Only two out of the four energy-consuming sectors—the industrial and utility sectors—measure the value of their activities or output by market prices. In the residential/commercial and transportation sectors, the value of goods and services produced can be estimated on the basis of the value of purchased inputs, but this provides only a lower boundary for value of output. Presumably, residential customers and automobile/truck drivers purchase petroleum because the heat and transportation derived from the fuel are worth more than its cost. However, since these are sales to final users, there is no market price to measure the value of actual end-use services.

For electric utilities, there is a market test of value. Since only a single commodity is produced, electricity, the value of production is simply the price per kilowatthour multiplied by the number of kilowatthours of electricity generated. Thus, in this case, energy intensity is proportional to engineering efficiency. Engineering efficiency rose significantly from about 21 percent (Btu electricity out per Btu fuel input) in 1952 to 29.5 percent in the mid-l960s and has leveled out since then.[7] Consequently, the energy intensity (value of output in constant prices divided by Btu inputs) declined by almost 30 percent by the mid-l960s, but has held steady since.

Industrial output can be measured in at least two different ways: 1) as an index of physical output, or 2) as an economic product. Both types of measurements involve difficult data analysis because of the diversity of industrial activities. Each of these output measures are discussed separately below because they give different perspectives on industrial energy intensity,

The Federal Reserve Board (FRB) has developed an index of industrial output designed to approximate the physical quantity of goods produced in mining and manufacturing. It does not include agriculture or construction. For this index, the FRB collects constant dollar or related physical unit measures of output or economic activity by 4- to 6-digit SIC[8] industries. In order to aggregate this large number of separate output indices into a single national index, the FRB normally uses fractional weights representing the share of each industry in total U.S. industrial value added. In other words, if plastic milk bottle mak-

[7]Energy Information Administration, 1982 Annnual Review of Energy, Washington, DC, April 1983, p. 13.

[8]The Standard Industrial Classification (SIC) defines industries in accordance with the composition and structure of the economy and covers the entire field of economic activities,

ers contribute 10 times as much to real national product as contact lense makers, then the multiplicative weight applied to the output index number for milk bottles would be 10 times as large as the corresponding weight for contact lenses. Note that value-added weights eliminate double-counting of the plastic that goes into both products. That value is attributed to plastic manufacturers.

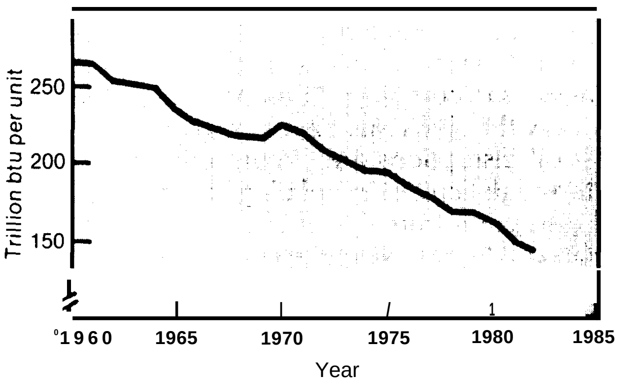
Dividing the FRB index of industrial output into energy used by mining and manufacturing yields the first indicator of industrial energy intensity. As shown in figure 14, all pertinent measures of energy per unit of output have fallen steadily, with the exception of a brief reversal around 1970. **Based on these data, it is reasonable to conclude that technological advances over the last 20 years have permitted steady, substantial reductions in the amount of energy needed to produce industrial commodities.**

A somewhat different view results if another reputable time series of industrial output is used. Industrial sector economic product is also measured as "value added" by, or "gross product originating" (GPO) from industry.[9] In 1952 total industrial GPO equaled about **38 percent of gross domestic product** (GDP), but has since declined steadily, to about 31 percent in 1982. This measurement, in dollars, is obtained via two alternative methods. From the perspective of income generated from production, value added should equal payments to all workers and investors engaged in mining, manufacturing, construction, and agriculture, plus taxes paid by firms that are also so engaged. In terms of product sales, the same value should also be obtained by subtracting the sales value of all intermediate products (as defined above) from total industrial sales.

In fact, because of data limitations, both approaches are used to estimate industrial economic product, whether it is called value added or "gross product originating, " and to cross-check data sources. Differences that arise between the two approaches must be reconciled by experienced judgment. The last step in the data analysis involves elimination of general price inflation by dividing the industrial product time series by a price deflator, which is based on a representative sample of industrial products. It is important to notice that upward or downward trends in the relative price of industrial products and changes in the product mix can make this time series behave differently than the index of physical output.

Industrial energy intensity as measured by the ratio of gross energy inputs to gross product originating is shown in figure 15. Prior to 1972, industrial energy use and dollar output grew apace; therefore, the intensity ratio stayed roughly constant at about 75,000 Btu/dollar. The probable reasons for this constancy, compared to the steady decline of the ratio of energy used to physical output (see above), are decreasing relative product prices and changing product mix. After 1972, energy use declined at an annual average rate of about 1.4 percent, while output continued to expand on the average of a little more than 1 percent per year. In other words, industrial

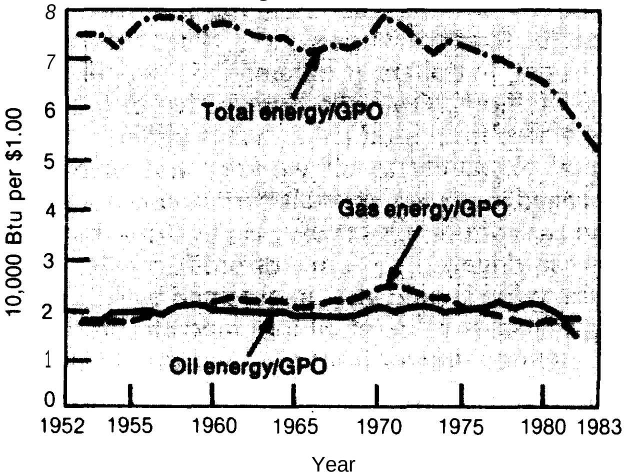
Figure 14.—Industrial Energy Intensity Using the FRB Output Index



SOURCES: **Energy Information Administration, State Energy** *Report, 19600 Through 1981,* **DOE/EIA-0214(81), Washington, DC, June 1983;** *Monthly Energy Review,* **DOE/EIA-0035(83/07); Council of Economic Advisors, "Report to the President," app. A. in** *The 1983 Economic Report of the President,* **Washington, DC, February 1983.**

[9] **There is a range of reputable time series estimates for industrial output since estimation involves many theoretical choices about what should be measured and problems related to how data are actually gathered. Discussions with data-base specialists indicate that, in general, the FRB index tends to show more rapid output growth than indices based on the quinquennial** *Census of* **Manufactures. The latter includes the estimates for industrial output, which are published as part of the National Income and Product Accounts (N I PA).**

Figure 15.—Industrial Energy Intensity Using Census Data



SOURCES: **Department of Commerce,** *The National Income and Producf Accounts of the U. S.,* **1929-76, Statistical Tables; and the Survey of** *Current Business;* **and Energy Information Administration, 1982** *Annual Review of Energy,* **Washington, DC, April, 1983.**

energy intensity made a sharp break from its past trend as it declined sharply over the last decade.

Compared to all sources of energy, the use of oil has moved more in step with industrial activity over the last 30 years, so industrial oil intensity has been relatively stable. This conclusion includes the last decade, when oil prices rose sharply. While total energy intensity declined by about 24 percent, oil intensity declined by only about 14 percent. Movements in natural gas intensity, on the other hand, were relatively large. While the other two intensity indicators exhibited minor fluctuations from 1952-1972, gas intensity grew by about 28 percent; and while overall energy intensity declined by about 14 percent during the last decade, gas intensity declined by about 35 percent.

INDUSTRIAL PRODUCT MIX SHIFT

When oil or gas prices increase, the costs and prices of goods and services, which use significant amounts of these fuels as inputs, also rise. This cost increase for final products can be moderated by investments in fuel efficiency improvements but cannot be entirely eliminated without technological innovation. Fortunately, higher fuel prices motivate innovations. Another important reaction to these rising prices is a shift in the overall mix of goods and services. In some product markets, rising prices induce sharp reductions in purchases, and so demand is said to be price elastic. However, in other markets, higher prices cause little change in sales volume, and so demand is called price inelastic.

For example, the demand for plastic milk containers is price elastic for two reasons: 1) the cost of plastic is a significant fraction of the total price of the milk to the consumer, and 2) paper containers are highly competitive both in cost and performance. Consequently, if the price of oil drives up the cost of plastic to bottlers, those bottlers will probably switch to paper. Over time, the shares of plastic and paper milk containers follow their relative prices.

In contrast, the demand for plastic in the manufacture of contact lenses is price inelastic. For this product, the price of plastic is not a major fraction of total cost and so an oil shock does not significantly raise the price of contact lenses. Furthermore, there is no good substitute material for making contacts and the other major alternative technology, eyeglasses, are also made primarily from plastic, so those with imperfect vision can do little else but pay the price.

After the two major oil price increases of the 1970s, large product mix shifts across the entire economy began to occur, and these shifts will take years to complete. Attempts to describe empirically the shifts that have accompanied these past oil disruptions are circumscribed by poor data and difficulties in isolating the impacts of an oil disruption from the effects of other disturbances and trends. Nevertheless, a useful snapshot of product mix shift following the 1973-74 disruption is provided in table 5. These data are based on industrial data collected by the FRB (see previous section) and on a number of related national indices, as described below.

Marlay has constructed a number of additional national indices using other weighting schemes based on fuel use for the same set of SIC industries.[10] Each industry was given a weight equal to its share in total industrial use of oil to construct an oil-weighted national index of industrial output. Similarly, a natural gas-weighted index was constructed, and so on for other fuels and combinations of fuels.

These alternative indices of industrial output are then compared in terms of their growth rates over time. If indeed there has been a shift away from oil-intensive commodities since 1974, then the oil-weighted time series should suffer a more dramatic decline after that year than the FRB series with value-added weights.

Table 5 reports Marlay's findings for the aggregate of manufacturing and mining. As shown, the value-added index lowered its average growth rate by 1.1 points (comparing the 19 years before 1973 to the 7 years after), while the oil-weighted index dropped by 1.8 points and the index weighted by the sum of oil and gas dropped by 2.1 points. Somewhat ironically, the coal-weighted index dropped the most (2.6 points), but that was due in large part to the steady decline of the integrated steel industry, which resulted from international and domestic economic events far removed from oil markets.

Marlay's analysis confirms that, indeed, industrial sector product mix of manufacturing plants and mines shifted toward less energy-intensive goods, including less oil-intensive goods. Although the shift away from oil was slightly smaller than the average for all fuels, the shift away from both premium fuels (oil and natural gas) was slightly greater than the average. The latter shift is relevant because of the large fuel-switching capability between oil and gas for stationary heat and steam applications. And as mentioned above, the relatively large decline in the coal-weighted index was only marginally related to the rising price of oil.

[10] Robert C. Marlay, Industrial Energy Productivity, *Ph. D. dissertation*, Massachusetts Institute of Technology, May 1983.

Table 5.—Growth Rates for Alternative Indices of Mining and Manufacturing Output

	Average growth rates		
Index	1954-73	1973-80	Difference
Coal weighted	1.9	-0.7	–2.6
Gas weighted	4.2	1.9	-2.3
Oil weighted	5.2	3.4	-1.8
Oil and gas	4.5	2.4	-2.1
Electricity	4.2	2.1	– 2.1
Total energy	4.0	2.0	-2.0
Value added	4.0	2.9	– 1.1

SOURCE: Robert C. Marlay, Industrial Energy *Productivity,* Ph.D. dissertation, Massachusetts Institute of Technology, May 1983, ch. 7.

ECONOMIC RECESSION AND PRODUCTIVITY DECLINE

A final economic adjustment to an oil supply shortfall involves a decline in the overall level of economic activity. While this adjustment is difficult to isolate from other factors affecting economic activity, two basic cause-and-effect mechanisms are clearly operating.

Immediately following an oil disruption, there is a temporary readjustment process analogous to a business cycle recession. Within a short time after a sharp oil price increase, producers realize that their factor input mix is suboptimal because they are spending too much on oil, given their available options to increase profits by changing their technology or at least by reorganizing the production process. Similarly, consumers realize that they are spending too much on oil, given their lifestyle objectives and the cost and availability of oil substitutes. For both, the period immediately after oil prices have risen involves retrenchment because producer revenues and consumer purchasing power decline. Both reductions in economic activity can interact to amplify the resulting decline in GNP, at least in the short term.

Although it is extremely difficult to isolate just how much an oil supply shortfall may have contributed to a subsequent economic recession, it is worth noting that both the 1973-74 and the

1978-79 disruptions were immediately followed by economic recessions that apparently were caused to a large extent by these incidents (see fig. 16). While a general recession of economic activity is a negative impact, it also has the effect of lowering demand for oil and thus oil prices.

Although this short-term adjustment process is an important stabilizing force in oil markets, the primary subject of this assessment involves longer term adjustments, which depend primarily on technological options for oil replacement and on the willingness of investors to invest in these options. Investors respond to general economic conditions as well as to opportunities created by changing prices and technology. Immediately after the last two shortfalls, investment activity declined more than in proportion to GNP (see fig. 17), but the economy can be expected to come out of its post-shortfall recession, with investors leading the way, if oil replacement options are attractive.

Needless to say, it is exceedingly difficult to evaluate these replacement opportunities, even after the last decade of experience because so

Figure 16.—Gross Nationai Product Over Time (constant 1972 dollars)

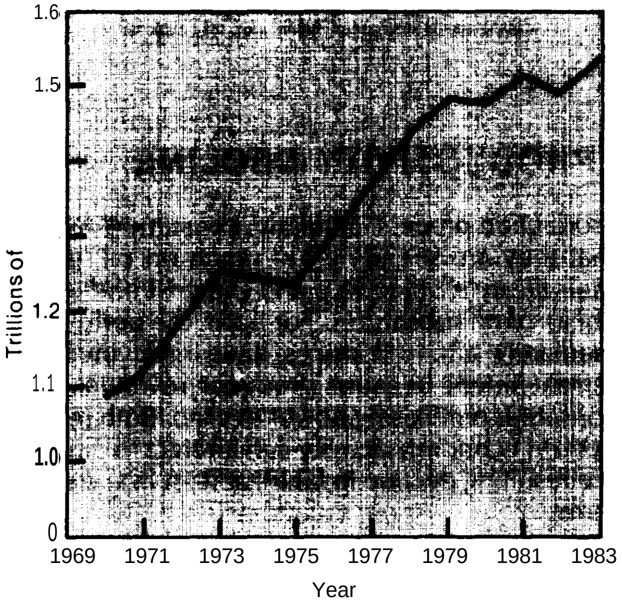
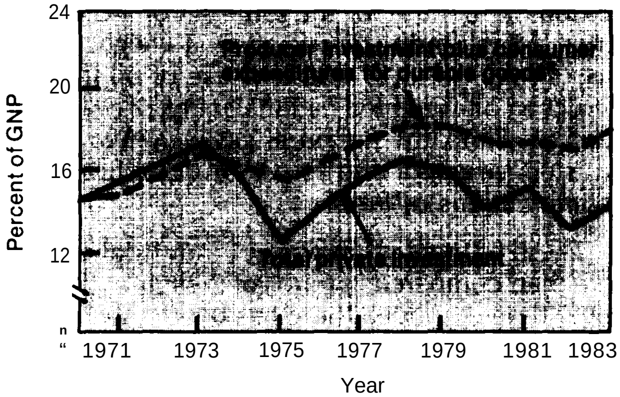


Figure 17.—Total Investment and Expenditures for Durable Goods[a] (as percent of GNP)



[a]Producer investment in durables is one component of total private investment. Consumer expenditures for durables is not included in total private investment but it is closely related because durables are investment goods. Both producer and consumer durables are also germaine to the discussion of investment for oil replacement.

SOURCES: *The National Income and Product Accounts of the United States, 1929-76,* Statistical Tables; and Survey of *Current Business,* "National Income and Product Accounts," Table 1.1, July 1983 and March 1984.

many other factors besides oil markets have contributed to the performance of the economy over that period. However, in the 5-year horizon of this assessment, the net macroeconomic impact of a permanent loss of oil supplies or permanent increase in the price of oil is most likely to be negative.

Barring technological breakthroughs or major changes in production processes or lifestyle, GNP and average labor productivity must decline because a permanent oil supply shortfall raises the cost of producing the prevailing mix of goods and services. Conversely, a permanent shortfall reduces the availability of a key resource input to the economy, and thus, everything else being more or less the same, total output must decline, Limiting attention only to changes in oil inputs becomes less realistic as the years pass following the onset of a shortfall. Indeed, based on the last two shortfalls, one might expect developments in technology and lifestyle to overcome shortfall losses within the time horizon of a decade, or at least to change expectations about the future which existed when imported oil was cheap and plentiful.

The point of this discussion is that oil consumption can be reduced by reducing economic activity, and that the market economy may decide that this is a better option than technical replacement. The main objective of the following discussion is to evaluate the technological options for reducing oil dependence and maintaining growth in the event of a future shortfall. The historical analysis provides an appropriate introduction to the technical analysis by showing that the economy has demonstrated resilience after the last two oil supply shortfalls, both in terms of continued economic growth and reduced oil intensity, presumably because oil replacement options have been effective.