Material Consumption Patterns and Industrial Energy Demand in Industrialized Countries

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Introduction

Forecasters have traditionally projected future energy demand using long-term historical trends in highly aggregated economic indicators. As long as the economy remained structurally stable, changing only gradually, if at all, energy forecasts based on such trends were relatively reliable. Even the effects of the well-recognized, long-term shift to a services-dominated society is generally well captured in aggregate indicators. However, long-term trends in aggregate indicators mask recent, fundamental changes occurring in the way society consumes basic materials -- changes that will probably exert as profound and lasting an influence on energy use in the industrial sector as the oil price shocks of the 1970s did, since the processing of basic materials is the most energy-intensive activity in all industry. Changing consumption patterns are in part reflected in recently accelerating shifts in the distribution of industrial production, away from basic materials processing to value-added-intensive fabrication and finishing activities. The reasons for this shift can be clearly understood in the context of historical patterns of basic materials consumption in industrialized countries, an analysis of which is the focus of this paper.

An Historical Perspective on Energy Demand Projections

Long-term projections of US energy demand made over the last two to three decades have consistently overpredicted total energy demand (Office of Policy, Planning and Analysis, 1983). Figure 1 shows US primary energy demand projections made since the early 1950s by various government, industry, private consultant, and academic research groups. Energy demand projections for the year 1980, after rising from the 1950s to the late

1960s, turned sharply downward in the 1970s, as the significance of the oil price shocks came to be more and more understood by the forecasting community (left graph). While projections for energy demand in 2000 have been steadily declining since the early 1970s, the majority of forecasts made in 1983, 17 years before the fact, still project energy demand in 2000 to be anywhere from 20 to 50% higher than the 1983 level of 71 quadrillion BTUs (75 EJ) (right graph).

In a recent US Department of Energy (DOE) planning report, a demand of over 98 EJ of primary energy is forecast for 2000 (Office of Policy, Planning, and Analysis, 1983), representing the midrange of projections in Figure 1. The same report projects over 108 EJ of primary energy demand in 2010. Final energy demand, which excludes transformation and distribution losses, is forecast to be about 71 EJ in 2010, an increase of 6.8 EJ over the 1980 level.

In light of the historical trend of overestimating future energy use, it is perhaps not surprising that the sectors which are the best understood in terms of the underlying factors shaping future demand (the transport and residential sectors), are projected to have negative or only modest positive energy demand growth. In this DOE forecast, a decrease of 1.7 EJ is projected for transportation energy use on the basis of the assumptions that the number of passenger cars on the road will grow only with population and that the average automotive fuel economy will increase from 15 mpg in 1980 to 34 mpg in 2010, as a consequence of the existing fuel economy standards and a projected increase in the world oil price, from

$41 in 1980 to more than $85* per barrel by 2010. The relatively small increase in demand projected for the residential sector (1.1 EJ) reflects the fact that most energy use here can be attributed to a few well-defined energy-intensive activities (e.g., space conditioning, water heating, refrigeration, lighting, cooking), which are presently approaching saturation levels in most homes in the U.S. (Williams, Dutt and Geller, 1983).

An increase of 4.8 EJ in final energy demand (71% of the total net increase) is projected by the DOE for the industrial sector, where the factors influencing future energy demand are much less well understood. This DOE forecast, like most conventional forecasts, is based on functional relationships, derived in part from historical data, between energy demand, energy prices, and highly aggregated economic indicators, supplemented by judgments to reflect some expected structural changes. The 31.1 EJ of final energy consumption projected for industry in 2010 (up from 26.6 EJ in 1980) is based on assumptions which include: average annual growth rates of 2.4% and 2.7% (1980-2010) in GNP and industrial production, respectively, and a declining rate of price-induced efficiency improvements, counteracted to an unspecified extent by a shift in the product mix, with energy-intensive products decreasing as a share of total output.

While forecasting energy demand is an inherently difficult task, a greater understanding of the major determinants of energy demand in the largest energy-consuming sector -- industry (accounting for 41% of final US energy demand in 1980) as has already been developed for the transportation

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* Unless otherwise noted, the GNP deflators (Bureau of Economic Analysis, 1984; Bureau of the Census, 1975) have been used to convert all monetary values to 1983 dollars.

and residential sectors, could provide a much better basis for long-range energy planning than that provided by conventional industrial energy demand models.

Energy Use in Industry

The US economy is shifting away from the production of goods toward the greater provision of services* (Ginzberg and Vojta, 1981). This trend is clearly visible in the changing distribution of US employment (Figure 2) and in the shifting mix of GNP over time (Figure 3).

Because the industrial sector contains within it some of the most energy-intensive subsectors (as measured by the amount of energy used to produce a dollar of value-added), this ongoing shift away from industry has been a major contributor to the decline in the ratio of primary energy consumed to GNP (PE/GNP). The PE/GNP ratio fell steadily into the 1960s, recovered slightly in the last few years of that decade, and then began an accelerated decline in 1970 which has continued to the present (Figure 4).

Also shown in Figure 4 is the energy intensity of the industrial sector -- the ratio of industrial primary energy use to gross product originating in industry (PIE/GPO) -- which paralleled the PE/GNP ratio up to 1970, but has since been dropping more rapidly. The latter rapid decline is typically attributed in large part to energy-saving measures induced by the oil price shocks of the 1970s (Office of Planning, Policy and Analysis, 1983). Conventional forecasting wisdom holds that once

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* Industry is here defined to include the manufacturing (MFG) and the mining, agriculture, and construction (MAC) sectors. Services, defined as everything else, includes: transportation, communications, public utilities, wholesale and retail trade, finance, insurance, real estate, hotels, personal services, product repairs, recreation, medical and legal services, education, government, etc.

this perturbation in the energy demand-energy price relationship subsides, the rate of decline in industrial energy intensity will return to its lower, long-term historical average (Office of Planning, Policy and Analysis, 1983). However, as Figures 4 and 5 make clear, the beginning of the accelerated decline in the PIE/GPO occurred in 1970, well before the first major jump in energy prices. This suggests that the relatively rapid decline in PIE/GPO since 1970 has not been entirely price-induced, a point to which we will return shortly.

Superimposed upon the ongoing shift from industry to services has been the recent relatively rapid decline in the basic materials processing (BMP) share of industrial output (Figure 6).* In the decade leading up to 1983, other manufacturing (OMFG) output (measured in constant dollars of gross product originating, a value-added measure) grew at an average rate of 2.2% per year, while BMP output grew only 0.4% per year and mining, agriculture and construction (MAC) grew at 0.5%. The declining energy intensity of the industrial sector shown in Figure 4 can be attributed primarily to the relatively slower growth of output of the BMP subsector, and to energy-efficiency improvements made in this subsector, which is by far the most energy-intensive.

In 1978, the BMP subsector consumed about 200 MJ of final energy to produce one dollar (1972$) of value-added, accounting for about 87% of total manufacturing energy use. At the same time however, it generated

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* The basic materials processing (BMP) subsectors (with their identifying two-digit Standard Industrial Classification (SIC) numbers include: food and kindred products (20), paper and allied products (26), chemical and allied products (28), petroleum and coal products (29), stone, clay and glass (32), and primary metals (33). Other manufacturing (OMFG) includes all SIC categories from 20-31, exluding the BMP subsectors.

only 32% of total manufacturing value-added (Figure 7). By contrast, OMFG used only about 12 MJ/1972$, consuming 13% of energy used in manufacturing to generate 68% of the manufacturing value-added. These subsectoral energy demand data indicate that to understand energy demand in industry, one must understand the factors that influence energy use in BMP.

While the skyrocketing energy prices of the 1970s stimulated the adoption of energy efficiency improvements in BMP, they also helped accelerate ongoing changes in the way US society consumes basic materials, as we will describe. While the role of energy price in encouraging energy conservation is generally well-understood, energy demand modellers have generally not recognized the implications of changing materials use patterns for future energy consumption in the BMP subsector (1). Yet because of the energy intensity of this sector, these changes are probably at least as significant in determining future total industrial energy demand as the energy efficiency improvements induced by the oil price shocks.

Historical Patterns of Basic Materials Consumption in the US

Idealized lifecycle demand patterns for a generic basic material are shown in Figure 8. The lower curve represents physical demand per dollar of GNP, and the upper represents demand per capita. The phase of rapid material demand growth per unit of GNP is associated with the formation of new material-intensive markets (following construction of some initial production capacity). The rapid growth at this stage in the materials cycle is conducive to the introduction of technological innovations into the new capital equipment stock needed to produce more of the material (Kuznets, 1953). These advances generally increase productivity, often leading to lower prices, which in turn feed demand growth. However, once income-generating activities shift away from the material-intensive markets, and as the development of new technologies permits more efficient use of the material, the demand for that material per unit of GNP generally begins to decline (Malenbaum, 1978), and eventually material demand per capita levels off for several reasons, numerous examples of which will be presented in this paper:

- Alternative materials, perhaps with more desirable properties, are increasingly substituted in uses historically reserved for one particular material (Malenbaum, 1978; Kuznets, 1953).
- Technological advances, e.g., higher strength-to-weight ratios or increased durabilility, permit the same demand for services provided by a material to be satisfied with lower levels of material use (Malenbaum, 1978; Kuznets, 1953). Such technological developments are often catalyzed by intense competition from substitutes.
- The distribution of material use in the economy changes as national income increases: after rapid initial growth, demand in traditional, materials-intensive markets matures as that from new, less materials-intensive markets grows. As a result, the ratio of the material content of goods to value-added drops. The most recent phase of this evolutionary process has been marked by the emergence of an information-centered society, dominated by high-technolgy, value-added intensive products with generally low intensities of materials use, such as solid-state electronics, computer hardware and software, biogenetics, and telecommunications (Cook, 1982; Dickson, 1983; Business Week, 11 Oct. 1982; Hibbard, 1984).

The rapidly rising energy prices since the 1970s have played an important catalytic role in influencing these factors. Higher energy prices in the BMP industries have led to higher prices for semi-finished materials. As a result, manufacturers of consumer goods have sought new ways of slowing rapidly rising production costs, while still maintaining profits. These have included, substituting alternative materials, increasing the efficiency with which material is used, and increasing the processing of material to increase its value-added.

Evidence of the declining importance of basic materials in the economy has been presented in a recent analysis of trends in basic materials' production, consumption, and markets from 1960-1980 (Ross, Aug. 1984). Ross concludes that growth in material consumption to 2000 in the US can be expected to be slower than population in steel and paper, while aluminum and ethylene consumption may grow somewhat faster than population. He also notes that, given trends in international trade and the current state of US materials processing industries, domestic production growth will probably be slower than that of consumption in three out of four of these industries -- paper being the lone exception.

In this paper, we extend Ross's work, one of the few detailed analyses of recent trends in the consumption of basic materials, by describing long-term consumption patterns and probing more deeply to understand better some of the major determinants of change for a representative sampling of basic materials, including both older basic materials (steel, cement, paper, and textile fibers) and their more modern counterparts (aluminum, ammonia, chlorine, and ethylene). In all cases we have found strong evidence of demand saturation.

Consumption Trends of "Old" Materials

We begin with a detailed analysis of the long-term consumption trends of "old" materials -- steel, cement, paper, and textile fibers -- materials used since the earliest days of industrialization.

Steel: Steel was the most important basic material in the industrial revolution. The historical pattern of steel consumption in the US, closely resembles the idealized curves in Figure 8, providing an archetypal example of long-term consumption trends of basic materials in industrialized countries. Data on steel consumption (2) per capita and per dollar of GNP over a 115 year period are shown in Figure 9.

The growing demand for steel created a favorable economic climate for introducing in the mid-1800s a number of cost-cutting innovations, including the Bessemer process (Hyde, 1977). The full impact of these inventions were not felt until the 1890s, however, at which time consumption began to grow much faster than GNP (Figure 9, lower). This rapid growth is attributed to the fact that much of the physical infrastructure of the country was built during the period up to about 1920: mines were dug, factories were constructed, commercial buildings multiplied, transportation systems developed, and the residential sector was expanding (Malenbaum, 1978).

The 1920s marked the end of the period of high growth in heavy infrastructure-building steels, e.g., rail and structural steel, and the increasing production of steels used more directly for improving "quality of life," e.g., sheet and wire used in fabrication and finishing activities. The peaking and downturn in steel use per unit of GNP observed in the 1920s can be attributed to this redirection of production. (The anamolous dip centered in the early 1930s reflects the effects of the Great Depression, when GNP was falling but steel consumption was falling even faster.) The role of steel in the overall economy today (measured in kg/$) is about what it was 100 years ago -- down to about 1/3 of the all-time high reached around 1920 (Figure 9, lower).

Per capita demand for steel continued to grow (Figure 9, upper), even as demand per unit of GNP was declining, since GNP was growing faster than population (Figure 9, upper scale), and markets for end-use products embodying steel (e.g., automobiles, refrigerators, and other appliances) had not yet saturated. However, as traditional end-use markets matured and no significant new markets appeared, the per capita level of consumption began to level off, as observed beginning around 1950 in Figure 9 (upper). Since 1970, per capita demand has been falling steadily.

The data are inadequate to determine whether this decline is temporary or whether it indicates a real and permanent downturn in steel consumption, but even the often "bullish" forecasters expect little growth of steel markets in the US (Bureau of Industrial Economics, 1984; Greenhouse, 1983), and as a result, a shakeout in the industry has been underway for some time (W. Williams, 1984).

Maturing markets, rising substitution by lighter materials, production of steels with increasingly higher ratios of strength to weight and production of increasingly more durable steel products have all contributed to the onset of saturation, if not decline, in per capita steel consumption.

The automotive market, accounting for 15 to 20% by weight of all steel industry shipments over the last decade (American Iron and Steel Institute, 1982), provides good specific examples of widespread patterns of change in the use of steel. While the automobile continues to be the mainstay of the US transportation system, the number of automobiles per person in the US has leveled off in recent years and now stands at one for every two men, women, and children (Figure 10). The average American already spends about an hour each day in a car (Ross and Williams, 1984) and travels nearly 8000 km by car each year (Figure 10). Given these figures, and a consensus among government, industry, and private consultants that new car sales are not likely to go much beyond 1975-1978 levels through 1990 (Public Policy Analysis, 1982), continued slowing growth in the demand for automobiles can be expected. In light of maturing automobile ownership and use, the markets for the many materials used to produce automobiles, particularly steel, are likewise maturing.

Automotive material suppliers have been further affected by the gasoline price shocks of the 1970s that motivated auto makers to raise automotive fuel economy. The result has been a general downsizing of automobiles and increased substitution of lighter materials for traditional ones. How much lighter automobiles have become is shown in Table 1. The weight of the average US-made car dropped from 1727 kg in 1975 to 1469 kg in 1984, a decrease of 15 percent. The iron and steel fraction, historically ranging up to 75% (Secretary of Commerce, 1983), saw particularly large reductions, dropping from 1139 kg to 802 kg in this period. Industry experts project total vehicle weight to decrease to 1069 kg by 1992, with steel dropping to 625 kg (see Table 1).

In an effort to compete for the tightening automobile materials market against makers of aluminum, plastics, fiberglass, and other high-strength, light-weight materials, the steel industry has increasingly emphasized the production of more sophisticated steels, such as those with higher strength-to-weight ratios and those galvanized or coated for rust prevention (Bittence, 1984). This trend is reflected in the increasing fraction of high-strength and stainless steels in the average car, which has risen from 5 to 13.5% since 1975 and is expected to rise to 23 percent by 1992 (Table 1).

Still another factor affecting steel consumption by the automotive industry has been a trend toward longer ownership of vehicles. While the average age of passenger cars in the US hovered around 5.5 to 6.0 years from the late 1950s up to 1975, it rose steadily to 7.4 years in 1983 (Motor Vehicle Manufacturers Association, 1984) indicating that people are getting more use out of the material in each car.

Examples of changing patterns of steel use can be seen outside of the transportation sector as well. The trend toward greater use of specialty steels having higher strength and higher value-added is a general phenomenon for the entire economy (Greenhouse, 1983; Bureau of Industrial Economics, 1984). A good example can be seen in construction steel use, which accounts for about 14% of all domestic steel shipments in the US. Steel girders used in recent repairs to the Eiffel Tower weigh 1/3 of those they replaced (Economist, 1984). Substitution effects can be seen in new commercial buildings using about 54 kg of steel per square meter of office space compared to 269 kg/m^2 used to build the Empire State Building in 1930 (Economist, 1984). And finally, several companies in the US and other industrialized countries are developing special coatings for steel-based materials and are redesigning steel parts to provide greater wear resistance and hence longer life (Chandler, 1984).

There is no apparent prospect for any dramatic recovery in the demand for steel. The International Iron and Steel Institute expects total steel consumption in the industrialized countries to remain stable over the next decade at a value slightly below the 1984 level (Economist, 1984). In an admittedly optimistic projection, the US Bureau of Industrial Economics expects US steel demand in 1988 to be about 105 million tonnes, which would be about 10% above the estimated 1984 level, but some 18 million tonnes less than in 1973 (Bureau of Industrial Economics, 1984).

Cement: Trends in the demand per dollar of GNP for cement, another material which played an important role in the early years of this century, lag those in steel by about a decade. Cement consumption rose significantly from the closing decades of the 1800s up to about 1930. Since then it has been dropping steadily except for 2 precipitous drops during the Great Depression and WWII (Figure 11, lower). Per capita consumption grew steadily (except during the Depression and WWII) from the late 1800s up to the early 1960s (Figure 11, upper). It then appears to have saturated and, as in the case of steel, has been declining since the early 1970s. Per capita consumption appears to have saturated at a per capita GNP level of around $12,000 (Figure 11, upper scale).

The primary reason for saturation in cement consumption has been the maturation of the transportation infrastructure, primarily the interstate highway system, over 80% of which was open for traffic by 1971 and 95% of which was open by 1981 (Public Policy Analysis, 1982). Much of the roadbed laid in the 60s was asphalt, and most upgrading today is being done with asphalt rather than concrete. With the decline of cement use in public works construction, the residential and commercial building markets now account for the largest fractions of cement consumption -- 26 and 25%, respectively (Portland Cement Association, 1984).

Several factors are likely to affect the future use of cement in residential buildings, among the most significant of which is the recent movement toward construction of fewer and smaller houses (New York Times, 1983). Of particular relevance to the cement industry is the trend away from homes built with full or partial basements, garages, or fireplaces (Portland Cement Association, 1984; New York Times, 1983). In part as a result of this shift, the residential share of cement used in all buildings dropped from 54% to 42% from 1978 to 1982 (Portland Cement Association, 1984).

While the recent recession has contributed to depressed housing starts, the long term trend will probably be toward slow growth in new home construction, due largely to the fact that the number of 25-34 year olds, products of the post-war baby-boom and the most probable first-buyers of new homes, will peak in the next 5 years and decline thereafter to the year 2000 (Figure 12, left), even though the number of adults and the total population will continue to grow (Figure 12, right).

The fraction of cement used in the commercial sector can be expected to grow, in light of the ongoing shift in the economy from industry to services. However, based on recent trends, absolute cement use in this sector can be expected to stay level or even decline. From 1978 to 1982, the commercial sector share of cement used in buildings rose from 37 to 50%, while absolute consumption dropped about 3% (Portland Cement Association, 1984). This drop can be attributed in part to the depressed construction market during the 1980-82 recession, but improvements in the efficiency of cement use may also be playing a role. For example, the greater ability to span longer sections with concrete beams has resulted in an increase in the number of new commercial buildings incorporating larger open areas for offices (Portland Cement Association, 1984).

As growth in markets for traditional uses of cement slows, cement continues to follow in the footsteps of steel in increasingly being utilized in more highly processed, value-added intensive products. For example, unfired ceramic cements are being used to coat electrical resistors and heating elements and as bonding or sealing agents for materials such as glass, metal, and wood (Zimmer, 1984). In addition, "super cements" are being developed with remarkably high levels of stiffness, tensile strength, and fracture toughness -- thereby allowing them to be used in a variety of applications (Birchall and Kelly, 1983). These cements can even be coiled into springs, and blocks made from them can be machined on a lathe!

Paper: Figure 13 shows the history of US demand for paper and paperboard, from which almost all paper products are derived. The changing role of paper in the economy is reflected in the recently declining ratio of consumption to GNP (lower curve), which was preceeded by a steady rise up to about 1940, and an extended period during which this ratio changed very little. (The dip in the mid-1940s can be attributed to skyrocketing GNP growth during WWII.) Per capita consumption (upper curve) follows the classic s-shaped pattern, rising steadily from the late 1800s until leveling in the mid 1970s at a per capita GNP of around $13,000. As in the case of steel and cement, a number of factors have contributed to what appears to be saturation in the consumption of paper.

An important technical change has been the improvement in material efficiency in the production of a number of large-volume paper and paperboard products. For example, newsprint, which accounted for about 30 percent of paper (or about 17 percent of total paper and paperboard) consumption in 1982 (McCampbell, 1984), saw a 6% reduction in basis weight -- the weight of 500 sheets 25" x 38" in size -- from 32 to 30 lbs (23.7 to 22.2 kg/m^2) around 1974 (McCampbell, 1984). The industry is currently contemplating a further decrease to 28 lbs (20.7 kg/m^2), a goal which is probably technically attainable, given that lighter weight newsprint is commonly used for publications in a number of other countries -- The Times of London is one example.

Another example of decreasing basis weights can be found in coated papers, which accounted for about 14 percent of paper consumption in 1982 (McCampbell, 1984). Number 5 coated groundwood, the lightest weight coated paper, accounts for about half the tonnage in this subsector. Because of its light weight and its opacity, which arises out of its high lignin content, No. 5 coated groundwood is used extensively in magazines, catalogues, and for direct-mail advertising campaigns. Rising postal rates have motivated significant reductions in basis weights in this subsector (McCampbell, 1984). In 1968, less than 6% of all No. 5 paper had basis weights of less than 36 lbs (26.7 kg/m^2). By 1972 the fraction had grown to 17% and had reached 27% in 1979. Further weight reductions appear to be limited by technical considerations, as the fraction has remained essentially constant since 1979 (McCampbell, 1984).

Bleached paperboard, which accounts for about 12% of all paperboard consumed (McCampbell, 1984), presents still another example of more efficient utilization of raw material. Bleached paperboard is typically used in food and pharmaceutical packaging applications where attractive appearance is desired. A major innovation occurred in 1959 when Westvaco, Inc. first introduced technology which allowed production of low-density, high yield bleached paperboard with increased strength-to-weight ratios (McGirr, 1984). Other companies were slow to catch up with Westvaco, and it has been only in the last 8 to 10 years that low-density technology has evolved into the industry standard. During this time the average density of bleached paperboard dropped some 15 to 20% (McGirr, 1984). While the long-term objective of companies like Westvaco is to further reduce densities without sacrificing quality, further decreases are likely to come only with significantly greater investment (McGirr, 1984).

Maturing markets for particular paper and paperboard products are also playing a role in determining overall consumption patterns. For example, the consumption of paperboard for shipping containers grew considerably faster than GNP in the 1950s and 60s, but just stayed even with GNP in the 1970s, a trend attributed to the fact that new uses of shipping containers were still being established in the 50s and 60s, while such applications were essentially exhausted by the 70s (Ross and Purcell, 1981).

Substitutes like plastics have increasingly been making inroads into many traditional paper markets (Ross and Purcell, 1981). Increased substitution of plastics have been noted for folding paperboard boxes, sanitary food containers, merchandise bags, set-up paperboard boxes, and fiber cans, drums, tubes, cores, and other similar paper and paperboard products (Bureau of Industrial Economics, 1984). One example is milk containers, the fraction of which made from plastic has steadily risen from only 15% in 1971 to 60% in 1982 (Chemical Week, 1 Feb 1984).

In the paper industry, great uncertainty surrounds the coming of the electronics/computer age. While copiers and computers have made the market for office papers the fastest growing of any paper market, a number of other factors have the potential for stifling future growth. These include: optical discs replacing office filing cabinets full of paper, personal computers which may encourage less use of paper for messages and transactions, and video systems replacing phone directories, catalogues, and business transactions traditionally completed using paper (Business Week, 5 April 1982). A study by Data Resources, Inc. estimates that if electronic media affect newspaper advertising the way television did, they could permanently displace US paper production equivalent to about 15% of the 1982 level (Business Week, 5 April 1982).

Projections of future growth in the demand for paper span a broad range, reflecting the uncertainty surrounding market trends in the paper industry. Ross's recent projection of a 0.7% per year rise in demand from 1979 to 2000 (Ross, Aug. 1984) is essentially a continuation of the recent trend of constant per capita demand. Given the above evidence, other recent projections of about 2.5% (Butts, 1984) and 3.5% (Business Week, 26 April 1984) growth rates to 1990 do not seem to be realistic.

Textile Fibers: While textiles manufacture is not usually classified as a BMP industry, a study of textile consumption patterns is warranted by the fact that within the OMFG subsector, energy consumption for textiles production is the highest of any industry except for food processing (Energy and Environmental Analysis (Vol.6), 1983).

In contrast to metals and minerals, the extensive use of textile fibers in the economy dates to the earliest phases of the industrial revolution. As illustrated in Figure 14 (lower) textiles consumption per unit of GNP rose rapidly before 1850 and has been more or less falling steadily since, although the rate of decrease has slowed in the last half of the 1900s. Per capita consumption of textile fibers in the form of clothes, carpets, upholstery, and other miscellaneous uses rose gradually from the mid-1800s to the early 1900s, saw a drop during the Great Depression, and rose and fell sharply during WWII (Figure 14, upper). After reaching a post-WWII low in the 1950s, it rose steadily until saturation trends appeared in the early 1970s. The upper scale in Figure 14 indicates that textiles demand saturated at a per capita GNP of about $12,000.

A large fraction of textile fibers -- on the order of 40% by weight -- are consumed as apparel. The balance is split roughly evenly between home furnishings and industrial manufactures (Textile Economics Bureau, Sept. 1984).

The steadily increasing percentage of synthetics in total fiber consumption -- from 22 percent in 1950 to 74 percent in 1983 (Figure 15, upper) -- has been an important factor in slowing growth in all sectors, since in most cases, a kilogram of synthetics will replace more than a kilogram of natural fibers (Textile Economics Bureau, Nov. 1981). In addition, synthetics tend to last longer than natural fibers.

Since the early 1970s, apparel consumers appear to have begun "trading up" -- purchasing higher quality rather than greater quantity -- as reflected in the upturn in the ratio of dollars spent to kilograms consumed

(Figure 15, lower). The movement to higher quality is also reflected in the recent relative recovery of the fraction of wool and cotton in the mix of apparel fiber (see Table 2). As the natural fiber fraction rises, so does the waste fraction of the quoted consumption figures, as there is considerably greater waste in producing cotton and wool products than there is in producing synthetic ones (Rudy, 1984). Given this fact, the relatively slow rise shown in Figure 15 (lower) probably understates the actual trend in final fiber consumption.

Man-made fibers in carpets and rugs, which account for over half the fiber used in the home furnishings sector, have seen phenomenal growth since they were introduced in the 1950s. Synthetics, which held less than 6% of the carpet market in 1950, accounted for 99% of all carpets by 1977 (Textile Fiber, Nov. 1961 and Nov. 1982). Given the reduced waste in using synthetics in comparison to natural fibers, the saturation of this market has probably been an important contributor to slowing growth in textiles consumption. In addition, it is likely that textile-using furnishings, including carpets and upholstered furniture, have already penetrated American homes to the high degree characterizing such other major home furnishings as stoves (present in 100% of all households) and refrigerators (118%) (Williams, Dutt and Geller, 1983).

Combined with these trends has been a recent movement toward the construction of fewer and smaller houses, as noted earlier. The number of homes with multiple bathrooms, three or more bedrooms, full or partial basements, garages, or fireplaces all declined between 1978 and 1982 (New York Times, 1983). Future demographic changes are likely to lead to a decreasing number of buyers of new-homes and correspondingly, amenities for the home (see Figure 12 and the discussion on cement).

In the automotive industry, the downsizing of the automobile has also had a significant impact on the textiles industry, as reflected in the transportation sector's share of industrial fiber consumption, which dropped from 29% in 1972 to 12% in 1983 (Textile Economics Bureau, Nov. 1978 and Sept. 1984). Most fiber used in the automotive market -- 85 percent in 1983 -- goes into tire production (Textile Economics Bureau Sept 1984). The introduction of radial tires in the early 1970s, therefore, was a significant event for the textiles industry. The doubled lifetime of radials in comparison to non-radials has resulted in reduced tire production -- from 202 million units in 1973 to 168 million in 1983 (Greek, 1984b). In addition, the average weight of a passenger tire declined from 13 kg in 1973 to 9.8 kg in 1983 (Greek, 1984b), resulting in a further decrease in fiber demand.

Consumption Trends of "Modern" Materials

Having seen that saturation trends are pervasive in the "old" materials, we consider in this section some relative new comers to the materials scene: aluminum, ammonia, chlorine, and ethylene. Surprisingly, we find that, while these modern materials have been used increasingly as substitutes for the older materials, their consumption patterns show signs of saturation qualitatively similar to those of the older ones, suggesting that materials saturation is occurring essentially across the board.

Aluminum: The use of aluminum in the economy grew rapidly as both steel and cement consumption approached saturation levels in the 1940s and 50s, reflecting the increasing use of aluminum as a substitute for these heavier materials (Figure 16, lower). Consumption of aluminum per dollar of GNP began declining over a decade ago, however. After growing nearly monotonically for 4 decades, per capita consumption peaked in the late 1970s at a GNP level just under $14,000 per capita (Figure 16, upper).

Substitution by other materials is playing only a small role in affecting aluminum consumption growth, as aluminum is already one of the most desirable materials to use in many applications requiring strength, stiffness, lightness, and durability. However, as in the case of most of the "old" materials, maturing markets and more efficient use of material in existing applications have both contributed to the observed demand saturation.

The largest single aluminum market category, containers and packaging, accounts for about 30% of all shipments, 80% of which is for beverage cans (O'Carroll, 1984). While aluminum cans first appeared in consumer markets in the early 1960s, their use has grown phenomenally since. By 1981, they accounted for nearly 90% of all beverage cans (Aluminum Association, 1982), indicating that the container and packaging market for aluminum has essentially reached maturity.

In the transportation market, total shipments of aluminum dropped at an average rate of 2.4% per year from 1972 to 1982, although the transportation market has maintained a 15 to 20 percent share of all aluminum use (Aluminum Association, 1982). Declining absolute use can be attributed in part to slowed growth of the automobile aluminum market: the rate of increase in the use of aluminum on average in new cars, as a substitute for steel, has been dropping steadily since the mid-1970s, a trend that is expected to continue for the foreseeable future (Table 3). Compounding this decreased rate of growth is the approaching saturation in car ownership noted earlier (see Figure 10).*

Total shipments to the building and construction sector fell at an average annual rate of 3.4%, and its share of all shipments dropped from 27% to 19% between 1972 and 1982 (Aluminum Association, 1982). These trends are attributable in part to the slowing and downsizing of homes described earlier. Shipments to the electrical market (overhead conductors and other wires), accounting for about 10 percent of the present total, reached a ten-year low in 1982 (Aluminum Association, 1982). Since aluminum has already completely replaced copper in high-voltage overhead transmission lines (Organization for Economic Cooperation and Development, 1983), the maturing electrical market for aluminum may be a direct result of the decreased rate at which new central station electrical generating capacity is being added to the grid.

At the same time that markets are maturing, reductions continue to be made in the material intensity of specific products. A good example is beverage cans. The relatively successful effort to reduce the amount of aluminum required is shown in Table 4. Thinner sidewalls have led to a 22% reduction in body weight since 1965, while the introduction of necking at the top of cans (among other changes) has reduced material requirements for the heavier, more expensive alloy used in the lids by about 13% over this same period. Can weight may be further reduced by as much as 17% over the next two years (Cook, 1984).

Still another factor clouding the future growth prospects for aluminum is the rising cost of electricity to the electricity-intensive

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* It is noteworthy that the energy savings that result from increased gas mileage obtained through lower vehicle weight more than outweigh the additional energy expended to produce aluminum rather than steel (Gray and von Hippel, 1981).

aluminum industry. While the average cost of electricity for primary aluminum production is less than half that of industry as a whole, both have been steadily rising since the early 1970s (see Figure 17).

Even at the historically low electricity prices enjoyed by aluminum producers, energy costs have accounted for a large share of the selling price of aluminum -- some 18% in 1981 (3), compared to an average of 8% for the entire primary metals industry (Ross, April 1984).

If new aluminum plants were built in the US they would probably have to obtain electricity from new thermal power plants, as cheap hydroelectric power sources are essentially exhausted (see Table 5). The cost of electricity to industrial users from new thermal plants would be about 6.5 cents/kWh -- or over 3 times the average electricity price paid by aluminum producers in 1981 (4). If aluminum ingot were produced in new efficient plants using electricity from new thermal power plants, if costs other than electricity were the same as with existing plants, and if the extra electricity costs were entirely passed on to consumers, then the price of aluminum ingot would be some 25% higher than in 1981, with electricity costs accounting for over 35% of the aluminum price (5).

In light of the evidence that markets are maturing and efficient use of aluminum is growing, projections for future growth in aluminum consumption are surprisingly high: Ross projects an average growth rate of 1.6% per year between 1979 and 2000 (Ross, Aug. 1984), while a shorter-term government projection is for consumption to grow from 6.5 million tonnes in 1979 to about 7.7 million tonnes in 1988 (Bureau of Industrial Economics, 1984). As energy costs continue to rise and environmental regulations place further monetary burdens on the domestic industry, imports can be expected to account for a greater and greater fraction of US consumption (Bureau of Industrial Economics, 1984). Ross suggests that domestic production may grow only 0.3% per year through 2000 (Ross, 1984).

Chemicals: The wide variety of products and coproducts typically found in the chemical industry, combined with extensively intertwining production chains, create difficulties in characterizing physical consumption patterns for the chemical industry as a whole. Some insights into consumption patterns of chemicals as they relate to energy use can be gained, however, by studying three chemicals -- ammonia, chlorine, and ethylene. The production of these chemicals and their major derivatives accounted for about 20% and 17%, respectively, of total final energy consumed in 1976 by the chemical industry, including feedstocks (from Ayres, 1981 -- cited by Ross, 9 Nov 1981). These three chemicals are also among the top ten chemicals (by weight) produced in the US (Chemical and Engineering News, June 1984).

Some general observations about the chemical industry provide a context for understanding what is happening to these three chemicals. Future growth in the use of organic chemicals like ethylene is dependent to a large degree on the growth in demand for such products as plastics, rubber, and synthetic fibers. Growth in the production of plastic products, which in 1973 was projected to grow 8.7% annually from 1973 to 2000 (Stanford Research Institute, 1973), is slowing as major markets such as polyvinyl chloride (PVC), polyethylenes, polystyrenes, epoxies, and polyesters are maturing (Greek, 1984c; Greek, 1984d). The growth rate of plastic resins, from which essentially all plastics are derived, dropped from a phenomenol 13.9% per year, 1958-1968, to only 2.9%, 1979-1983 (Table 6).

The automotive market accounts for nearly 80 percent of all rubber demand (primarily petrochemically derived synthetic rubber), 75 percent of which is attributed to tires alone (Secretary of Commerce, 1983). The saturation in the use of the automobile discussed earlier is one factor limiting growth in the rubber industry. In addition, new cars have been using less and less rubber. The amount of rubber in the average new automobile dropped 10%, 1976-1984 (see Table 1). This was in part due to the introduction of radial tires, which last twice as long as bias-ply tires and contain about 28% less synthetic rubber (Chemical Week, 17 Oct 1984). In addition, lighter weight cars and front-wheel drive, both of which have become more common in the last decade, contribute to additional tire life beyond that gained by shifting from bias-ply to radials (Greek, 1984b). Radials, which are now original equipment on 84% of all new cars (compared to 6% in 1972), are also being made smaller, weighing 25% less in 1983 than in 1972 (Greek, 1984b).

Largely as a result of decreasing demand and rising raw materials costs (including petroleum feedstocks), a third of the 60 pneumatic tire plants operating in 1977 are now closed (Bureau of Industrial Economics, 1984). The total amount of rubber used in the automobile is projected to continue to decline, reaching a value 20% less than today by 1987 (see Table 1). Tire manufacturers, in an attempt to remain viable, are diversifying to provide services (e.g., automotive repair and service), in addition to retail sales (Business Week, 26 April 1982).

As the use of chemically-derived synthetic materials as substitutes for more traditional materials saturates, and as other markets for commodity chemicals mature, chemical companies are increasingly looking for greater profits from less materials-intensive, higher value-added specialty chemicals used in small volume, but fast-growing, electronics and biotechnology markets (Chemical Week, 17 Oct 1984; Webber, 1984; Chemical Week, 4 Jan 1984; Greenhouse, 1984; Marcus, 1984; Jaffe, 1984).

Ammonia: The data on consumption of ammonia (in terms of the nitrogen it contains) per unit of GNP displays characteristics which have been seen in data throughout this paper: consumption rose steadily and rapidly up until the late 1960s, slowed for a decade and then began a descent which has continued to the present (Figure 18, lower). The peaking of per capita consumption of ammonia followed in the mid-1970s (see Figure 18, upper). Since then, per capita consumption has dropped significantly.

Official ammonia demand growth projections of 1 percent (Bureau of Industrial Economics, 1984) and 1.3 percent per year (Bureau of Mines, 1984) for the next several years suggest that ammonia consumption will barely keep ahead of population, which is projected to grow annually about 0.9% to 1990 (Bureau of the Census, 1983).

Some clues as to why growth projections are relatively low can be found in trends in the use of nitrogenous fertilizers, which incorporate about 80 percent of all ammonia produced (Davis, 1982). First, most cropland is already being fertilized. Figure 19 shows, for example, that by 1970, nearly 95% of cultivated land under corn production was being fertilized with an average application rate of about 125 kg/ha. Moreover, the amount of fertilizer used per hectare can be expected to slow significantly in the near future, since increases in fertilizer application beyond the current rate (154 kg/ha in 1983) will lead to significantly diminishing incremental yields, as illustrated by the experimental data on corn in Figure 20.

In addition to saturation in fertilized area and diminishing returns with increased application using current practice, increases in the efficiency with which nitrogen is applied could also contribute to slowing the growth in nitrogenous fertilizer demand. Currently about half the nitrogenous fertilizer that is applied to fields is not utilized by the crop. Factors which could lead to improvements in this fraction include more appropriate application rates, better timing of application, and alternative methods of application (Sundquist, Menz, and Neumeyer, 1982).

Increased use of nitrogen-fixing legumes in crop rotations may also reduce nitrogenous fertilizer demand, and it may one day be possible through genetic engineering to develop strains of cash crops like corn which fix nitrogen (Sundquist, Menz and Neumeyer, 1982).

Rising natural gas prices are also likely to affect the growth in demand for ammonia (NH_3), the production of which currently depends almost exclusively on natural gas as its source of hydrogen. The nearly 4-fold increase in the real deflated price of natural gas since the early 1970s has already had a strong impact on the ammonia industry: the cost of energy feedstocks contributed about 75 percent to total production costs in 1982, up from 46 percent in 1975 (Davis, 1982).

Chlorine: The history of chlorine consumption per unit of GNP is similar to that of ammonia. From the late 1940s until the late 1960s this index grew rapidly. It then remained constant for several years, and has fallen in most years since the mid 1970s (Figure 21, lower). Per capita consumption of chlorine grew steadily through the 1960s and part of the 1970s before peaking in 1979 (Figure 21, upper), when per capita GNP reached about $13,000.

Chlorine is widely used in a number of major end-use markets, including: assorted organic compounds, accounting for 37% of all use; the multipurpose plastic, polyvinylchloride (PVC), (21%); inorganic chemicals (20%); the pulp and paper industry (16%); and water treatment (5%) (Fiedler and Zengierski, 1984). The onset of saturation has been acknowledged as resulting from a number of individual factors acting to permanently slow growth in demand in most of these markets: reduced fluorocarbon aerosol production arising out of concern for depletion of the protective ozone layer of the atmosphere; the acclerated phasing-out of leaded gasoline, resulting in less use of antiknock additives derived from chlorine; the largely completed shift in the pulp and paper industry to sodium chlorate as a bleaching agent; process changes to less chlorine-intensive routes in the production of important chemicals, including propylene oxide, and linear alkyl benzene; reduced production of agricultural chemicals embodying chlorine (e.g., DDT); and increased regulation of solvent emissions and a general tightening of process controls for many chlorinated organic chemicals (Fiedler and Zengierski, 1984).

Maturing markets for end-use products are also contributing to slowing growth in demand. For example, 56% of PVC production goes to the construction market, the residential portion of which can be expected to grow relatively slowly in the future for demographic reasons, as noted earlier. The slowing growth in paper demand is also probably contributing to saturating chlorine demand. There appear to be no existing high-growth markets for chlorine left and no new markets on the horizon (Fiedler and Zengierski, 1984), suggesting that the leveling in per capita consumption is not a temporary phenomenon.

The energy cost of producing chlorine, which like aluminum production is electricity-intensive, may act to further limit chlorine consumption. The chlor-alkalai industry has historically paid less for electricity than industry as a whole (see Figure 17), but as noted earlier, new sources of low cost hydro-electricity, are being exhausted in this country (see Table 5). While electricity costs at a typical chlorine factory represented about 50% of total production cost in 1975 (Council on Wage and Price Stability, 1976), they now constitute about 60 percent of total costs on the Gulf Coast, where a large fraction of US production occurs (Bureau of Industrial Economics, 1984).

In summary, substantial future growth in chlorine demand is unlikely, as supported by the above analysis and as suggested by a recent projection for long-term growth in the chlor-alkali industry of 1-2% per year (Greek, 1984a).

Ethylene: The use of ethylene, a very modern basic material, did not become significant until the 1950s and 60s, as shown in Figure 22. Consumption grew faster than GNP through the early 1970s, grew only very slightly faster through most of the 1970s, and has been decreasing gradually since (Figure 22, lower). Absolute per capita consumption has been slowly declining since the late 1970s (see Figure 22, upper).

Ethylene is a major building-block for a number of intermediate chemicals. The energy consumed in the production of ethylene and some of its major derivatives amounts to about 20% of the total energy consumed by the chemical industry (Ross, 9 Nov 1981). The direct derivatives of ethylene include: low-density polyethylene (LDPE), which accounts for about

26% by weight of total US ethylene demand; high-density polyethylene (HDPE), 19%; ethylene oxide, 18%; ethylene dichloride, 15%; and ethyl benzene, 7% (Sciancalepore, 1984). A number of factors affecting chlorine demand are also affecting ethylene demand, including changing process technologies, maturing product markets, and stricter environmental regulations. Since ethylene is largely derived from crude oil and natural gas, rising energy prices have probably catalyzed process changes and market maturation rates.

The production of LDPE, used primarily in consumer plastic films, was revolutionized by the commercialization in the late 1970s of linear low-density polyethylene (LLDPE), which presently accounts for about 36% of all LDPEs, a fraction expected to grow to near 60% by 1990 (Klestadt, 1984). Because of significant chemical differences, LLDPE is generally stronger than conventional LDPE, allowing downgauging of film thicknesses -- saving up to half the resin required for LDPE, while providing equivalent strength (Kline's Guide, 1982). As a result of the downgauging permitted by the use of LLDPE, the overall tonnage demand for <u>all</u> polyethylene is projected to be about 6% less in 1990 than it would have been without the introduction of LLDPE (Klestadt, 1984).

A number of trends discussed earlier can also be expected to limit future growth in ethylene consumption. Since about 62% of ethylene oxide goes to antifreeze production, and most of the rest to the manufacture of polyester fibers, the market for ethylene oxide is significantly affected by the relatively recent downsizing of cars (see section on steel), and correspondingly their cooling systems, and by the maturation of synthetic fibers markets (see Figure 15, upper) (Chemical Week, 7 March 1984). PVC markets, which account for almost all ethylene dichloride use, are also reaching maturity (see section on chlorine). The consumption of ethyl benzene, used largely to produce styrene, a basic component of styrene-butadiene rubber (SBR) used in tires, was negatively affected by the introduction of longer-lived radials, which contain only 61% SBR compared to 85% in ordinary bias-ply tires (Chemical Week, 17 Oct 1984).

Tighter environmental regulation is another factor which is likely to influence future ethylene demand. For example, the US Environmental Protection Agency is considering a total ban on the use of several ethyl glycols commonly used in solvents, paints, and stains (Chemical Week, 8 Feb 1984).

Material Trends in Other Industrialized Countries

The trend toward saturating consumption of basic materials is not restricted to the US. On the contrary, it appears to be a phenomenon occurring in many industrialized countries. For example, Figure 23 shows steel, cement, and aluminum consumption trends from 1950 to the present in the U.K., Germany, France, and Sweden. As these figures demonstrate, the growth in steel and cement consumption is clearly waning, while consumption of the more modern material, aluminum, has essentially leveled off in all countries. Furthermore, just as future growth in chlorine and ethylene consumption may be expected to slow in the US, projections of European demand growth suggest a similar trend may hold in Europe. The chlor-alkali demand has been projected to grow ±1-2% year for the next 2-3 years (Chemical Week, 1 Feb 1984), while ethylene consumption has been projected to grow only about 0.8% per year to 1990 (O'Sullivan, 1984).

An Overview of Basic Materials Consumption

In summary, basic materials are declining in importance in the economy, as evidenced by declining demand per dollar of GNP. In addition, per capita consumption of most of these materials appears to have reached saturation. Figure 24 summarizes consumption trends in the US for materials discussed in this paper. (Textile fibers have been excluded for clarity.)

The lower curves graphically display the shifting importance of various materials in the economy -- including steel and cement, the major building blocks of industrialization in the first half of the 20th century; paper, the steady influence of which is observed through most of the middle decades of this century; and aluminum and chemicals, materials which rose to prominence in the 1950s and 60s.

The upper set of curves display the slow climb to saturation in per capita consumption characterizing the older materials -- steel, cement, and paper, and the comparatively rapid rise of the modern materials -- aluminum, ammonia, chlorine, and ethylene, followed by sharp declines. The relatively recent downturn in the per capita consumption of the modern materials might raise the question of whether this is a true saturation effect, or merely a consequence of the 1980-82 recession. The data, however, indicate a marked decoupling of the demand for modern basic materials from GNP in this period, extending through the 1983 recovery. While there was no net change in GNP per capita between 1979 and 1983, the per capita demand fell 13% for aluminum, 25% for ammonia, 10% for chlorine, and 8% for ethylene * in this period. It is premature, because of the recent recession, to infer from these data that a dramatic turn downward in per capita demand for modern materials is underway, but these data, together with our analyses of the reasons for recent trends and the prospects for future growth in each case, provide strong evidence to support at least a case for saturation, and thereby indicate that the transition to a post-industrial era is fully underway.

Rethinking Energy Demand

The above finding, suggesting that future consumption of basic materials in the US will grow only about as fast as population, compels a fundamental rethinking of the basis for making industrial energy demand projections.

A Simple Model for Estimating Future Industrial Energy Demand: To illustrate the significance of our findings for energy planning purposes, we make a simple, heuristic estimate of future industrial final energy demand. We project energy demand to the year 2010 from a base year of 1972, the last year before the long-term, relatively stable relationship between economic output, energy prices, and energy demand was disrupted by the oil price shocks. For the calculation, we assume that:

- the material output of the BMP sector will grow from the base year at the rate of population, as suggested by the data presented in this paper.
- GNP will grow as projected by the US Department of Energy (Office of Planning, Policy and Analysis, 1983), at an average annual rate of

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* These are the actual percentage changes, whereas running averages have been plotted in the figures to illustrate trends. See the notes to the individual figures for further explanation of the averaging.

2.6%, 1982-2010.

- for each 1% growth in GNP, value-added of OMFG will grow 1.1% and that of MAC will grow 0.5%, as given by regression equations of historical data relating GNP to value-added for these sectors.
- energy efficiency improvements are taken into account as the long term response to changes in the average industrial energy price.

We consider a range of 2010 energy prices, from no change over the 1981 price (the last year for which reliable data are available) to a doubling of the 1981 price. We also consider the full range of what economists generally believe the long-run price elasticity is: -0.4 [see, for example, (International Energy Agency, 1982)] to -0.8 [see, for example (Pindyck, 1979)].

Energy demand levels for 2010 calculated on the basis of these assumptions are shown in Table 7, expressed as fractions of the 1980 demand level of 24.4 EJ (6). Our calculations suggest that final industrial energy use in 2010 could range from a low of some 1/3 that in 1980 (assuming a doubling of energy prices and the high price elasticity of -0.8) to a high value about equal to that in 1980 (assuming energy prices do not rise, 1981-2010, and a price elasticity of -0.4).

Alternatively, the results of our calculations can be viewed in terms of the corresponding reductions in final energy intensity (FEI) of the industrial sector (final energy per dollar of gross product originating), as shown in Table 8. For the same limiting cases, the FEI in 2010 would range from 21% to 40% of the 1980 level, and the corresponding annual average rate of decline in the FEI, 1980-2010, would be 5.1% and 1.7% per year, respectively. For comparsion, the annual rate of decline in FEI between 1970 and 1983 was 3.0% (7).

While Table 7 presents a matrix of possible energy demand levels in 2010, not all of these outcomes are equally probable. The assumption of a doubling of the energy price is probably not consistent with the low demand level that would result from assuming a high elasticity; at such a low demand level the pressure on energy supplies would be low, suggesting much lower energy prices. However, even restricting consideration to the cases involving no price increase, 1981-2010, our model indicates that final energy demand in 2010 would still be only 60 to 100% of the 1980 level.

A Comparison with the US DOE Energy Demand Forecast: In constrast to our results, the US Department of Energy (DOE) projects a final industrial energy demand of 31.3 EJ for 2010, as we discussed in detail near the beginning of this paper. In this, their baseline case, they assume that in the year 2010 the average price of energy delivered to industry would be 2.2 times the 1981 level (Office of Planning, Policy and Analysis, 1983).* The main reason for the large discrepancy between our calculations and the DOE projection [and many other projections made using similar methodologies (9)] is that conventional forecasts have not adequately taken account of saturation occurring in the consumption of basic materials.

Although it is now widely accepted that total energy demand for the country and GNP need not evolve in lock-step, many conventional industrial sector forecasts tend to project future industrial energy demand on the basis of historical correlations between industrial energy use and highly aggregated measures of industrial output. So doing provides an

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* The DOE also considers an alternative low-price case, in which the 2010 price is 1.5 times the 1981 level, but final industrial energy demand in this case is essentially the same as in their baseline case (9).

unsatisfactory basis for projecting energy demand if there are major structural changes taking place, since energy intensities can vary by up to an order of magnitude from one industry to another (see Figure 7).

Highly aggregated indices of economic activity can mask structural changes of importance to energy demand modelling, as can be seen from a consideration of the widely used Federal Reserve Board (FRB) Index. This index is constructed by assigning fixed weights to each subcategory within a given industry according to the share of value-added contributed by that subcategory, multiplying these weights by an index of physical production for the industry as a whole, and summing the products. Thus, the FRB index is proportional to the value-added which would have been generated at the actual physical production level, had the distribution of value-added within the industry remained constant in time relative to a base year.

In the BMP industries, the value of the FRB index is primarily determined by the downstream value-added intensive activities, while a large fraction of energy use occurs in upstream activities (Ross, 1983) (10). Since the trend in many BMP industries is a shift to higher value-added products, the use of the FRB index as an indicator of energy demand is likely to lead to overestimates of future energy demand in the BMP industries. The FRB index, if it is to be used for energy planning purposes, should only be used with care (Ross and Boyd, 1984).

This problem with aggregate economic indicators is not restricted to the FRB index but would occur as well with pure value-added measures such as gross product originating by industry. The most promising way to circumvent the problem for energy forecasting purposes would be to develop models that correlate energy use with some more appropriate disaggregated measures of physical production.

The DOE forecasting group (like many other modelling groups that rely on aggregate economic indices to forecast industrial energy demand) attributes the accelerated drop in FE/O (the ratio of industrial final energy demand to industrial output) during the 1970s almost entirely to transient price effects, largely overlooking the structural changes we have described here. They project that as prices stabilize, the average annual rate of decline of FE/O will drop back from its 4% value in the 1970s* to 2%, its value in the 1960s (Office of Policy, Planning and Analysis, 1983).

Materials Production vs. Materials Consumption: The discussion in this section has assumed that production in the US would grow at the same rate as consumption. However, the energy-intensive basic materials processing industries are increasingly moving overseas, where abundant raw materials, inexpensive energy (e.g., hydro-electric power), cheap labor, and less rigid environmental regulations contribute to lowering the overall cost of production (Ross, Aug. 1984). As an example of shifts to production overseas, total steel tonnage produced in the US in 1982 was less than half that in 1973, while at the same time, the US went from being a net exporter to a net importer of raw steel (American Iron and Steel Institute, 1982). In the case of aluminum, imports of raw and finished products as a fraction of apparent consumption in the US rose from about 8 percent in 1973 to about 17 percent in 1983 (Aluminum Association, 1983).

Shifts to overseas production of basic materials can affect US energy

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* This rate of decline cited in the US DOE analysis is faster than the 3% rate we estimated for the rate of decline in the FEI (the ratio of final energy use per dollar of GPO), in the period 1970-83. This is probably because the US DOE analysis uses the FRB index to measure industrial production, an index which typically grows more rapidly than GPO.

consumption two ways. First, the reduction in domestic material output would lead to a reduction in energy demand beyond that associated with saturation, given constant or declining energy intensities. Second, the need for US smokestack industries to increase their overall productivity to maintain a substantial market share in the face of increased foreign competition may lead to accelerated replacement of older capital equipment with more energy-efficient new equipment, which would mean lower overall energy requirements, given constant production levels.

Conclusion

The ongoing trend within industry away from basic materials processing to higher value-generating fabrication and finishing activities can be expected to continue, in light of what appears to be the poor prospects for growth in the per capita consumption of a wide range of basic materials, as illustrated in this paper for steel, cement, paper, textile fibers, aluminum, ammonia, chlorine, and ethylene.

This trend reflects in part more effective use of basic materials in product design, brought on by today's high energy prices and the intense competition from different materials in meeting the same needs. But the phenomenon appears to be much more than just a transient response to the energy crises, and was well underway even before the first oil price shock. It appears that the use of basic materials in the US, and in other industrialized countries as well, is reaching saturation, and that these countries are beginning to enter a new Post-Industrial Era. On reflection, this finding should not come as a surprise. The average American consumes his or her weight in basic materials each day (see Figure 25). The difficulties of managing this much "stuff" provide a powerful incentive to seek out economic activities that lead to improved quality of life without so much effort.

This trend has far-reaching implications for future industrial energy demand which have not been taken into account in long term energy demand forcasts based on extrapolations of historical correlations of energy demand with highly aggregated measures of economic activity, which are relatively insensitive to these structural changes.

In the decades ahead final energy use by industry will probably not increase and may well decrease considerably, even if there are no further increases in industrial energy prices. This means that capital requirements for energy supply expansion will not be nearly as great as indicated by conventional forecasts -- a welcome prospect in light of the high cost of new energy supplies. It is the good fortune of the US and other highly industrialized countries that the beginning of the era of high cost energy also marks the beginning of the Post-Industrial Era.

List of Tables

Table 1. Estimated materials use in the average US-made car. (Values are in kg/car.)

MATERIAL	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	PROJECTION (a) 1987	1990	1992
Plain Carbon Steel	966	943	907	870	839	790	728	668	687	694	591	500	479
High Strength Steel	46	55	58	60	68	80	86	92	94	95	136	136	145
Stainless Steel	13	13	12	12	12	13	12	12	13	13	-	-	-
Total Steel	**1139**	**1010**	**977**	**943**	**919**	**883**	**826**	**772**	**794**	**802**	**727**	**636**	**625**
Iron	264	255	245	233	226	220	214	210	215	219	159	123	114
Fluids/Lubricants	82	86	91	90	86	81	80	81	83	86	-	-	-
Plastics/Composites	71	74	78	82	84	89	90	91	91	93	91	102	114
Rubber (b)	68	70	68	67	63	60	60	61	63	63	50	50	50
Aluminum	37	39	45	51	54	59	59	61	62	62	62	62	61
Glass	39	40	39	39	39	38	38	38	39	39	36	34	34
Copper	15	15	14	13	13	13	13	13	13	13	10	10	10
Lead	11	11	11	11	11	10	10	11	11	11	-	-	-
Zinc Die Castings	22	20	17	14	11	9	8	7	8	8	7	7	7
Others (c)	94	89	84	80	74	69	70	70	73	74	55	75	55
TOTAL	**1727**	**1709**	**1670**	**1623**	**1580**	**1529**	**1467**	**1415**	**1451**	**1469**	**1197**	**1100**	**1069**

a. Categories in projections and in pre-1985 figures do not match exactly, but totals are comparable.
b. Includes tires.
c. Pre-1985 figures include alloy steel, cloth, cardboard, brass, etc.
Source: Historical data are from (Wards Automotive Yearbook). Projections are from a survey of automotive industry experts originally presented in (Office for the Study of the Automobile, 1984) and cited in (Wards Automotive Yearbook, 1984).

Table 2. Percentage distribution by fiber type in the consumption of apparel.

Year	Cotton	Wool	Natural Subtotal	Synthetics
1965	57.2	10.5	67.7	32.3
1966	55.4	9.2	64.6	35.4
1967	51.4	7.9	59.3	40.7
1968	44.7	7.8	52.5	47.5
1969	42.9	7.2	50.1	49.9
1970	41.0	5.5	46.5	53.5
1971	39.6	3.5	43.1	56.9
1972	36.8	3.1	39.9	60.1
1973	33.2	2.4	35.6	64.4
1974	35.9	2.0	37.9	62.1
1975	33.6	2.2	35.8	64.2
1976	35.9	2.6	38.5	61.5
1977	33.8	2.6	36.4	63.6
1978	33.5	2.8	36.3	63.7
1979	35.2	2.7	37.9	62.1
1980	35.8	2.6	38.4	61.6
1981	34.8	3.2	38.0	62.0
1982	37.5	3.2	40.7	59.3
1983	37.5	3.3	40.8	59.2

Source: (Textile Economics Bureau, various years)

Table 3. Average annual percentage growth rates in the mass of aluminum used in the average US-made automobile, 1975 - 1992.

Time period	Average growth per year (%)
1975 - 1978	11.0
1978 - 1981	4.8
1981 - 1984	1.6
1984 - 1987	0.1
1987 - 1990	0.0
1990 - 1992	-0.7

Source: Table 1.

Table 4. The evolution of the material-efficient aluminum beverage can.

Year	Kg per 1000 12-ounce cans		
	Body	Lids	Total
1966-73	22.3	7.3	29.6
1974-76	21.6	7.0	28.6
1977-78	21.1	6.8	27.9
1979	20.0	6.6	26.6
1980	18.6	6.5	25.1
1981	18.1	6.4	24.5
1982	17.8	6.4	24.2
1983	17.5	6.4	23.9
1984	17.4	6.4	23.8

Source: (Vais, 1984).

Table 5. U.S. elecrical generating capacity (GW) by source. Numbers in brackets are percentage of total capacity.

Year	Fossil(a)	Nuclear	Hydro/Geoth(b)	Total
1960	135 [81]	0.3 [0]	32.4 [19]	167.7
1965	191 [81]	0.9 [0]	43.8 [19]	235.7
1970	279 [82]	6.5 [2]	55.2 [16]	340.7
1975	402 [80]	36.0 [7]	66.5 [13]	504.5
1980	480 [78]	55.0 [9]	77.4 [13]	612.4
1985(c)	537 [77]	80 [11]	80 [11]	697.0

a. Includes conventional steam, internal combustion, and gas turbine capacity.
b. Includes other renewable capacity, including wood-fired capacity.
c. USDOE estimate.
Source: (Office of Policy, Planning and Analysis, 1983)

Table 6. Average annual percentage growth rates in sales of plastic resins since 1958.

Time period	Average growth per year (%)
1958 - 1968	13.9
1968 - 1973	6.4
1973 - 1978	5.0
1978 - 1983	2.9

Source: (Kibbel, 1984)

Table 7. Estimated industrial final energy demand in 2010 (expressed as a fraction of the actual 1980 demand), as a function of the long-run price elasticity and the average industrial energy price over the 1981 level.*

Long-run Price Elasticity	Energy Price in 2010/Energy Price in 1980		
	1.0	1.5	2.0
-0.40	1.01	0.86	0.77
-0.60	0.80	0.62	0.53
-0.80	0.63	0.45	0.36

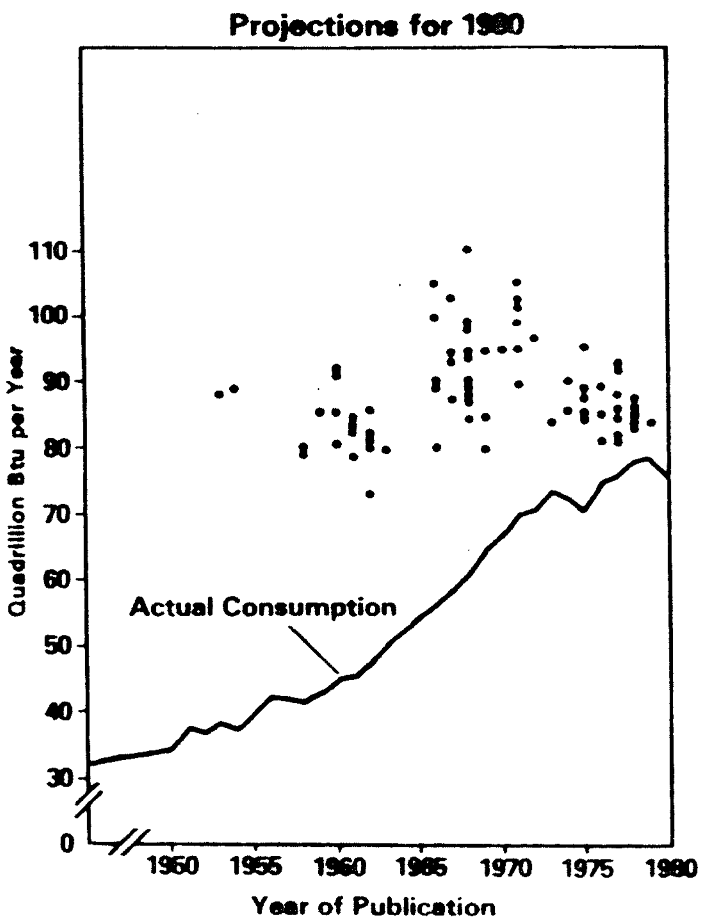
* See note 6 and the text for details of calculations.

Table 8. Estimated industrial sector percentage final energy intensity reduction, 1980-2010 (and % per year), as a function of the long-run price elasticity and the average industrial energy price over the 1981 level.*

Long-run Price Elasticity	Energy Price in 2010/Energy Price in 1980		
	1.0	1.5	2.0
-0.40	39.6 (1.7)	48.6 (2.2)	54.0 (2.6)
-0.60	52.2 (2.5)	62.9 (3.3)	68.3 (3.8)
-0.80	62.3 (3.3)	73.1 (4.4)	78.5 (5.1)

* See note 6 and the text for details of calculations.

List of Figures



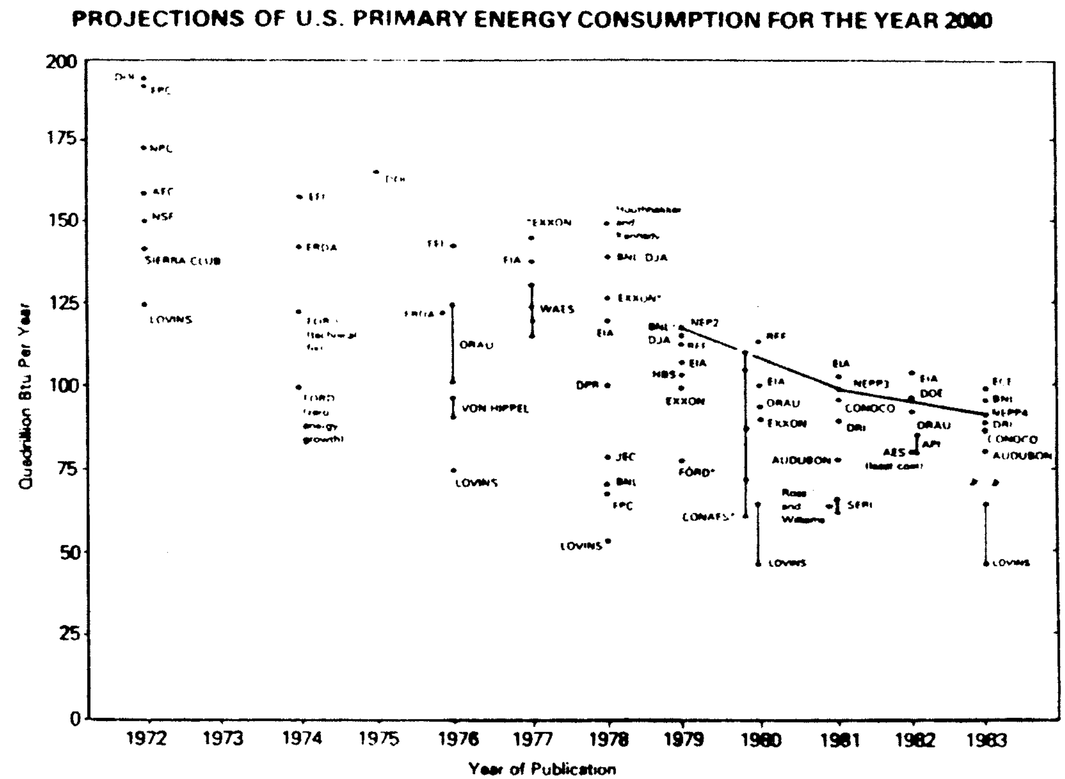


Figure 1. Historical Energy Demand Projections

Notes: from (Office of Policy, Planning, and Analysis, 1983).

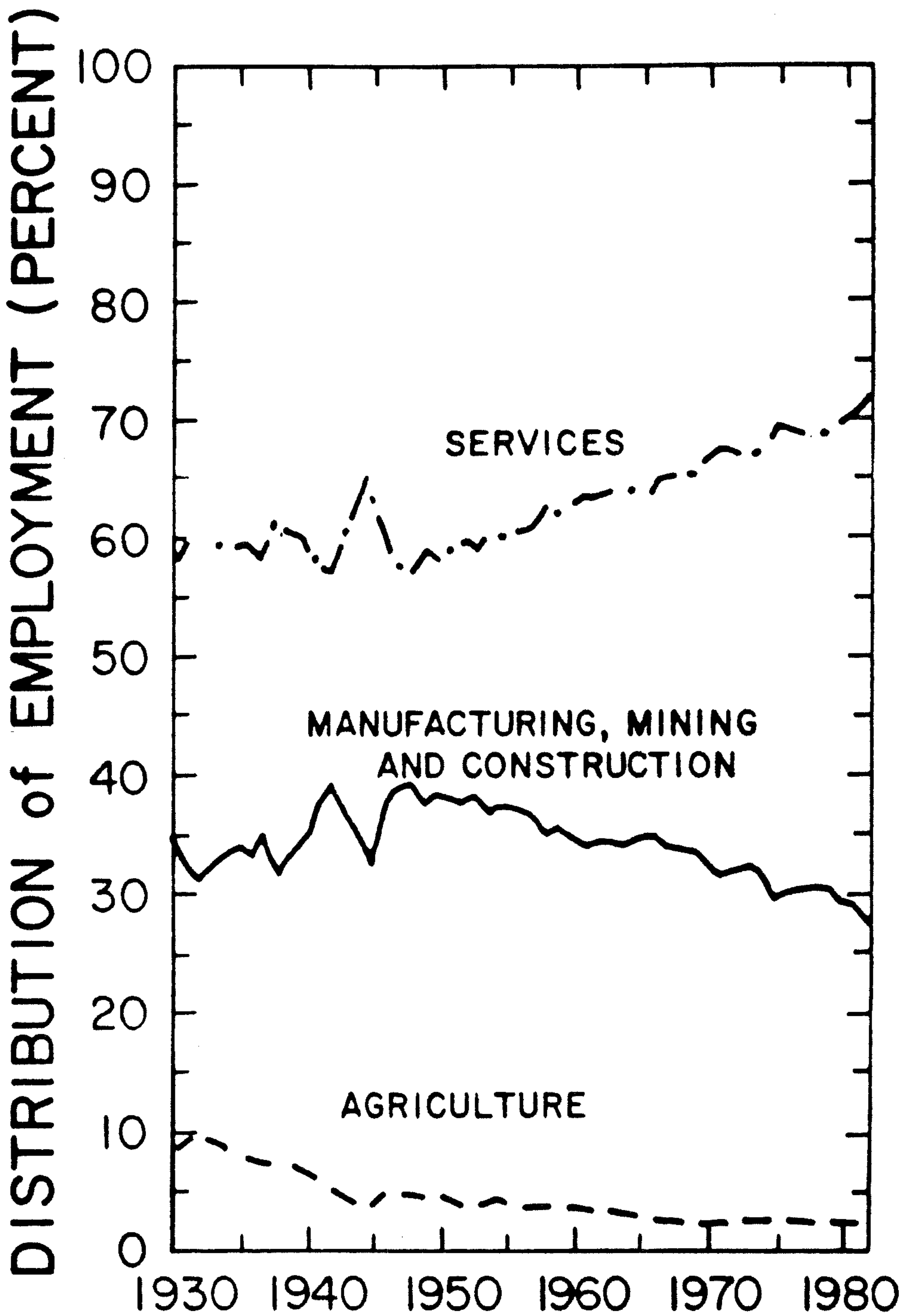


Figure 2. Employment Distribution in the U.S.

Notes: Data are for full-time equivalent employees from (Bureau of Economic Analysis, various issues).

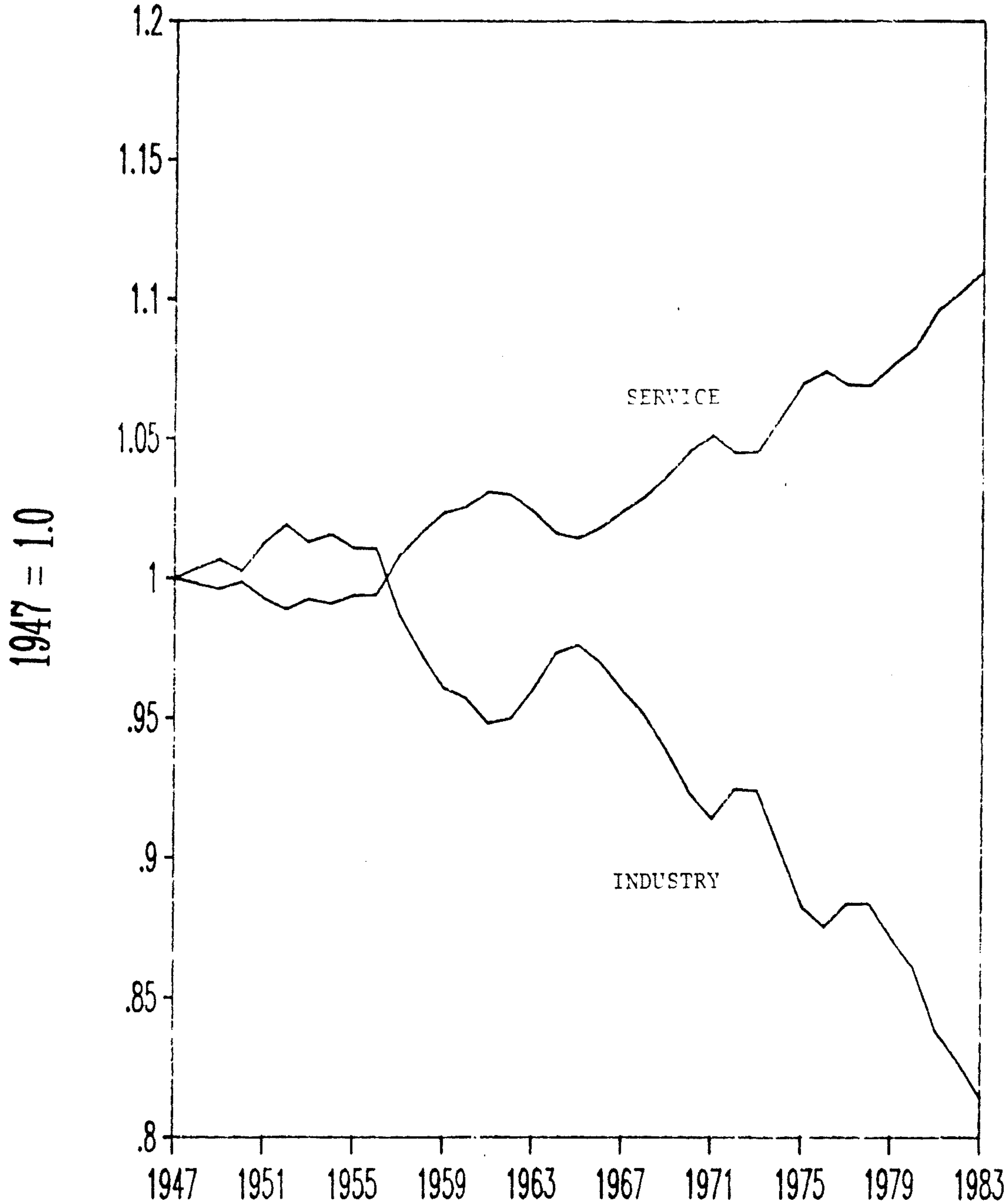


Figure 3. GPO/GNP by Sector

Notes: The value-added measure used here is gross product originating (GPO) by sector. Industry includes the manufacturing, mining, agriculture, and construction subsectors. The ordinate numbers are 3-year averages centered around the year against which they are plotted. Source: (Bureau of Economic Analysis, 1984).

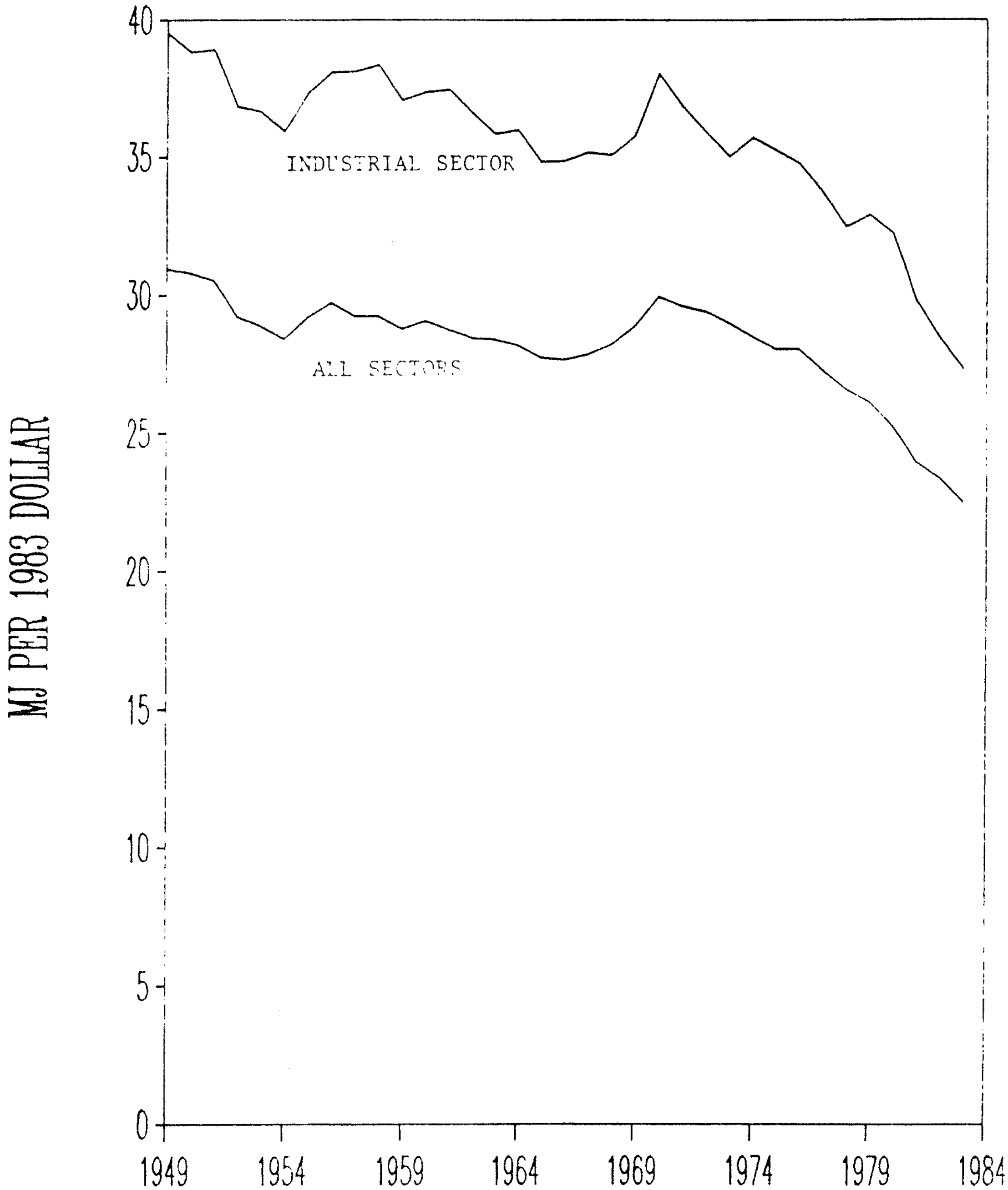


Figure 4. Energy Intensities in the Economy

Notes: These energy intensities are the ratio of primary energy consumption to GPO. Primary energy consumption data include wood consumed and are taken from (Energy Information Administration, April 1984; Energy Information Administration, 1982). GPO data are from (Bureau of Economic Analysis, 1984).

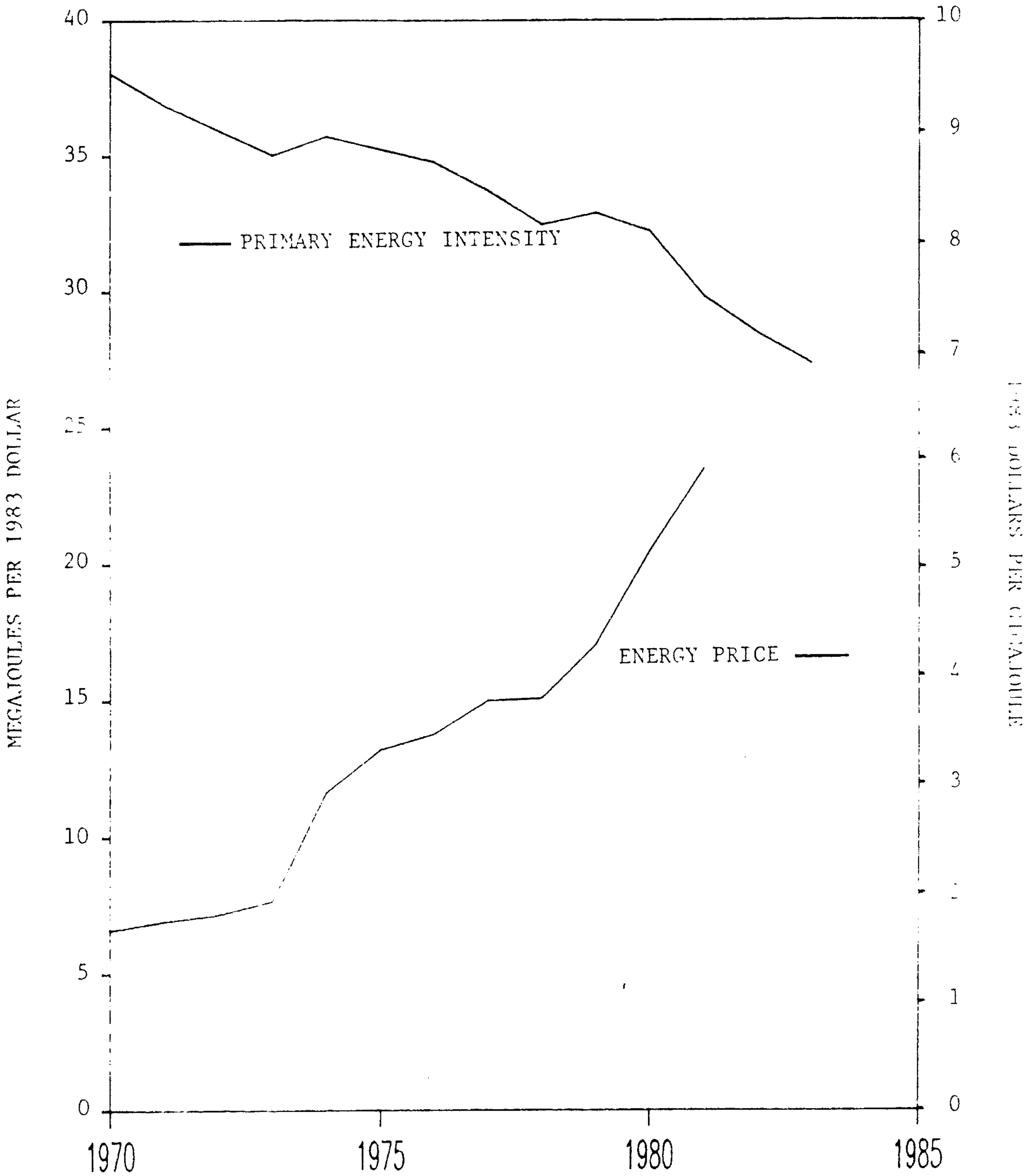


Figure 5. Industrial Sector: Energy Intensity and Average Energy Price

Notes: Energy intensity data are from figure 4; Final-energy prices are from (Energy Information Administration, June 1984).

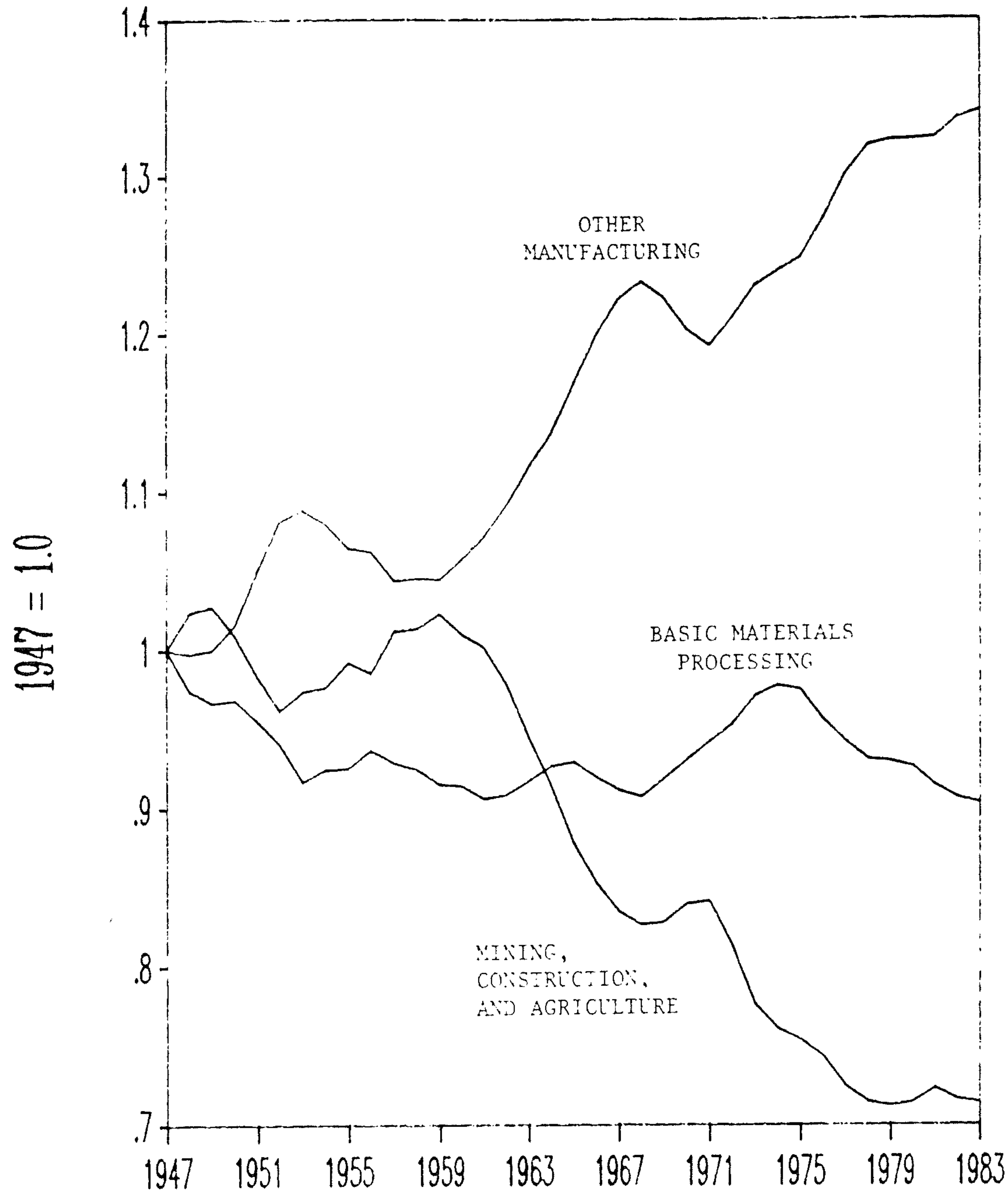


Figure 6. GPO by Industrial Sector/GPO by All Industry

Notes: Within manufacturing, the basic materials processing (BMP) industries (and their corresponding 2-digit Standard Industrial Classification (SIC) codes are: food and kindred products (SIC 20), paper and allied products (26), chemical and allied products (28), petroleum and coal products (29), stone, clay, and glass (32), and primary metals (33). Other manufacturing (OMFG) includes all SIC categories from 20-31, excluding the basic materials subsectors. The ordinate numbers are 3-year averages centered around the year against which they are plotted. Data are from (Bureau of Economic Analysis, 1984).

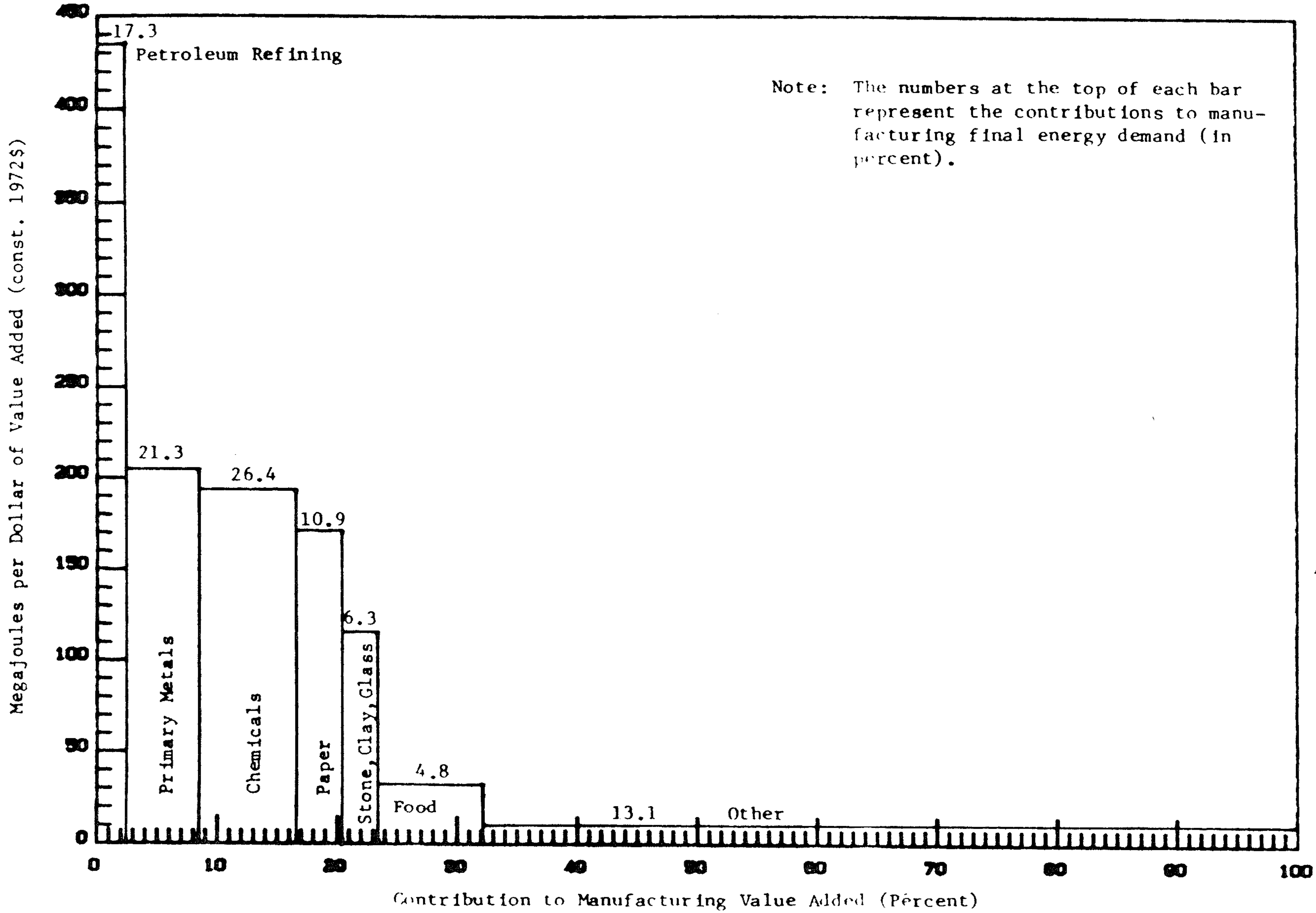


Figure 7. Energy Intensity vs. GPO for U.S. Manufacturing in 1978

Notes: Final energy consumption data are from (Solar Energy Research Institute, 1981). GPO data are from (Bureau of Economic Analysis, 1984).

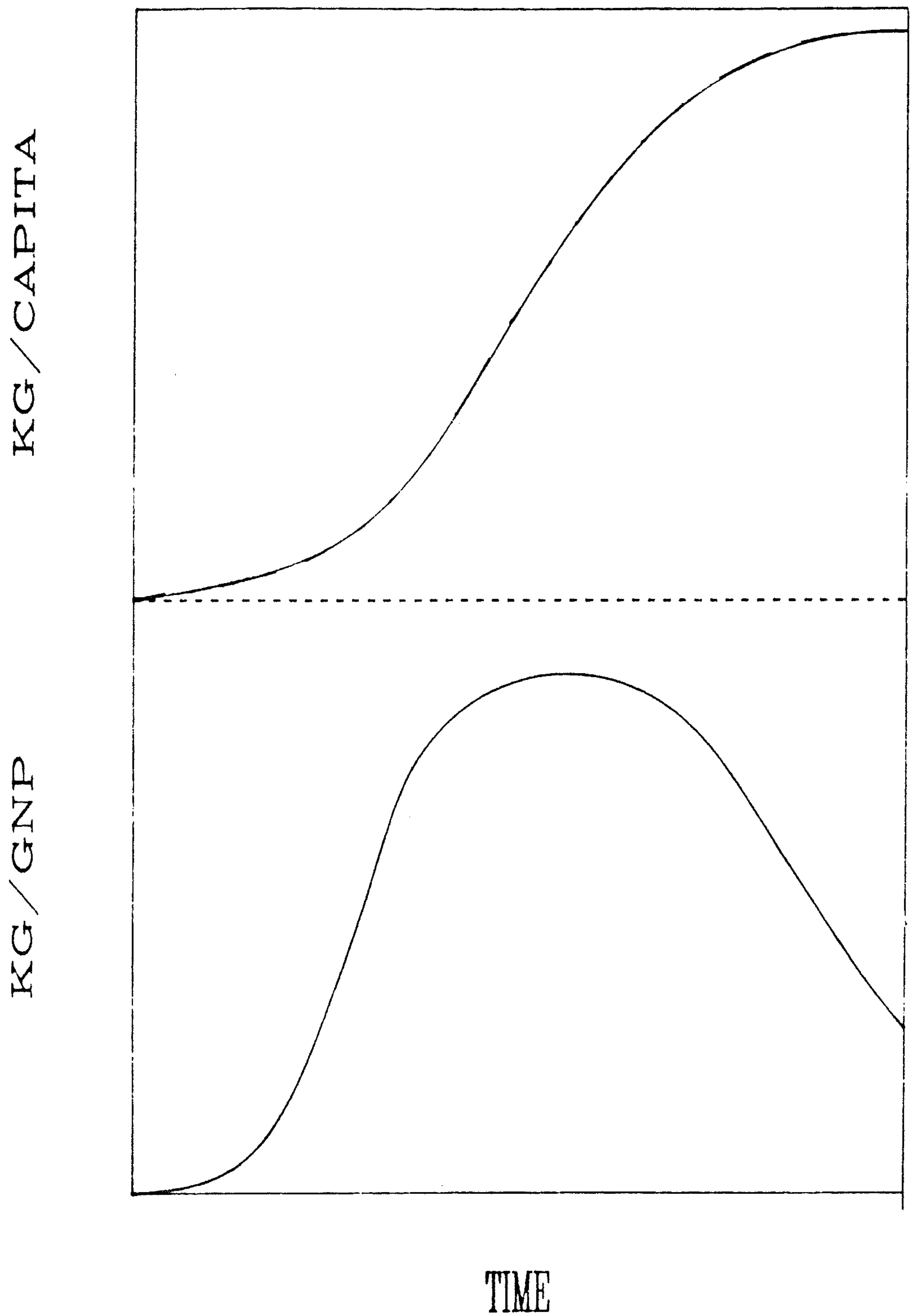


Figure 8. Idealized Material Consumption Pattern

Notes: Authors' conception.

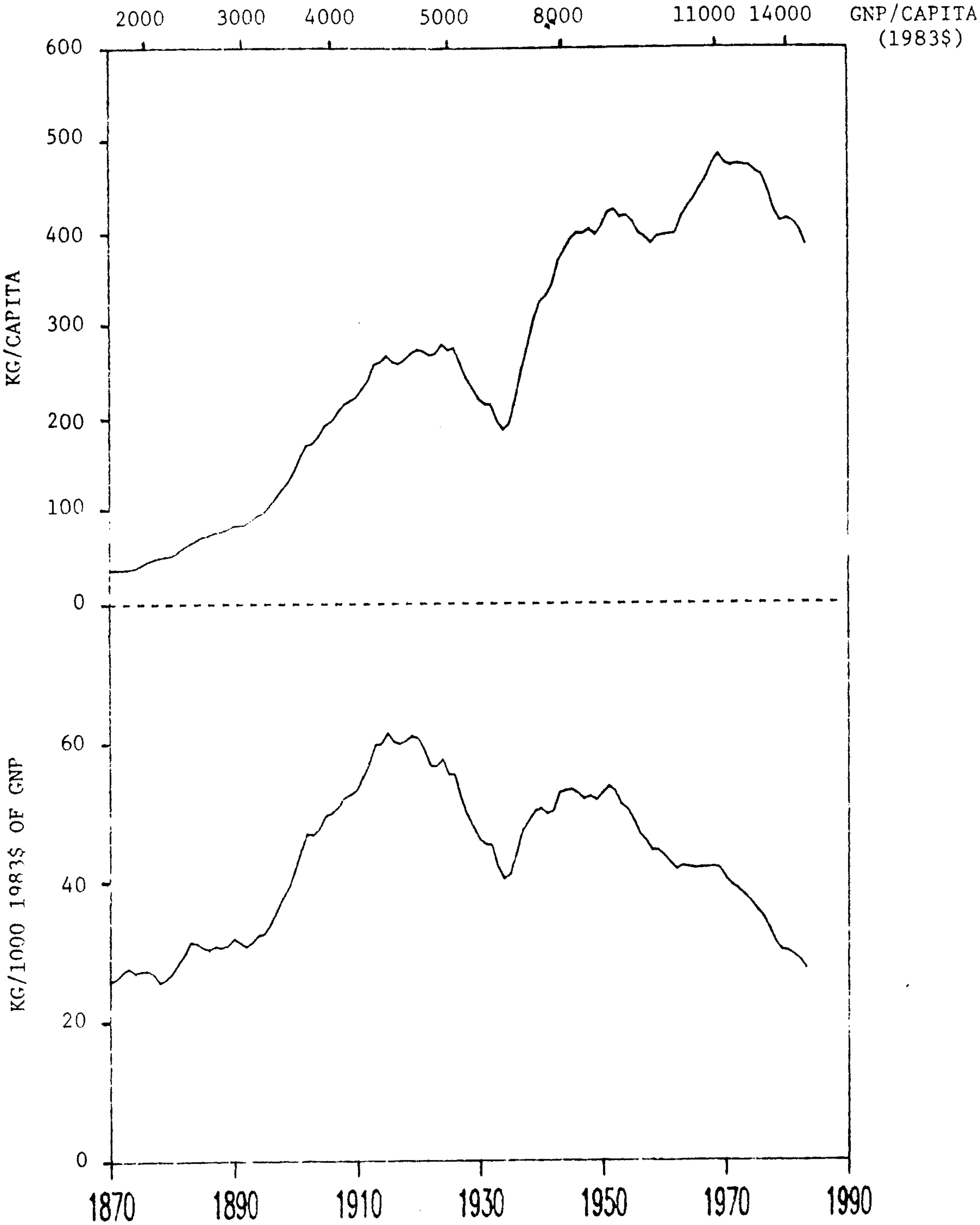


Figure 9. U.S. Steel Consumption

Notes: The ordinate numbers are 5-year averages centered on the year against which they are plotted. See the Appendix for actual yearly data. Data sources: **Apparent steel consumption:** 1870-1927 (Bureau of the Census, 1975, data series P270), 1928-1981 (Schottman, F.J., 1984), 1982-1983 (American Iron and Steel Institute, 1983). **Population:** 1840-1899 (Bureau of the Census, 1975), 1900-1983 (Bureau of the Census, 1983b). **Gross National Product:** 1840-1888 - Regression equation of data for 1873, 1883, and 1889-1900 given in (Bureau of the Census, 1975): (r^2 = 0.98)

$$GNP\ (\text{billion } 1958\$) = 1.234 * \exp\{(.04135) * (Year - 1800)\}$$

1889-1946 (Bureau of the Census, 1975), 1947-1983 (Bureau of Economic Analysis, 1984

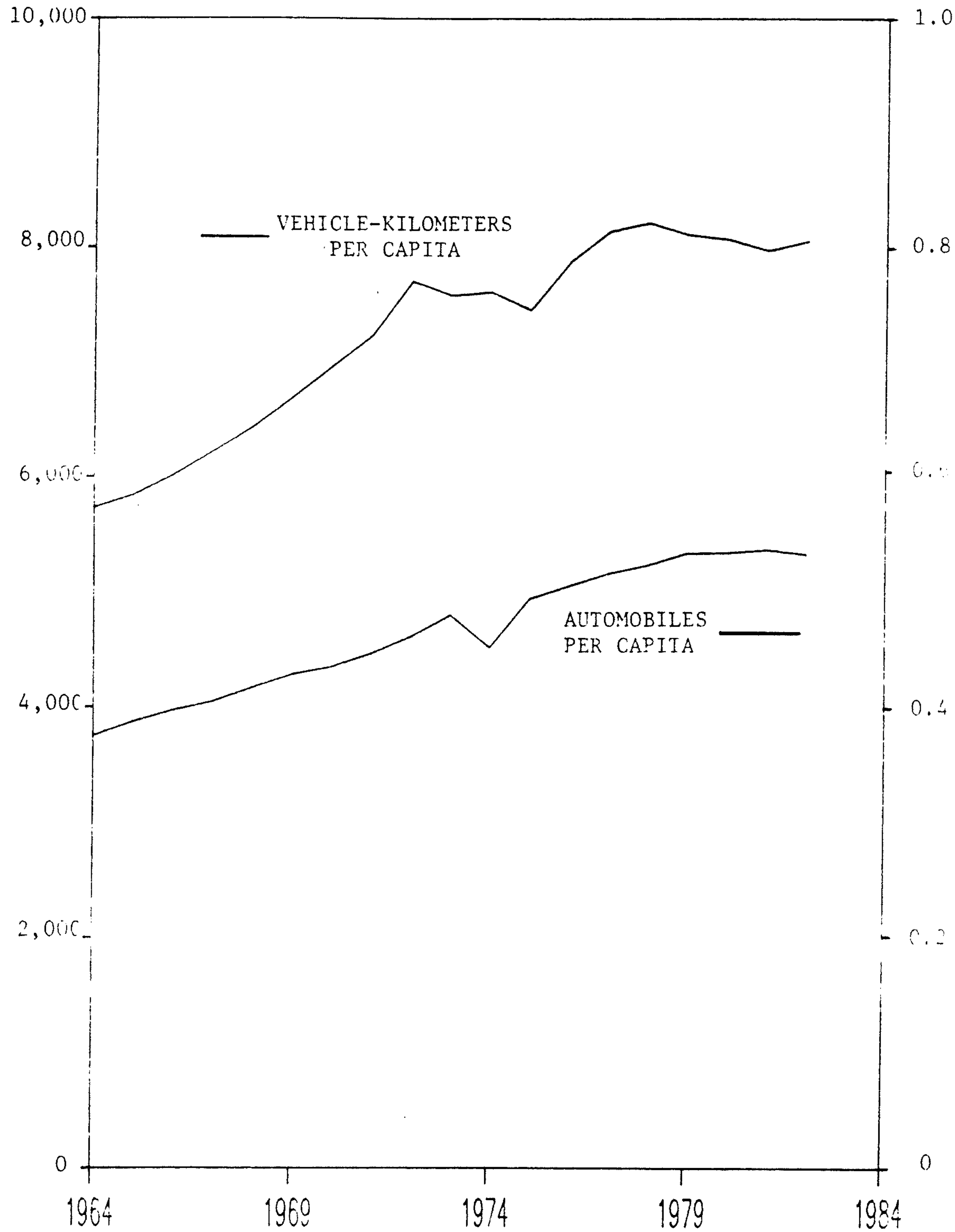


Figure 10. Automobile Ownership and Travel

Notes: The ordinate numbers are 3-year averages centered on the year against which they are plotted. Data are from (Transportation Systems Center, 1984 and 1976).

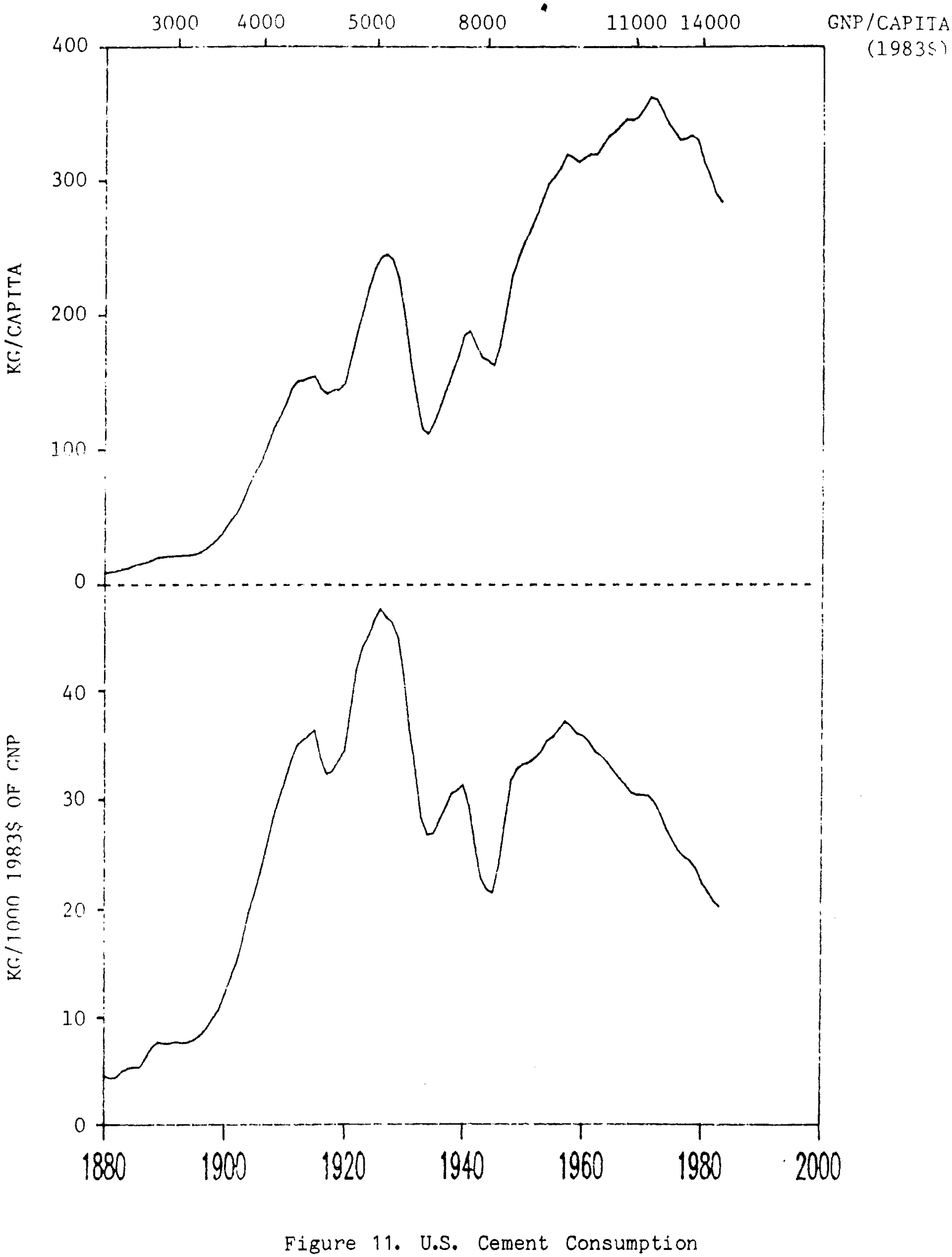


Figure 11. U.S. Cement Consumption

Notes: The ordinate numbers are 5-year averages centered around the year against which they are plotted. See the Appendix for actual yearly data. Data for apparent cement consumption are from: 1880-1928 (Bureau of Mines, 1936); 1929-1982 data (Commodity Research Bureau, various years). For population and GNP sources refer to Figure 9 notes.

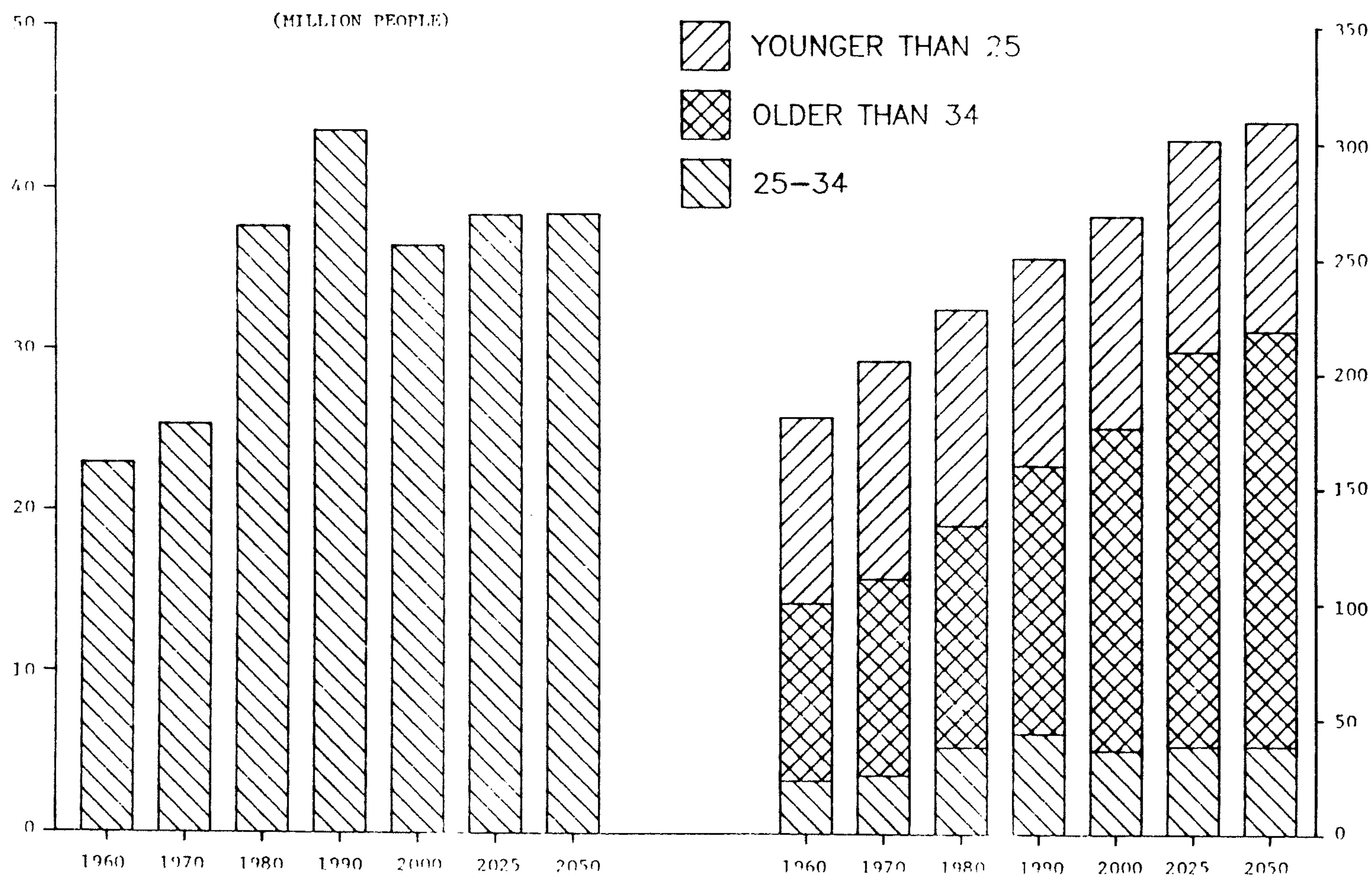


Figure 12. U.S. Demographic Profile

Notes: Historical data are from (Bureau of the Census, 1983b); Projections are from (Bureau of the Census, Oct. 1982).

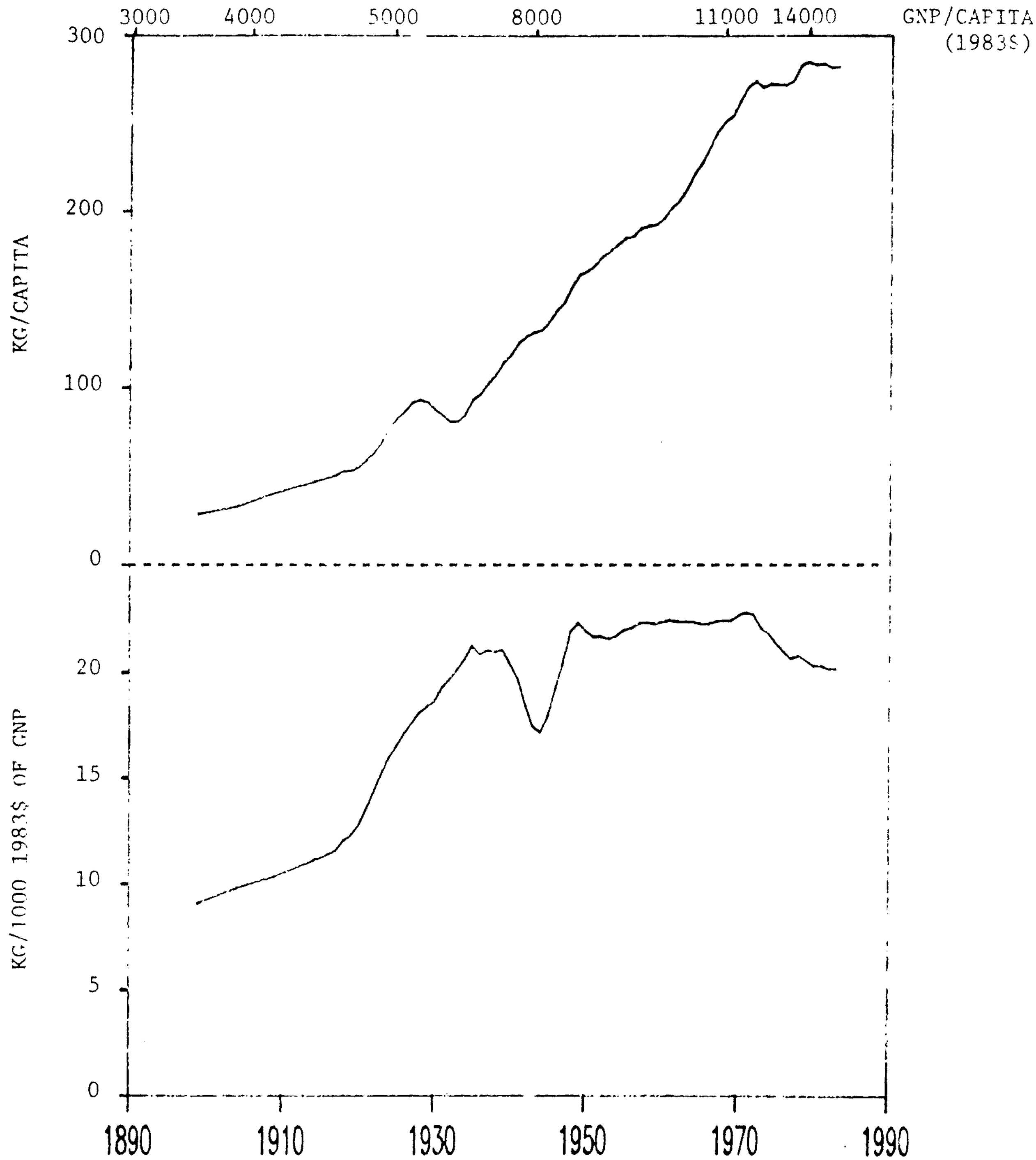


Figure 13. U.S. Paper Consumption (Paper and Paperboard)

Notes: The ordinate numbers are 5-year averages centered around the year against which they are plotted. See the Appendix for actual yearly data. Data for apparent paper consumption are from: 1899-1946 (U.S. Department of Agriculture, various years); 1947-1982 (American Paper Institute, 1979 and 1983); 1983 (American Paper Institute, June 1984). The 1979-1983 figures have been adjusted to include wet machine board, building board, and insulating board, which were excluded from the ongoing data series beginning in 1979. For population and GNP sources, see Figure 9 notes.

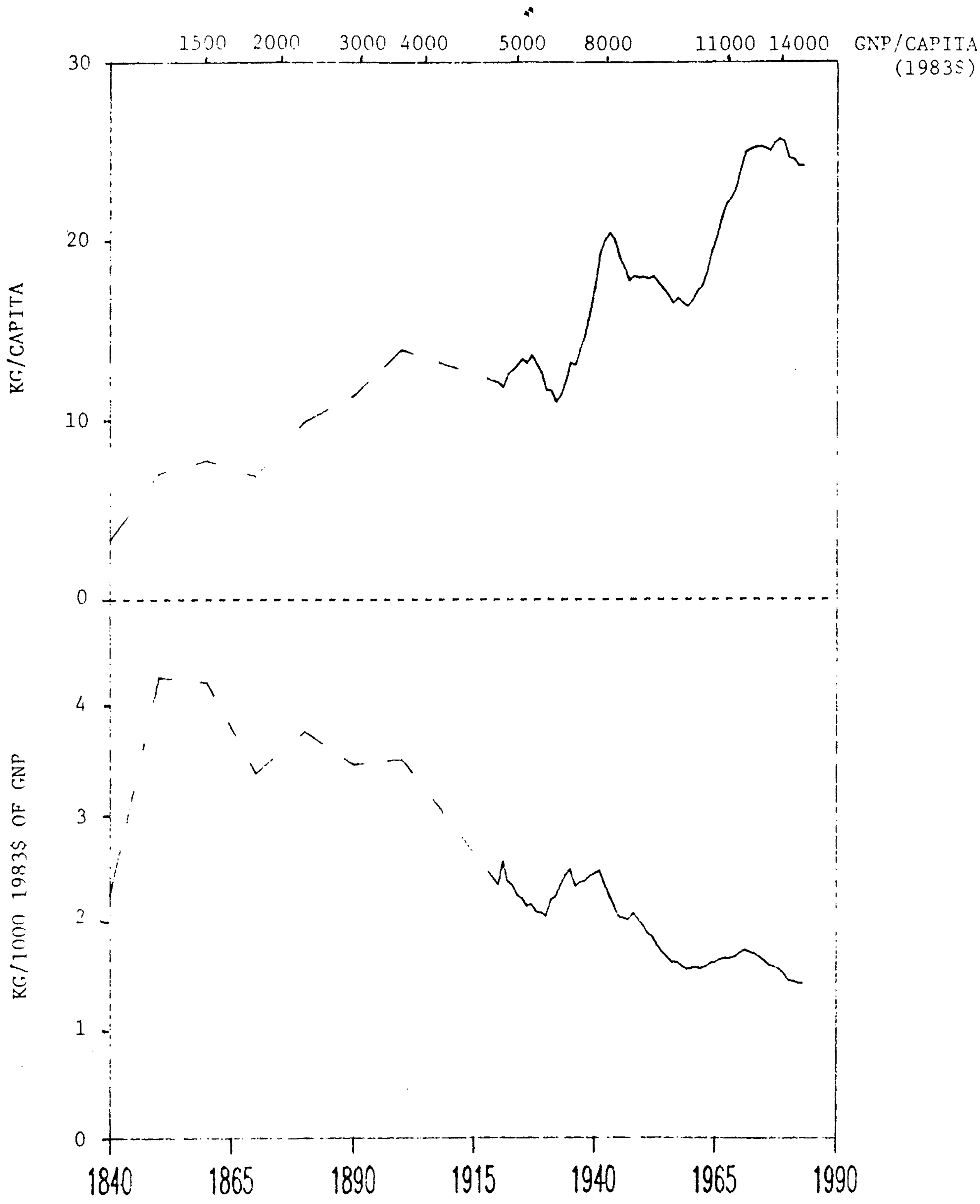


Figure 14. U.S. Textile Fibers Consumption

Notes: The ordinate numbers are 5-year averages centered around the year against which they are plotted. See the Appendix for actual yearly data. Where the lines are dashed, yearly demand figures were unavailable. Data for apparent consumption of textile fibers (including waste) are from: 1840-1900 (Bureau of the Census, 1902); 1900-1983 (Textile Economics Bureau, various years). For population and GNP sources, see Figure 9 notes.

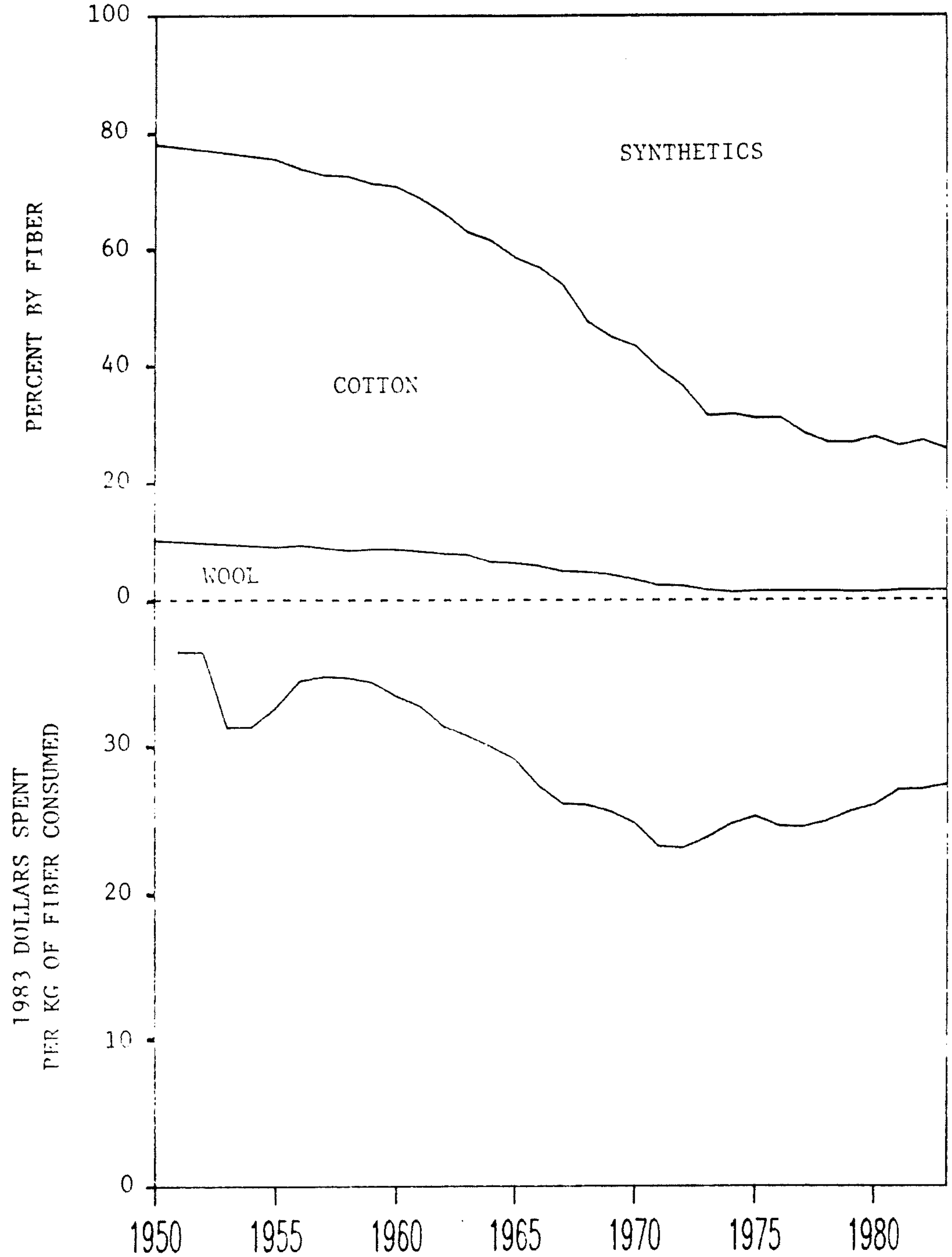


Figure 15. Consumption of All Textiles by Type (upper)
Retail Expenditures on Apparel (lower)

Notes: Upper figure data are from: (Textile Economics Bureau, various years). The ordinate numbers in the lower figure are 3-year averages centered on the year against which they are plotted. Data are from: fiber consumption (Textile Economics Bureau, various years); retail expenditures on apparel (Bureau of the Census, Current Business Reports, various years).

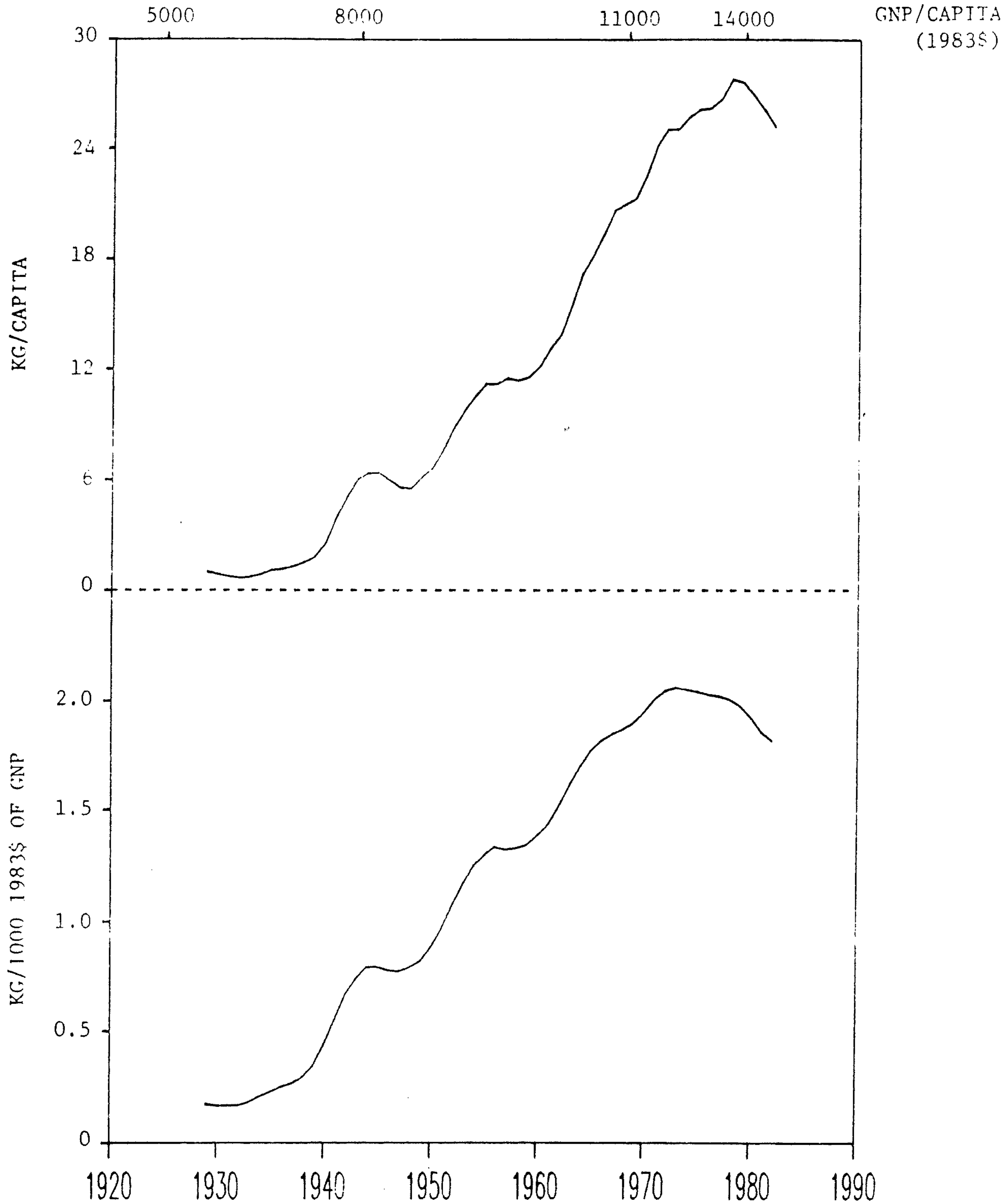


Figure 16. U.S. Aluminum Consumption

Notes: The ordinate numbers are 5-year averages centered on the year against which they are plotted. See the Appendix for actual yearly data. Data for apparent aluminum consumption are from: 1928-1959 (Commodity Research Bureau, various years) excludes inventory changes; 1960-1983 (Aluminum Association, various years) includes inventory changes. For population and GNP sources, see Figure 9 notes.

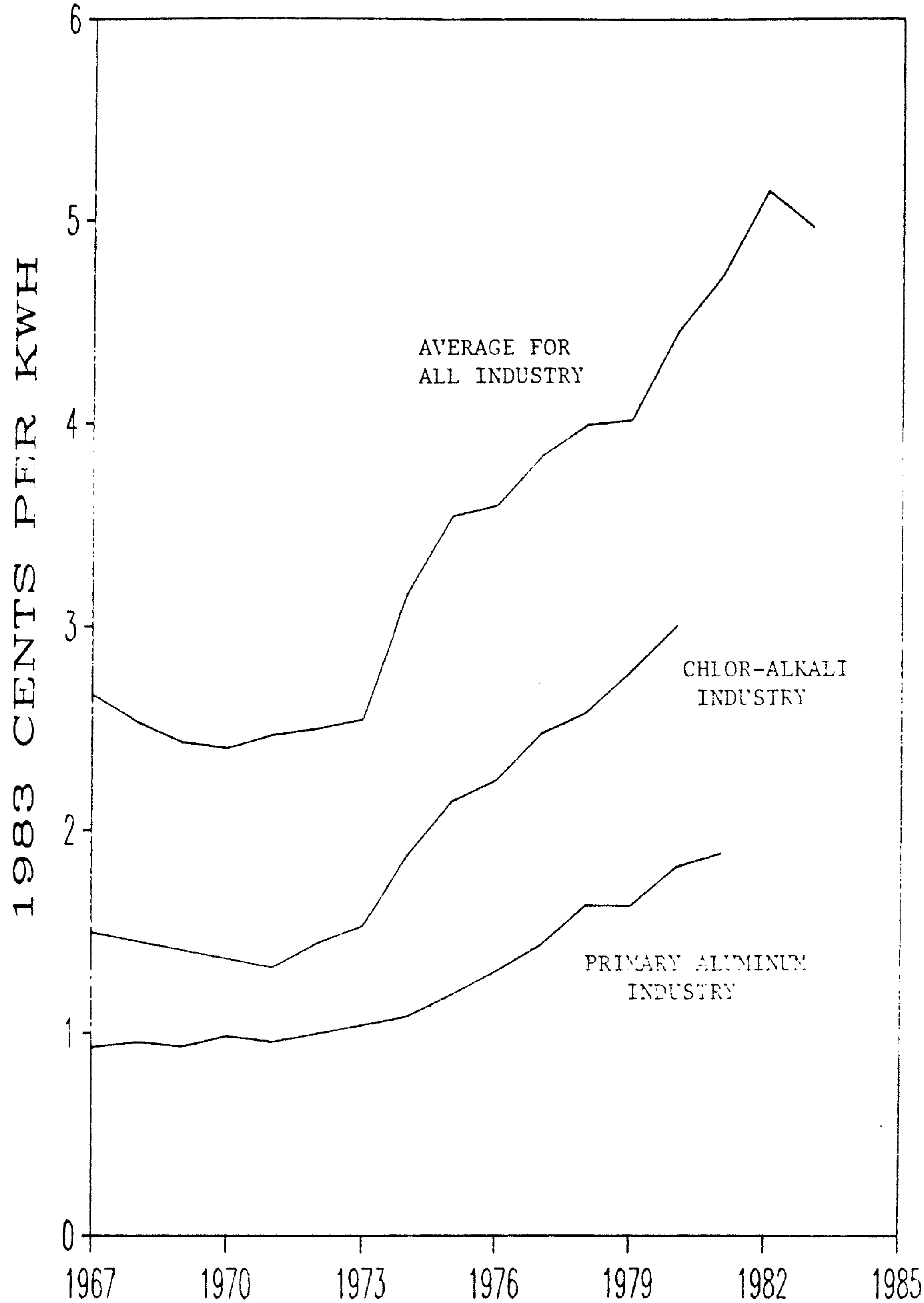


Figure 17. Industrial Sector Electricity Prices

Notes: Data are from: average industrial energy prices (Energy Information Administration, April 1984; Energy Information Administration, March 1984); specific industry prices (Bureau of the Census, Fuels and Electric Energy Consumed, various years).

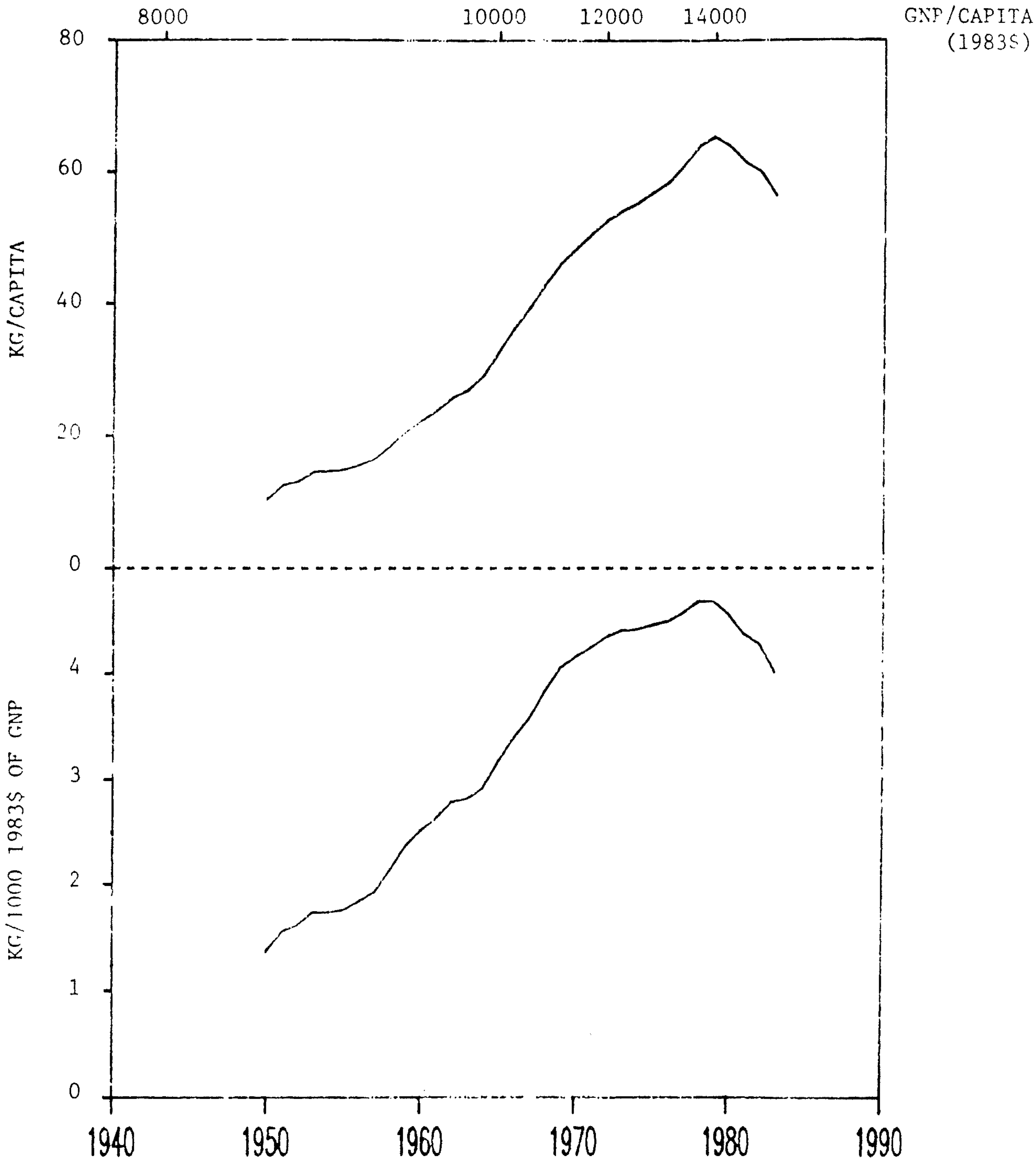


Figure 18. U.S. Ammonia Consumption (in terms of contained nitrogen)

Notes: The ordinate numbers are 5-year averages centered on the year against which they are plotted. See the Appendix for the actual yearly data. Apparent ammonia (nitrogen content) consumption data are from: (Bureau of Mines, Minerals Yearbook, various years). For population and GNP sources, see Figure 9 notes.

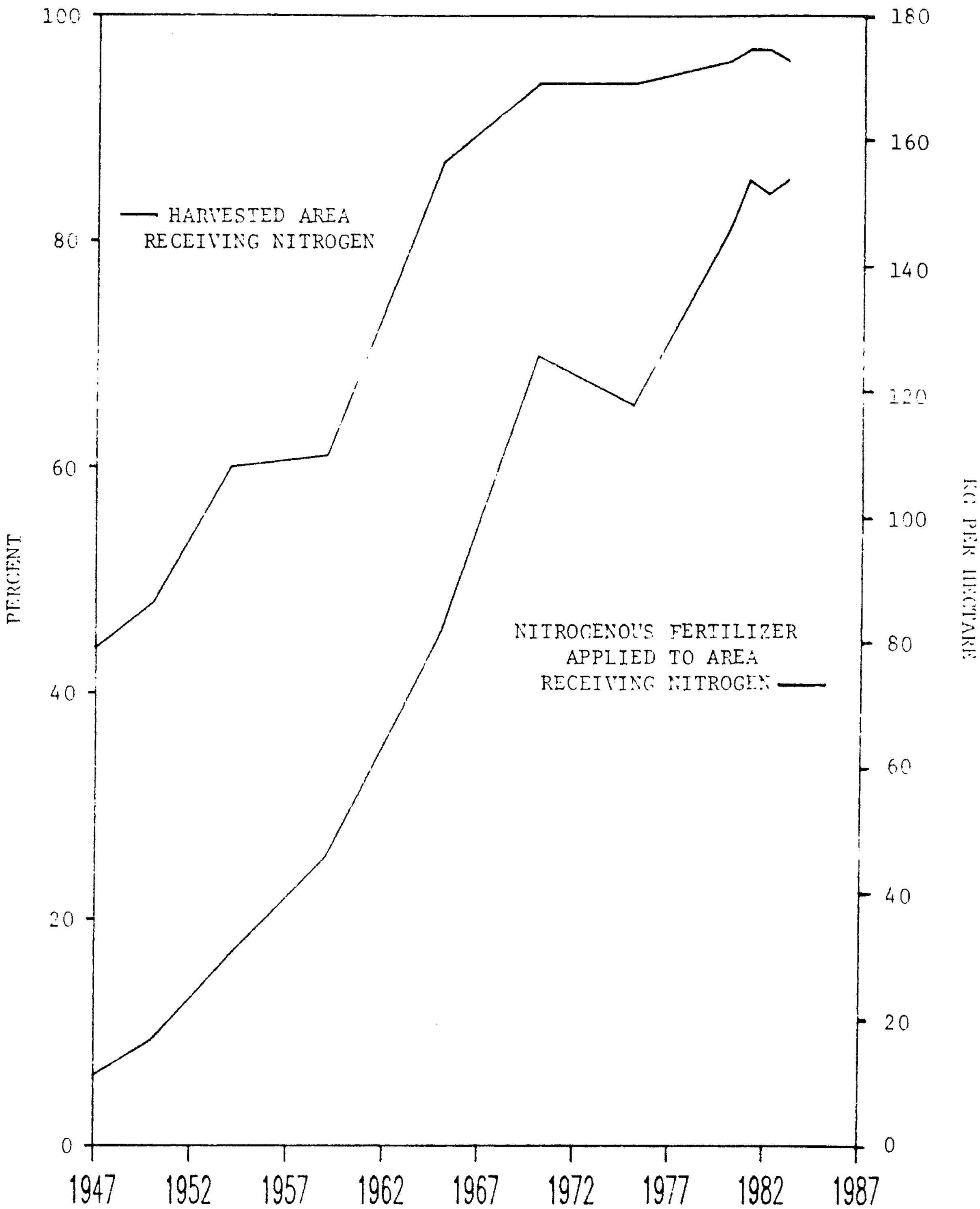


Figure 19. U.S. Nitrogen Fertilizer Use for Corn

Notes: Data are from (Sundquist, Menz, and Neumeyer, 1982)

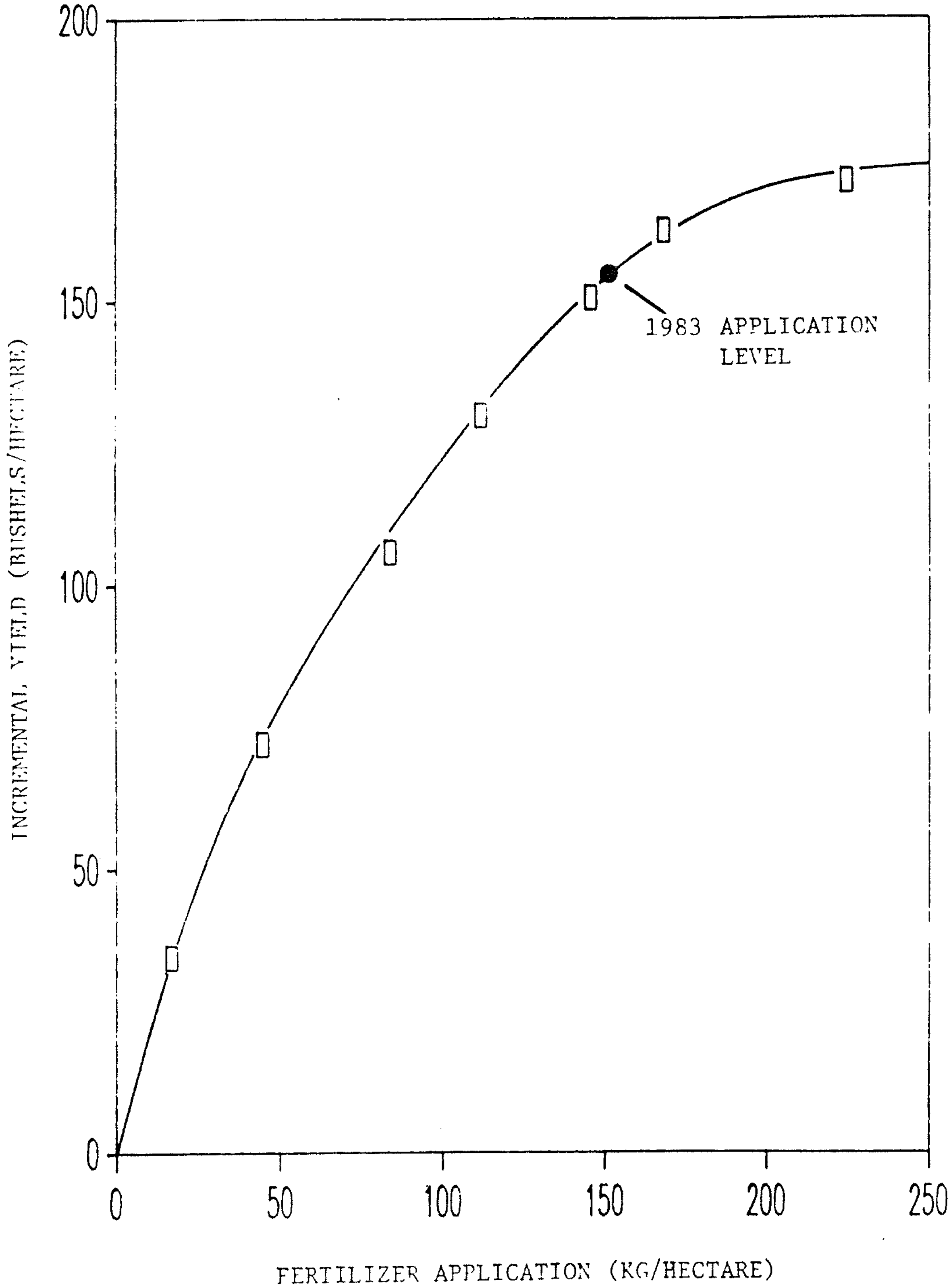


Figure 20. Incremental Corn Yield with Increased Fertilizer Application

Notes: The data represent the average of a number of agronomic experiments conducted at various locations in the Corn Belt (Sundquist, Menz, and Neumeyer, 1982).

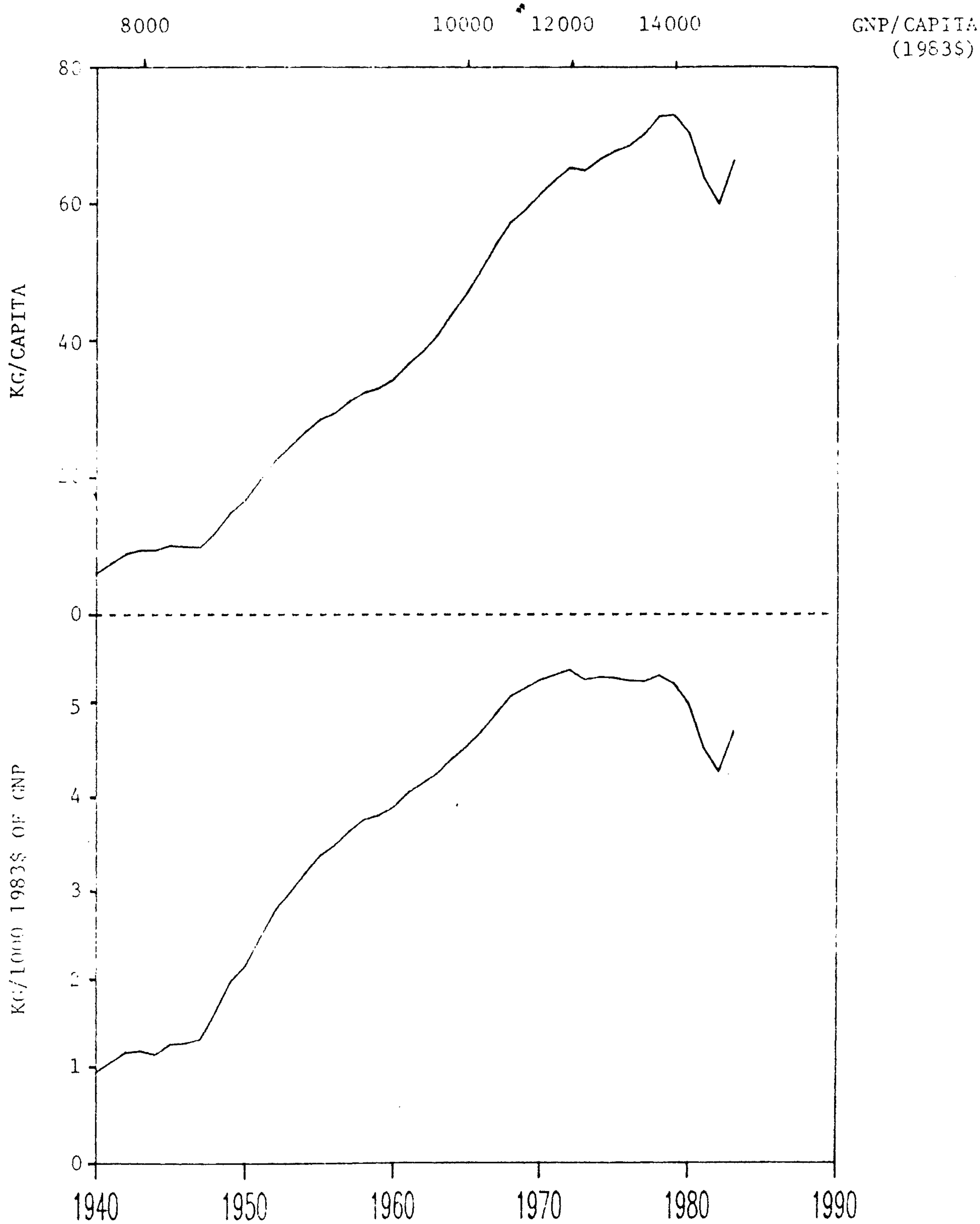


Figure 21. U.S. Chlorine Consumption

Notes: The ordinate numbers are 5-year averages centered on the year against which they are plotted. See the Appendix for actual yearly data. Data are actually for production of liquid and gas (not including inventory changes), but net imports represent less than 0.3% of total consumption (Chlorine Institute, 1984). For population and GNP data, see Figure 9 notes.

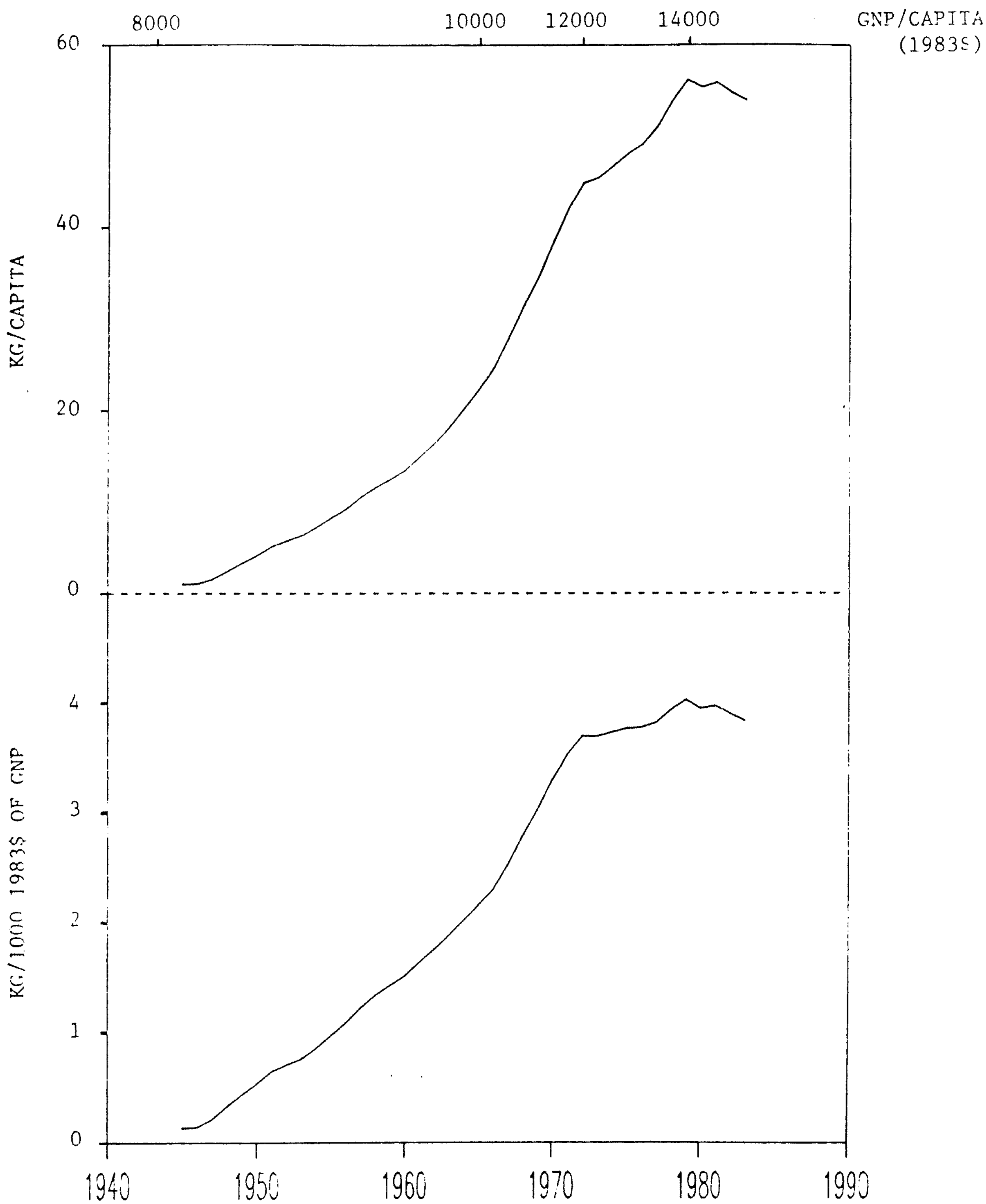


Figure 22. U.S. Ethylene Production

Notes: The ordinate numbers are 5-year averages centered on the year against which they are plotted. See the Appendix for actual yearly data. Consumption data were unavailable. Data are from: 1945-1964 (Lopez, 1970), 1965-1983 (Chemical and Engineering News, various years). For population and GNP data, see Figure 9 notes.

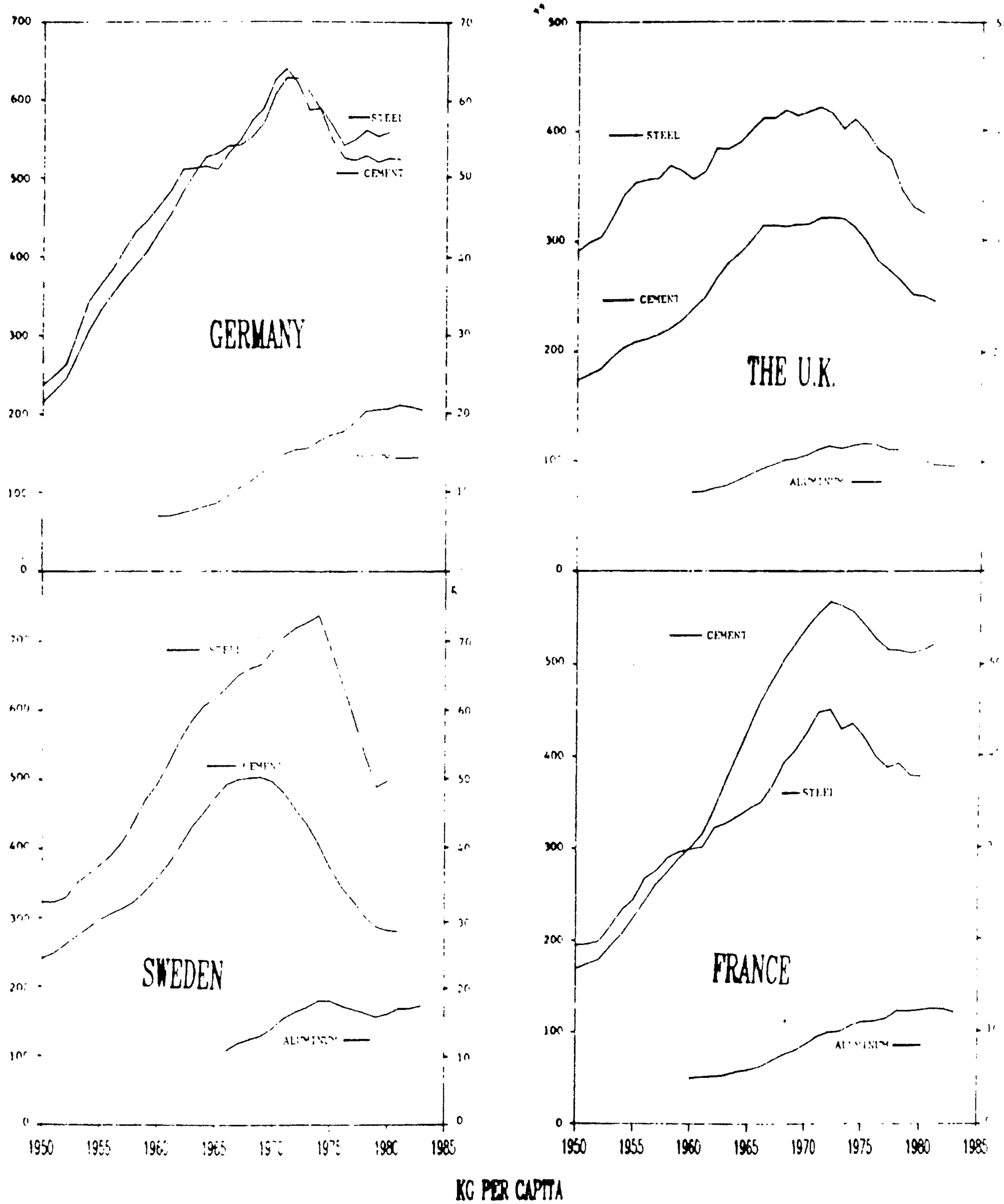
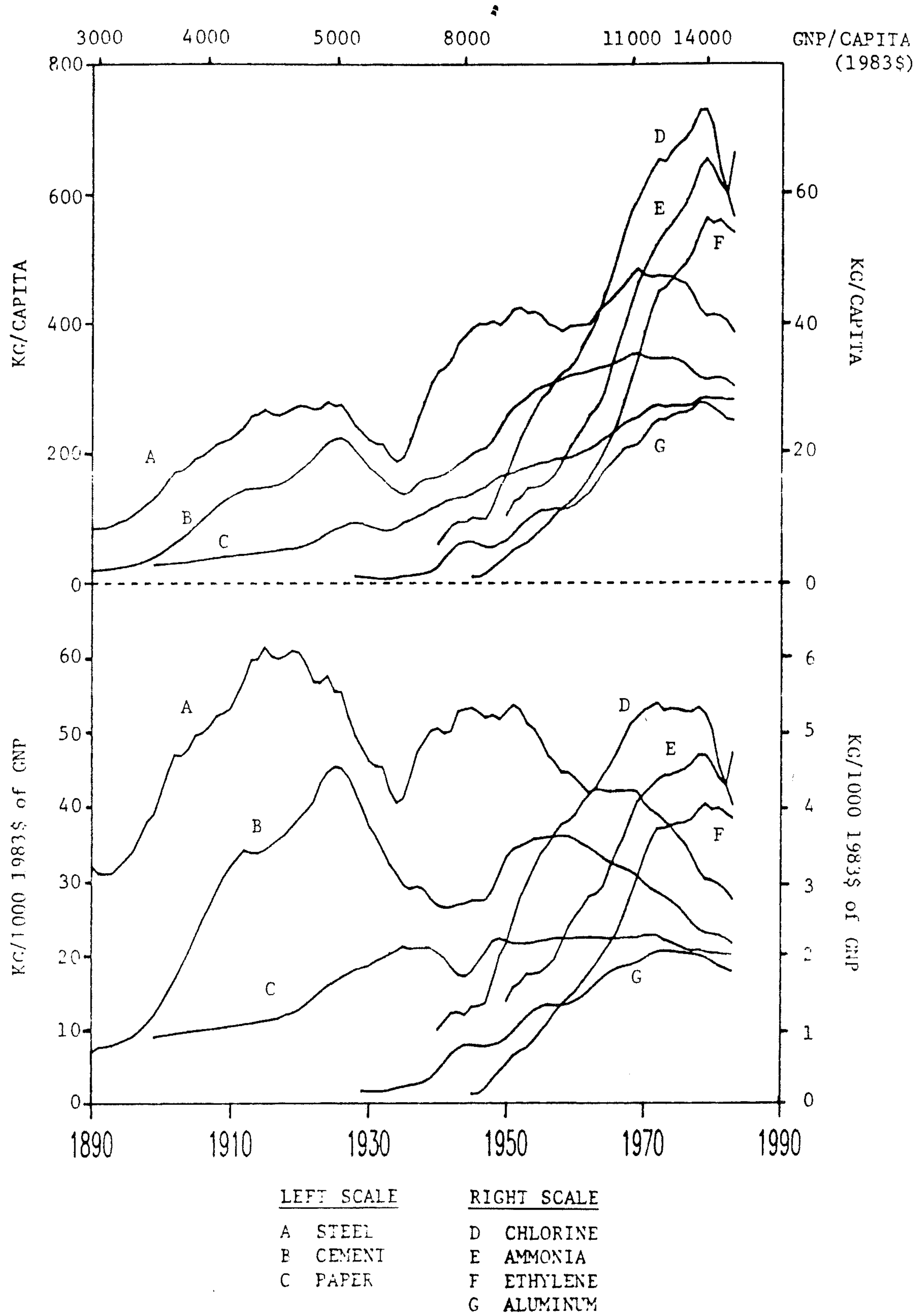


Figure 23. Material Consumption in Europe

Notes: The ordinate numbers are 5-year averages centered on the year against which they are plotted. Data sources: apparent aluminum consumption (Aluminum Association, various years); apparent steel consumption (United Nations, various years); apparent cement consumption 1950-1974 (Organization for European Economic Cooperation, various years) and 1975-1981 (Economic Commission for Europe, 1982).



Figuare 24. Basic Materials Use in the U.S.

Notes: All data are from this paper. Steel and cement demand data are 10 year running averages. The others are as in figures 13, 16, 18, 21, and 22.

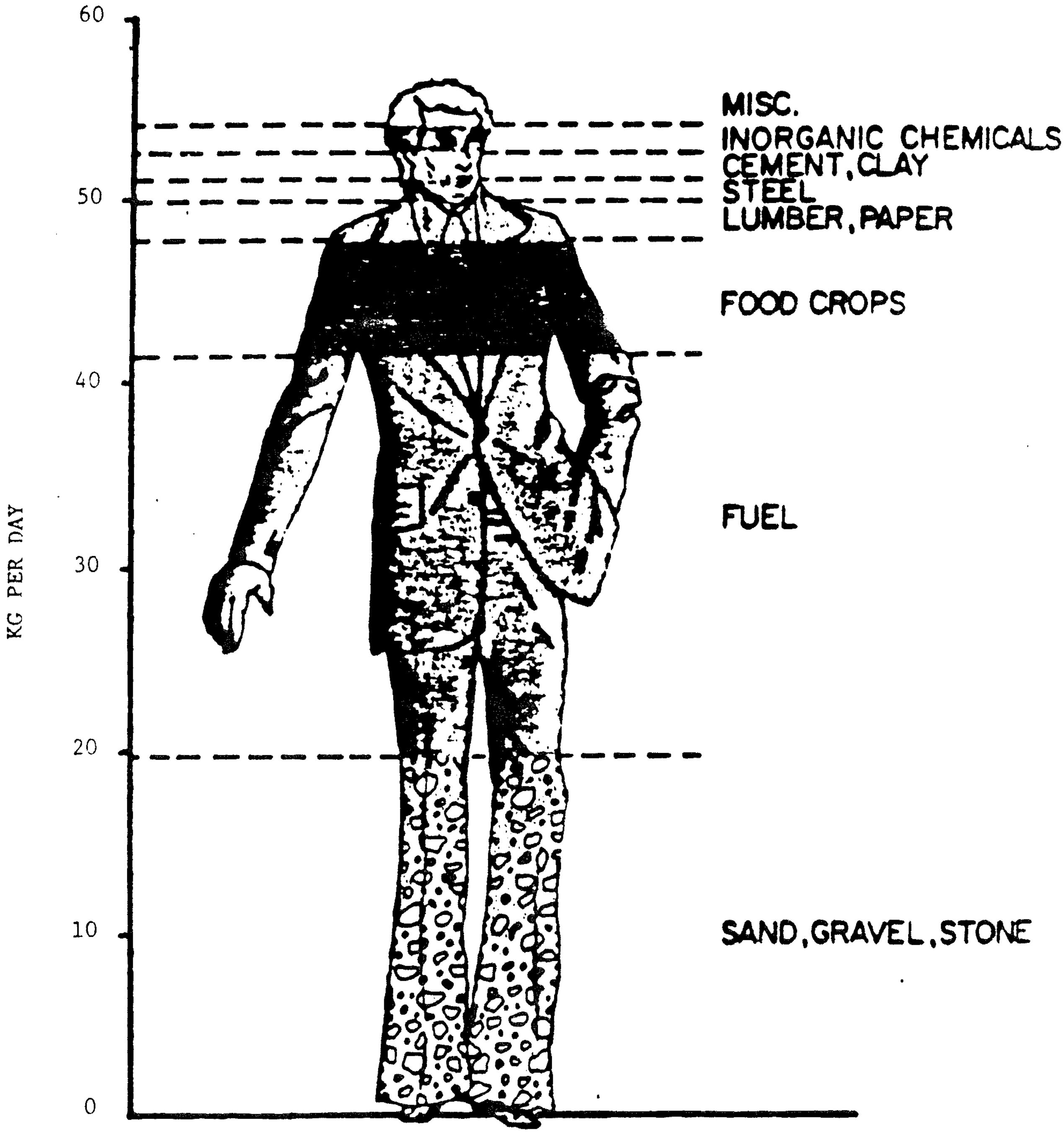


Figure 25. Per-Capita Consumption of Basic Materials in the U.S. (1975)

Notes: Source: (Ross and Williams, 1981).

Notes

1. In discussing industrial energy demand projections, USDOE analysts make several statements which serve to illustrate that the implications of changing materials use patterns for future energy consumption in the BMP subsector are not adequately appreciated by many forecasters (Energy Information Administration, May 1984):

- They project that the output of the paper, chemicals, stone, clay and glass, and primary metals industries will grow, 1983-1990, at average annual growth rates of 3.2, 4.6, 3.9 and 4.4 percent per year, respectively. Actual average annual percentage growth rates of gross product originating (GPO) in these 4 BMP industries over the past 20 years (see table below) reflect the declining material intensiveness of the economy, and suggest that the DOE figures, may be rather high.

  The DOE figures are probably based on the growth in the Federal Reserve Board (FRB) index (described later in the text) which tends to grow somewhat faster than GPO. However, the recent change in GPO has been negligible or negative, in sharp contrast to the large positive figures projected by the DOE.

  Average annual growth rates (*) in value added of selected basic materials industries.

	1963-68	68-73	73-78	78-83
Paper (SIC 26)	4.6	5.5	1.0	0.5
Chemicals (SIC 28)	7.0	5.8	4.0	0.1
Stone,Clay,Glass (SIC 32)	1.9	3.6	0.5	-3.7
Primary Metals (SIC 33)	0.0	1.3	-4.0	-8.7

  * The 1963-1983 growth rates are taken from regression equations derived using the actual data.

  Sources: Data, (Bureau of Economic Analysis, 1984); Projections, (Energy Information Administration, May 1984).

- They project that "improved economic conditions, particularly in the steel industry," will be a major contributor to growth in the electricity fraction of industrial energy use. Future upturns in the demand for steel in the US are doubtful, however, as discussed in the text.

- They cite high real interest rates and foreign trade competition as reasons why energy-intensive industries did more poorly than the economy as a whole during the 1982 recession, essentially disregarding the role that materials consumption saturation may be playing in the poor showing.

2. For steel, as well as all other materials considered in this paper besides chlorine and ethylene, consumption data presented refer to apparent consumption. (See the notes to Figures 21 and 22 for descriptions of the

chlorine and ethylene data.) Apparent consumption consists of the production of mill products originating in the particular BMP industry, plus net imports of such products, corrected for stock changes. Data on final consumption -- apparent consumption plus net imports of material embodied in finished products, corrected for stock changes, are generally not available.

Because of the relatively closed nature of the US economy, the difference between apparent and final consumption is generally not significant in the US. In the case of steel, for example, a study done by the OECD shows that final consumption in the US was within ±1-2 percent of apparent consumption from 1962 to 1979 (Committee on Economic Studies, 1982).

3. The percentage of the total manufacturing cost of aluminum attributable to electricity in 1981 can be estimated based on the average requirement of 18 kWh to produce one kg of aluminum ingot (Bureau of Industrial Economics, 1983). With aluminum ingot selling for $1.670 per kg (1981$) (Bureau of Economic Analysis, 1983), and electricity costing $0.0171 per kWh (1981$) (Bureau of the Census (Fuels and Electric Energy Consumed), 1982), electricity costs accounted for about 18 percent of total manufacturing cost in 1981.

4. Note 2.2-A of (Goldemberg, Johansson, Reddy, and Williams, 1984) gives a detailed calculation of the marginal cost of electricity averaged over all sectors. Using official US DOE cost estimates for new central station coal and nuclear power plants they calculate an average busbar cost of electricity in the US from an appropriate mix of new baseload, cycling, and peaking power plants of 5.9 cents per kWh (1983$). Adding 8% transmission and distribution losses, they obtain an average delivered cost of 6.4 cents/kWh. To this they add the average cost of transmission and distribution, which averaged 1.6 cents/kWh in 1982, bringing the total average cost of electricity from new plants to 8.0 cents/kWh.

To obtain the average marginal electricity price to industry, we apply the 1982 ratio of industry-to-total average electricity price of 0.808 (Energy Information Administration, March 1984) to this 8.0 cents/kWh, yielding 6.5 cents/kWh. The aluminum industry paid $0.0189/kWh (1983$) in 1981 (see Figure 18).

5. From note 3, the non-energy component of the price of aluminum ingot, converted to 1983$, amounts to $1.504/kg (1983$) in 1981. Assuming a new aluminum plant requires only 13 kWh/kg produced (Bureau of Industrial Economics, 1983), but pays $0.065/kWh for electricity (see note 4), electricity costs amount to $0.85/kg produced. Adding this to the non-energy costs gives a total aluminum price of $2.32/kg, 36% of which is accounted for by electricity.

6. The most reliable detailed data available for industrial energy consumption in a year close to the 1973 oil price shock are 1974 data.

In 1974, final energy use (in EJ) in industry was: MAC, 4.35, OMFG, 2.70, and BMP, 18.51 (Solar Energy Research Institute, 1981), while GPO values for these sectors (in billions of 1972$) were: MAC, 108.4; OMFG, 191.8; and BMP, 119.8 (Bureau of Economic Analysis, 1984). Based on these figures, the energy intensities (MJ/1972$) of MAC, OMFG, and BMP were 40.2, 14.1, and 154.5, respectively.

To convert these 1974 energy intensities into the corresponding 1972 energy intensities, we assume that the 1972 values are higher because of the lower average energy price then [$0.93 per GJ compared to $1.51 per GJ (in 1972$) in 1972 (Energy Information Administration, June 1984)]. Assuming a short-run price elasticity of -0.14 (Goldemberg, Johansson, Reddy, and Williams, 1985, chap. 2), we estimate that the 1972 energy intensities (in MJ/1972$) for each of the three sectors are: MAC, 43.0; OMFG, 15.1; and BMP, 165.3.

From the 1972 BMP energy intensity and the corresponding GPO of $110.3 billion (1972$), energy consumption in BMP is estimated to be 18.24 EJ in 1972. The output of the BMP subsector is assumed to grow from 1972 to 2010 at the same rate as the population, 0.0079% per year (Bureau of the Census, Dec 1983). For the other two sectors, GPO in 2010 is assumed to be related to a GNP value of $3,025, billion (1972$) [the value forecast by DOE (Office of Policy, Planning and Analysis, 1983) based on a 2.6% annual growth rate from 1982] via regression equations relating GPO to GNP data over the time period 1947-1983 (Bureau of Economic Analysis, 1984). Thus, in billion 1972$:

$$GPO(OMFG) = 75.1*(GNP)^{1.101} \qquad r^2 = 0.989$$

$$GPO(MAC) = 3411*(GNP)^{0.4885} \qquad r^2 = 0.913$$

Price elasticities of -0.4, -0.6, and -0.8 are applied using 3 ratios of average industrial energy prices: Price(2010) = Price(1981), P(2010) = 1.5*P(1981), and P(2010) = 2*P(1981). The 1972 and 1981 average industrial energy prices were 0.93 $/GJ and 3.04 $/GJ (1972$), respectively (Energy Information Administration, June 1984).

To obtain a 1980 energy demand figure consistent with the 1974 energy demand data used above, the ratio of the final industrial energy demand in 1980 to that in 1974 given by DOE (Energy Information Administration, March 1984) was used to scale the 1974 final energy demand figure given above to a 1980 demand value of 24.4 EJ.

7. The industrial energy price ratios in the DOE scenarios (2.2 in the baseline case and 1.5 in the low-price case) are consumption-weighted average industrial energy prices derived from the DOE documentation (Office of Policy, Planning and Analysis, 1983). The industrial energy demand in the low-price case is not given explicitly by DOE, but is assumed to be the same fraction of the total final energy demand as in the baseline case.

8. The average annual rate of reduction of the final energy intensity (FEI) of 3.0% was obtained from a regression fit of the ratio of final energy demand data (Energy Information Administration, April 1984) to GPO for all industry (Bureau of Economic Analysis, 1984). The average rate of reduction of primary energy intensity (see figure 5) was 2.2% per year. The difference between this and the FEI arises because of the increased electricity fraction of industrial energy demand.

9. In energy projections made by 9 different industry, government, and

private research groups, summarized in (Office of Policy, Planning and Analysis, 1983), final energy demand in the industrial sector in 2000 ranged from 28.1 EJ to 37.1 EJ. (Demand projections for 2010 were evidently made only by DOE.)

10. For example, Ross and Purcell describe a visit to a paper mill, where large labor involvement is seen in the cutting, boxing, and packaging activities, while hardly an employee is in sight at mammoth pulping and paper-making machines (Ross and Purcell, 1981).

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Appendix

HISTORICAL

POPULATION, ECONOMIC, AND MATERIAL DEMAND

DATA*

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* The data in this appendix are actual yearly figures. The figures in the text show running averages, as described in the notes accompanying each figure. Sources of the data are cited in these notes.

U.S. POPULATION AND GROSS NATIONAL PRODUCT

YEAR	GNP DEFLATOR	GNP (MILLION DOLLARS) CURRENT DOLLARS	1983 DOLLARS	POPULATION (MILLION)	(1983 $) GNP/CAP
1840	The	6451	21048	17.12	1229
1850	current	9755	31826	23.26	1368
1860	dollar	14750	48125	31.51	1527
1869	GNP data	21400	69822	39.10	1786
1870	from	22304	72770	39.90	1824
1871	1840-	23245	75842	40.90	1854
1872	1888	24227	79044	42.00	1882
1873	are	25250	82380	43.00	1916
1874	actually	26316	85858	44.00	1951
1875	given	27427	89483	45.10	1984
1876	in 1958	28584	93261	46.10	2023
1877	dollars	29791	97198	47.10	2064
1878	(defl =	31049	101301	48.20	2102
1879	30.65).	32360	105578	49.20	2146
1880	¦	33726	110035	50.30	2188
1881	¦	35150	114680	51.50	2227
1882	¦	36633	119522	52.80	2264
1883	¦	38180	124568	54.10	2303
1884	¦	39792	129826	55.40	2343
1885	¦	41472	135307	56.70	2386
1886	¦	43222	141020	57.90	2436
1887	¦	45047	146973	59.20	2483
1888	¦	46949	153178	60.50	2532
1889	7.78	12500	160567	61.80	2598
1890	7.63	13100	171654	63.10	2720
1891	7.54	13500	179052	64.40	2780
1892	7.23	14300	197699	65.70	3009
1893	7.39	13800	186828	67.00	2788
1894	6.93	12600	181904	68.30	2663
1895	6.83	13900	203372	69.60	2922
1896	6.65	13300	199974	70.90	2821
1897	6.68	14600	218513	72.20	3026
1898	6.87	15400	224313	73.50	3052
1899	7.11	17400	244705	74.80	3271
1900	7.45	18700	251082	76.10	3299
1901	7.39	20700	280243	77.60	3611
1902	7.63	21600	283032	79.20	3574
1903	7.72	22900	296494	80.60	3679
1904	7.82	22900	293006	82.20	3565
1905	8.00	25100	313772	83.80	3744
1906	8.18	28700	350713	85.50	4102
1907	8.52	30400	356787	87.00	4101
1908	8.46	27700	327455	88.70	3692
1909	8.77	33400	381032	90.50	4210
1910	9.01	35300	391749	92.40	4240
1911	8.92	35800	401394	93.90	4275
1912	9.29	39400	424262	95.30	4452

Population and GNP (cont.)

1913	9.23	39600	429249	97.20	4416
1914	9.41	38600	410232	99.10	4140
1915	9.84	40000	406570	100.50	4045
1916	11.03	48300	437749	102.00	4292
1917	13.70	60400	440870	103.30	4268
1918	15.42	76400	495571	103.20	4802
1919	17.59	84000	477472	104.50	4569
1920	20.04	91500	456482	106.50	4286
1921	16.70	69600	416671	108.50	3840
1922	15.36	74100	482571	110.00	4387
1923	15.72	85100	541244	111.90	4837
1924	15.69	84700	539752	114.10	4731
1925	15.91	93100	585279	115.80	5054
1926	15.66	97000	619344	117.40	5275
1927	15.32	94900	619266	119.00	5204
1928	15.57	97000	623001	120.50	5170
1929	15.51	103100	664797	121.80	5458
1930	15.11	90400	598277	123.10	4860
1931	13.73	75800	552042	124.10	4448
1932	12.32	58000	470742	124.80	3772
1933	12.05	55600	461597	125.60	3675
1934	12.93	65100	503326	126.40	3982
1935	13.06	72200	552979	127.30	4344
1936	13.09	82500	630386	128.10	4921
1937	13.64	90400	662810	128.80	5146
1938	13.46	84700	629506	129.80	4850
1939	13.24	90500	683511	130.90	5222
1940	13.46	99700	740988	132.60	5588
1941	14.47	124500	860613	133.90	6427
1942	16.24	157900	972046	135.40	7179
1943	17.41	191600	1100596	137.30	8016
1944	17.84	210100	1177833	138.90	8480
1945	18.30	211900	1158077	140.50	8243
1946	20.44	208500	1019908	141.90	7188
1947	23.03	233054	1011811	144.70	6992
1948	24.61	259504	1054370	147.20	7163
1949	24.38	258316	1059538	149.80	7073
1950	24.89	286457	1150852	152.30	7556
1951	26.52	330765	1247407	154.90	8053
1952	26.89	347967	1294149	157.60	8212
1953	27.31	366792	1343282	160.20	8385
1954	27.63	366847	1327678	163.00	8145
1955	28.23	400042	1416859	165.90	8540
1956	29.16	421699	1445998	168.90	8561
1957	30.14	443959	1473068	172.00	8564
1958	30.65	449670	1467151	174.90	8389
1959	31.39	487902	1554213	177.80	8741
1960	31.90	506512	1587661	180.70	8786
1961	32.18	524554	1629978	183.70	8873
1962	32.79	565036	1723440	186.60	9236
1963	33.30	596714	1792139	189.20	9472
1964	33.81	637719	1886352	191.90	9830
1965	34.55	691051	2000147	194.30	10294
1966	35.66	755981	2119700	196.60	10782

Population and GNP (cont.)

1967	36.73	799584	2176769	198.70	10955
1968	38.31	873392	2279712	200.70	11359
1969	40.31	943996	2341937	202.70	11554
1970	42.44	992734	2338899	205.10	11404
1971	44.58	1077619	2417234	207.70	11638
1972	46.44	1185923	2553767	209.90	12167
1973	49.13	1326396	2699680	211.90	12740
1974	53.45	1434220	2683275	213.90	12545
1975	58.42	1549212	2651886	216.00	12277
1976	61.44	1718018	2796357	218.00	12827
1977	65.06	1918324	2948550	220.20	13390
1978	69.84	2163863	3098180	222.60	13918
1979	75.88	2417759	3186293	225.10	14155
1980	82.85	2631688	3176613	227.70	13951
1981	90.60	2954069	3260529	229.80	14189
1982	96.08	3072989	3198344	232.10	13780
1983	100.00	3304800	3304800	234.20	14111

U.S. STEEL CONSUMPTION

YEAR	MILLION TONNES	KG/CAP	(KG/1000 1983$) KG/GNP
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1870	1.20	30.19	17.84
1871	1.35	33.03	19.16
1872	1.77	42.03	23.98
1873	1.79	41.56	23.26
1874	1.67	38.02	20.86
1875	1.72	38.10	20.52
1876	1.75	37.90	20.00
1877	1.74	36.85	19.07
1878	1.92	39.89	20.28
1879	2.49	50.65	25.33
1880	3.00	59.66	29.33
1881	3.64	70.59	34.10
1882	3.60	68.10	32.30
1883	3.31	61.25	28.47
1884	2.80	50.49	23.02
1885	2.70	47.70	21.33
1886	4.41	76.20	33.39
1887	5.33	90.05	38.66
1888	4.70	77.70	32.67
1889	5.33	86.28	33.21
1890	6.13	97.19	35.73
1891	5.49	85.23	30.66
1892	6.28	95.56	31.76
1893	5.07	75.62	27.12
1894	4.73	69.20	25.98
1895	6.30	90.54	30.99
1896	5.62	79.22	28.09
1897	7.13	98.74	32.63
1898	8.67	117.93	38.64
1899	10.48	140.13	42.83
1900	9.66	126.94	38.47
1901	12.57	162.03	44.87
1902	14.20	179.26	50.16
1903	13.45	166.85	45.36
1904	12.23	148.81	41.75
1905	17.15	204.61	54.65
1906	19.94	233.27	56.87
1907	20.23	232.49	56.69
1908	12.04	135.78	36.78
1909	20.00	221.01	52.49
1910	22.01	238.25	56.20
1911	19.39	206.45	48.30
1912	25.11	263.44	59.17
1913	25.24	259.69	58.80
1914	18.70	188.74	45.60
1915	24.84	247.13	61.09
1916	32.97	323.23	75.32

Steel (cont.)

1917	33.67	325.94	76.37
1918	31.72	307.38	64.01
1919	25.56	244.58	53.53
1920	32.94	309.26	72.15
1921	15.04	138.64	36.10
1922	26.93	244.84	55.81
1923	33.88	302.79	62.60
1924	28.60	250.63	52.98
1925	33.99	293.55	58.08
1926	36.14	307.84	58.35
1927	33.48	281.32	54.06
1928	38.82	322.14	62.31
1929	42.18	346.32	63.45
1930	30.36	246.66	50.75
1931	19.82	159.70	35.90
1932	10.82	86.68	22.98
1933	17.18	136.80	37.22
1934	17.82	140.97	35.40
1935	22.73	178.53	41.10
1936	32.00	249.80	50.76
1937	35.18	273.15	53.08
1938	19.55	150.58	31.05
1939	31.91	243.77	46.68
1940	41.82	315.37	56.44
1941	55.45	414.15	64.44
1942	55.09	406.88	56.68
1943	56.55	411.84	51.38
1944	58.45	420.84	49.63
1945	52.09	370.75	44.98
1946	44.36	312.64	43.50
1947	57.36	396.43	56.69
1948	60.09	408.23	56.99
1949	53.09	354.41	50.11
1950	66.64	437.53	57.90
1951	73.73	475.97	59.10
1952	62.91	399.17	48.61
1953	74.36	464.19	55.36
1954	58.09	356.39	43.75
1955	77.91	469.61	54.99
1956	76.91	455.35	53.19
1957	73.73	428.65	50.05
1958	56.00	320.18	38.17
1959	67.09	377.34	43.17
1960	67.73	374.81	42.66
1961	63.00	342.95	38.65
1962	67.91	363.93	39.40
1963	73.64	389.20	41.09
1964	83.09	432.99	44.05
1965	93.73	482.38	46.86
1966	91.64	466.11	43.23
1967	86.73	436.47	39.84
1968	99.82	497.35	43.79
1969	98.09	483.92	41.88
1970	94.73	461.86	40.50

Steel (cont.)

1971	95.73	460.89	39.60
1972	99.55	474.25	38.98
1973	115.09	543.14	42.63
1974	114.00	532.96	42.49
1975	83.64	387.21	31.54
1976	94.27	432.44	33.71
1977	100.45	456.20	34.07
1978	108.27	486.40	34.95
1979	107.09	475.75	33.61
1980	90.27	396.45	28.42
1981	97.18	422.90	29.81
1982	71.09	306.29	22.23
1983	77.00	328.78	23.30

U.S. CEMENT CONSUMPTION

YEAR	KG/CAP	(KG/1000 1983$) KG/GNP
1880	7.04	3.22
1881	8.30	3.73
1882	10.52	4.65
1883	13.24	5.75
1884	12.34	5.27
1885	12.51	5.24
1886	13.28	5.45
1887	20.04	8.07
1888	18.37	7.26
1889	18.89	7.27
1890	21.06	7.74
1891	21.82	7.85
1892	22.79	7.57
1893	20.41	7.32
1894	20.92	7.86
1895	21.44	7.34
1896	22.96	8.14
1897	26.13	8.63
1898	28.70	9.41
1899	36.23	11.07
1900	38.70	11.73
1901	44.20	12.24
1902	55.58	15.55
1903	63.40	17.23
1904	65.86	18.48
1905	81.79	21.84
1906	101.95	24.85
1907	102.60	25.02
1908	101.95	27.62
1909	125.94	29.91
1910	143.88	33.94
1911	144.79	33.87
1912	149.48	33.58
1913	163.43	37.01
1914	153.58	37.10
1915	147.45	36.45
1916	154.76	36.06
1917	154.62	36.23
1918	118.44	24.66
1919	132.98	29.10
1920	161.75	37.74

Cement (cont.)

1921	156.54	40.76
1922	179.73	40.97
1923	211.89	43.81
1924	225.85	47.74
1925	241.14	47.71
1926	242.58	45.98
1927	251.81	48.39
1928	253.19	48.97
1929	239.27	43.84
1930	220.47	45.36
1931	174.33	39.19
1932	111.09	29.45
1933	87.16	23.72
1934	102.55	25.75
1935	102.55	23.61
1936	155.53	31.60
1937	155.53	30.22
1938	143.56	29.60
1939	164.07	31.42
1940	169.20	30.28
1941	213.64	33.24
1942	235.85	32.85
1943	158.95	19.83
1944	112.80	13.30
1945	123.05	14.93
1946	201.67	28.06
1947	217.05	31.04
1948	234.15	32.69
1949	234.15	33.10
1950	259.78	34.38
1951	268.33	33.32
1952	273.45	33.30
1953	280.29	33.43
1954	287.13	35.25
1955	317.89	37.22
1956	328.15	38.33
1957	300.80	35.12
1958	312.76	37.28
1959	338.40	38.71
1960	307.64	35.01
1961	309.35	34.86
1962	316.18	34.23
1963	326.44	34.46
1964	336.69	34.25
1965	341.82	33.21
1966	343.53	31.86
1967	333.27	30.42
1968	350.36	30.85
1969	360.62	31.21
1970	336.69	29.52
1971	357.20	30.69
1972	367.45	30.20
1973	389.67	30.59
1974	352.07	28.07

Cement (cont.)

1975	295.67	24.08
1976	309.35	24.12
1977	336.69	25.14
1978	357.20	25.66
1979	355.49	25.11
1980	309.35	22.17
1981	290.55	20.48
1982	254.65	18.48
1983	305.93	21.68

U.S. PAPER CONSUMPTION

YEAR	KG/CAP	(KG/1000 1983$) KG/GNP
1899	25.73	7.86
1904	33.82	9.49
1909	41.27	9.80
1914	49.36	11.92
1917	53.55	12.55
1918	55.55	11.57
1919	54.14	11.85
1920	52.05	12.14
1921	50.64	13.19
1922	65.09	14.84
1923	74.68	15.44
1924	74.55	15.76
1925	82.45	16.31
1926	90.36	17.13
1927	91.73	17.63
1928	94.45	18.27
1929	100.14	18.35
1930	91.23	18.77
1931	83.18	18.70
1932	70.82	18.77
1933	79.00	21.50
1934	81.18	20.39
1935	91.14	20.98
1936	104.00	21.13
1937	113.09	21.98
1938	94.82	19.55
1939	110.77	21.21
1940	115.45	20.66
1941	139.36	21.68
1942	133.50	18.60
1943	129.45	16.15
1944	128.00	15.09
1945	128.09	15.54
1946	144.91	20.16
1947	156.09	22.32
1948	161.77	22.59
1949	150.45	21.27
1950	173.23	22.92
1951	179.36	22.27
1952	167.41	20.39
1953	178.00	21.23

Paper (cont.)

1954	175.00	21.48
1955	190.23	22.27
1956	196.45	22.95
1957	186.41	21.77
1958	182.55	21.76
1959	197.95	22.65
1960	196.95	22.42
1961	199.55	22.49
1962	205.77	22.28
1963	210.05	22.17
1964	219.82	22.36
1965	229.82	22.33
1966	243.73	22.61
1967	237.64	21.69
1968	252.23	22.21
1969	264.27	22.87
1970	257.09	22.54
1971	261.50	22.47
1972	280.27	23.04
1973	290.91	22.83
1974	281.36	22.43
1975	238.18	19.40
1976	271.82	21.19
1977	278.18	20.77
1978	290.45	20.87
1979	293.03	20.70
1980	280.51	20.11
1981	283.54	19.98
1982	269.19	19.53
1983	294.09	20.84

U.S. TEXTILES CONSUMPTION

YEAR	KG/CAP	(KG/1000 1983$) KG/GNP
1840	3.35	2.72
1850	7.02	5.14
1860	7.76	5.08
1870	6.89	4.07
1880	9.92	4.53
1890	11.33	4.16
1900	13.93	4.22
1920	12.09	2.82
1921	11.82	3.08
1922	13.18	3.00
1923	14.14	2.92
1924	11.64	2.46
1925	13.09	2.59
1926	13.36	2.53
1927	14.73	2.83
1928	12.95	2.51
1929	13.95	2.56
1930	10.55	2.17
1931	11.00	2.47
1932	9.91	2.63
1933	12.64	3.44
1934	10.86	2.73
1935	12.18	2.80
1936	14.91	3.03
1937	15.27	2.97
1938	12.05	2.48
1939	15.27	2.92
1940	16.27	2.91
1941	21.09	3.28
1942	22.50	3.13
1943	21.00	2.62
1944	19.14	2.26
1945	18.41	2.23
1946	19.45	2.71
1947	17.45	2.50
1948	18.27	2.55
1949	15.23	2.15
1950	19.77	2.62
1951	18.95	2.35
1952	17.68	2.15
1953	17.64	2.10

Textiles (cont.)

1954	16.05	1.97
1955	17.91	2.10
1956	17.27	2.02
1957	16.00	1.87
1958	15.23	1.82
1959	17.50	2.00
1960	16.50	1.88
1961	16.32	1.84
1962	17.64	1.91
1963	17.82	1.88
1964	18.95	1.93
1965	20.50	1.99
1966	21.82	2.02
1967	21.41	1.95
1968	23.18	2.04
1969	23.18	2.01
1970	22.32	1.96
1971	24.82	2.13
1972	26.68	2.19
1973	27.73	2.18
1974	23.91	1.91
1975	22.86	1.86
1976	25.14	1.96
1977	26.27	1.96
1978	26.91	1.93
1979	26.05	1.84
1980	24.14	1.73
1981	24.27	1.71
1982	21.82	1.58
1983	26.41	1.87

U.S. ALUMINUM CONSUMPTION

YEAR	THOUSAND TONNES	KG/CAP	(KG/10^6 1983$) KG/GNP
1928	149.68	1.24	240.26
1929	149.77	1.23	200.37
1930	99.59	.81	184.44
1931	80.73	.65	141.49
1932	53.50	.43	149.58
1933	77.05	.61	169.34
1934	104.27	.82	208.40
1935	133.82	1.05	247.00
1936	172.00	1.34	272.38
1937	209.59	1.63	250.58
1938	116.64	.90	279.38
1939	201.45	1.54	290.12
1940	279.41	2.11	383.39
1941	372.41	2.78	527.01
1942	714.00	5.27	740.22
1943	1083.00	7.89	838.58
1944	973.00	7.01	864.09
1945	996.00	7.09	748.73
1946	627.23	4.42	786.97
1947	790.05	5.46	751.48
1948	866.14	5.88	758.08
1949	740.91	4.95	830.80
1950	1035.45	6.80	846.10
1951	1151.82	7.44	917.75
1952	1250.91	7.94	1064.25
1953	1737.27	10.84	1187.62
1954	1808.18	11.09	1366.67
1955	1900.91	11.46	1325.96
1956	1929.09	11.42	1330.59
1957	1942.73	11.29	1299.88
1958	1868.18	10.68	1378.77
1959	2261.82	12.72	1304.94
1960	1954.85	10.82	1360.38
1961	2262.85	12.32	1400.22
1962	2637.85	14.14	1517.45
1963	2949.80	15.59	1626.77
1964	3166.35	16.50	1721.72
1965	3629.88	18.68	1822.16
1966	4146.47	21.09	1819.85
1967	3793.36	19.09	1875.43
1968	4305.93	21.45	1862.13

Aluminum (cont.)

1969	4643.67	22.91	1868.74
1970	4185.90	20.41	1929.20
1971	4711.01	22.68	1959.34
1972	5314.29	25.32	2125.79
1973	6270.31	29.59	2154.93
1974	5872.53	27.45	2058.12
1975	4408.36	20.41	2004.20
1976	5658.09	25.95	1917.07
1977	6035.48	27.41	2074.09
1978	6667.88	29.95	2090.14
1979	6732.54	29.91	2017.70
1980	5878.80	25.82	1931.02
1981	5765.89	25.09	1756.64
1982	5538.75	23.86	1814.22
1983	6099.85	26.05	1768.44

U.S. AMMONIA CONSUMPTION

YEAR	MILLION TONNES	KG/CAP	(KG/1000 1983$) KG/GNP
1950	1.59	10.45	1.38
1951			
1952			
1953	2.35	14.67	1.75
1954	2.32	14.23	1.75
1955	2.48	14.97	1.75
1956	2.51	14.83	1.73
1957	2.74	15.94	1.86
1958	3.19	18.25	2.18
1959	3.41	19.20	2.20
1960	4.47	24.72	2.81
1961	4.66	25.39	2.86
1962	4.42	23.69	2.56
1963	4.96	26.21	2.77
1964	5.56	28.98	2.95
1965	5.93	30.53	2.97
1966	7.10	36.12	3.35
1967	8.38	42.16	3.85
1968	8.80	43.86	3.86
1969	9.05	44.64	3.86
1970	9.90	48.27	4.23
1971	10.82	52.10	4.48
1972	11.18	53.26	4.38
1973	11.62	54.82	4.30
1974	11.71	54.73	4.36
1975	12.02	55.65	4.53
1976	12.67	58.13	4.53
1977	13.48	61.23	4.57
1978	13.88	62.36	4.48
1979	15.15	67.31	4.76
1980	16.14	70.88	5.08
1981	14.87	64.70	4.56
1982	12.60	54.28	3.94
1983	11.75	50.15	3.55

U.S. CHLORINE CONSUMPTION

YEAR	THOUSAND TONNES	KG/CAP	(KG/1000 1983$) KG/GNP
1940	633.18	4.78	.85
1941	1069.91	7.99	1.24
1942	1268.45	9.37	1.30
1943	1509.91	11.00	1.37
1944	1553.91	11.19	1.32
1945	1083.73	7.71	.94
1946	1059.18	7.46	1.04
1947	1897.45	13.11	1.88
1948	1490.91	10.13	1.41
1949	1606.36	10.72	1.52
1950	2786.55	18.30	2.42
1951	3356.09	21.67	2.69
1952	3564.27	22.62	2.75
1953	3891.18	24.29	2.90
1954	4080.45	25.03	3.07
1955	4815.18	29.02	3.40
1956	5366.91	31.78	3.71
1957	5489.00	31.91	3.73
1958	5095.27	29.13	3.47
1959	5982.18	33.65	3.85
1960	6395.36	35.39	4.03
1961	6435.27	35.03	3.95
1962	7180.09	38.48	4.17
1963	7622.00	40.29	4.25
1964	8241.27	42.95	4.37
1965	9092.27	46.80	4.55
1966	10052.00	51.13	4.74
1967	10559.73	53.14	4.85
1968	11512.73	57.36	5.05
1969	12506.36	61.70	5.34
1970	12902.45	62.91	5.52
1971	12571.45	60.53	5.20
1972	13517.64	64.40	5.29
1973	14389.27	67.91	5.33
1974	15095.73	70.57	5.63
1975	13167.27	60.96	4.97
1976	14972.09	68.68	5.35
1977	15445.09	70.14	5.24
1978	16051.09	72.11	5.18
1979	17819.27	79.16	5.59
1980	16808.09	73.82	5.29
1981	15979.64	69.54	4.90
1982	13312.73	57.36	4.16
1983	16611.55	71.57	5.07

U.S. ETHYLENE PRODUCTION

YEAR	THOUSAND TONNES	KG/CAP	(KG/1000 1983$) KG/GNP
1945	140.91	1.00	.12
1946	131.82	.93	.13
1947	154.55	1.07	.15
1948	172.73	1.17	.16
1949	522.73	3.49	.49
1950	827.27	5.43	.72
1951	818.18	5.28	.66
1952	822.73	5.22	.64
1953	972.73	6.07	.72
1954	1063.64	6.53	.80
1955	1386.36	8.36	.98
1956	1636.36	9.69	1.13
1957	1795.45	10.44	1.22
1958	1886.36	10.79	1.29
1959	2318.18	13.04	1.49
1960	2477.27	13.71	1.56
1961	2572.73	14.01	1.58
1962	2854.55	15.30	1.66
1963	3418.18	18.07	1.91
1964	3927.27	20.47	2.08
1965	4350.00	22.39	2.17
1966	4818.18	24.51	2.27
1967	5090.91	25.62	2.34
1968	5978.18	29.79	2.62
1969	7470.91	36.86	3.19
1970	8222.27	40.09	3.52
1971	8386.36	40.38	3.47
1972	9478.18	45.16	3.71
1973	10149.55	47.90	3.76
1974	10859.55	50.77	4.05
1975	9317.73	43.14	3.51
1976	10215.91	46.86	3.65
1977	11441.82	51.96	3.88
1978	11797.73	53.00	3.81
1979	13592.73	60.39	4.27
1980	13030.45	57.23	4.10
1981	13371.82	58.19	4.10
1982	11136.82	47.98	3.48
1983	12993.64	55.48	3.93