ENERGY DEMAND AND MATERIALS FLOWS IN THE ECONOMY

Marc Ross[a]
Eric D. Larson[b]
Robert H. Williams[c]

PU/CEES Report No. 193

July 1985

the
center for
energy and
environmental
studies

princeton university

ENERGY DEMAND AND MATERIALS FLOWS IN THE ECONOMY

Marc Ross[a]
Eric D. Larson[b]
Robert H. Williams[c]

PU/CEES Report No. 193

July 1985

(a) Professor of Physics
University of Michigan
Ann Arbor, MI 48109

(b) Research Associate
Center for Energy and Environmental Studies
Princeton University

(c) Senior Research Scientist
Center for Energy and Environmental Studies
Princeton University

Presented at the
Soviet-American Symposium on Energy Conservation
Moscow, June 6-12, 1985

Center for Energy and Environmental Studies
Princeton University
Engineering Quadrangle
Princeton, NJ 08544

Table of Contents

Synopsis

Many forecasts of energy demand in highly industrialized nations show industrial requirements growing rapidly. These forecasts do not, however, fully reflect (1) the diminishing importance of the use of basic materials in the economic activity of mature industrial societies, (2) the emerging shift of production based on virgin materials to less-developed and resource-rich countries, and (3) the increased recycling of materials. Since materials processing dominates industrial energy demand, this global pattern of development will upset those forecasts. While energy consumption by industry will grow in countries like China, Saudi Arabia, Korea, Canada, Brazil, Mexico, South Africa and Australia, it will continue to decline or stagnate in the United States, Europe and Japan.

Materials and Industrial Energy Demand

Superimposed on the well-recognized shift toward services in "post-industrial" economies (e.g., the United States -- Figure 1) has been an accelerating shift within industry away from the processing of basic materials toward fabrication and finishing activities (Figure 2). This shift within the industrial sector will tend to slow the growth in industrial energy demand, because the industrial sectors growing most rapidly are not very energy-intensive.

In the United States in 1978, the industries that process basic materials (petroleum refining, primary metals, paper, chemicals, glass, cement, and related products) consumed about 207 MJ of final energy* to produce one dollar (1972$) of value-added, accounting for about 82% of

----

* Electricity consumption is counted as 3.6 MJ per kWh of electricity consumed.

total manufacturing energy use. At the same time however, it generated only 23% of total manufacturing value-added (Figure 3). By contrast, food processing plus fabrication and finishing activities ("Other" in Figure 3) used only about 14 MJ/1972$, consuming 18% of energy used in manufacturing to generate 77% of the manufacturing value-added.

Materials Consumption

The declining importance of basic materials can be understood in the context of the changing needs of society as the economy evolves.[1,2] After a material is introduced, when consumption rates (in tons per capita per year) are low, consumption grows very rapidly -- usually much more rapidly than average economic activity. The rapid growth at this stage of the materials cycle is conducive to the introduction of technological innovations into the new capital equipment stock needed to produce more of the material. These advances generally increase productivity, often leading to lower prices, which in turn feed demand growth. In the next stage of the cycle, as income-generating activities shift away from materials-intensive markets and further innovations permit more efficient use of the material, the demand for that material per unit of GNP peaks and then declines. In the final stage of the cycle per capita demand for the material ceases to grow.

This classic materials use cycle is well illustrated by the long-term history of steel use in the United States (see Figure 4[3]). The consumption of steel per real dollar of GNP has followed a bell-shaped curve which peaked about 1920 and has now declined to the level that characterized the 1880s, about 1/3 of the peak value. The consumption of steel per capita has followed an S-shaped curve; it grew by nearly a factor of 10 from the

1880s to the 1940s and has been almost constant since then. (Actually, it may now be entering a long-term decline.)

Developments of the 1970s in the U.S. for all major energy-intensive materials fit a similar pattern, as illustrated by the consumption patterns for a representative sampling of basic materials shown in Figure 5. The ratio of consumption to real GNP grew much more slowly in the 1970s than in the 1960s. In fact, the ratio of consumption to GNP for all such materials declined in the 1970s, except for organic chemicals (as represented by ethylene). Moreover, there is strong evidence of saturation (a cessation of growth in per capita materials use) for most materials (see Figure 5), a phenomenon which seems to be occurring for materials use in Western Europe as well (see Figure 6).

The maturing of basic materials in the U.S. economy can be attributed to several factors.[1] Substitution of new materials is one factor which contributes to the decline of traditional materials. But, as shown in Figure 5, it appears that saturation is being approached for many new basic materials as well.

A second factor contributing to the declining importance of basic materials is that materials being supplied to traditional bulk markets are being used far more efficiently now than in the past -- in part as a strategy for mitigating the impacts of increased costs, especially energy costs, and in part as a response to competitive pressures from substitutes with more desirable properties. This competition from substitutes has intensified technological advances in the use of the traditional materials, e.g., the development of higher strength-to-weight ratios or increased durability, permitting the same material services to be provided with lower levels of material inputs.

Still another important factor is the shift in consumer preferences at high levels of affluence (see upper scale in Figure 5) to less materials-intensive products. These changing consumer preferences are leading to saturation in markets for bulk materials (e.g., sheet steel for automobiles and heavy appliances), and growth in new markets for value-added-intensive products. We are now seeing the emergence of an information-centered society, where growth is dominated by high-technology products with generally low intensities of materials use, such as solid-state electronics, computer hardware and software, biogenetics, and telecommunications.

Materials Production

During the 1970s the trend in materials production in the United States followed that for consumption. More exactly it can be said that aggregate consumption of materials grew only slightly faster than production - i.e., international trade did not have a major effect on materials production in this period. In the 1970s, increased exports of paper and organic chemicals balanced the increased imports of paper and steel.

Since 1980 it has become clear that the pattern of United States trade in materials is shifting. Manufacturing is beginning to move to less-developed countries (LDCs) and resource-rich countries, with the net result that production in the United States (and other advanced industrial countries) will grow more slowly than demand.

Initially this shift in production will emphasize the most basic upstream products (i.e., those manufactured in the first levels of processing within each materials industry). Upstream products such as steel in rough shapes, pulp and products such as linerboard (for the facing of shipping containers), industrial chemicals immediately derived from ethylene, and primary aluminum have become international commodities. Improvements in shipping, especially larger ships and modernization of ports and materials-handling facilities, have substantially reduced costs, thereby changing the determinants of plant location.[4] One result is that in locating new basic steel mills there is no longer a strong raw-materials supply source orientation. In addition, the character of these products as international commodities has been enhanced by the decreasing concentration of ownership of production facilities.[5] Although some new facilities are subsidiaries or joint projects of the major old firms, many are independent, with LDC government ownership common. Many major new entities have come into being in steel and aluminum and are being created in petrochemicals.

Many of the countries and regions which could compete with domestic manufacturers for four important materials in the U.S. market are listed in Table 1, along with a qualitative indication of their cost advantage or disadvantage relative to the United States and the main reason for it. A critical reason in all cases except steel is local availability of hard-to-transport natural resources. (Coal, iron ore and scrap are relatively easy to transport between ports, while methane, ethane, electricity and wood are not.) Table 1 shows that for steel, ethylene and aluminum, there are countries with major or significant cost advantages over the U.S. Of the industries listed, only the paper industry in the US has a strong international position.

The qualitative results shown in Table 1 are based primarily on information on new plants and/or plans for construction of additional capacity around the world. The situation has been confused because extremely ambitious plans for steel (China, South Africa), petrochemicals (Alberta, Mid-East, Indonesia, China) and primary aluminum (Australia) have been wholly or partly postponed or cancelled in the last 2 or 3 years due to recently reduced global demand and the debt problems of some LDCs. In many cases the planned expansion was simply too rapid in light of world demand. But when demand rises once again, most of these plans will probably be revived. Moreover, the threat that highly competitive production facilities can be created elsewhere will prevent major investment in these product areas in the U.S.

A likely structural change is for United States producers to gradually yield certain upstream products to foreign plants, while trying to secure their role: (1) in less capital-intensive downstream finishing and fabrication operations and (2) in secondary industries, those based on recycled materials.

There is the potential for sizable growth, in value rather than tonnage terms, in sophisticated materials such as high-strength steels, corrosion-resistant steels, composites and plastic-aluminum laminates. In these downstream functions, U.S. producers would have the powerful advantage of being close to markets. Of course this doesn't guarantee that they can beat out foreign competition in these new product areas. In this picture, the international trend would be to produce the relatively unspecialized international commodities in large facilities at sites with advantages such as low prices for hard-to-transport inputs or low labor costs, but, in many cases, to finish the material close to markets.

As materials use patterns approach saturation, recycled materials can in principle come to play a much larger relative role than is feasible in the earlier stages of rapid demand growth. Indeed, manufacture based on recycled material is growing in importance in the U.S. Recycling has long been important for a relatively costly metal like copper, and for the highest quality recycled material like fabricator's scrap. During the past 15 years or so recycling of post-consumer aluminum has rapidly increased as a result of the development of the beverage can, which can be recycled into itself. Steel and paper recycling are also increasing, and post-consumer recycling of plastics is beginning.

The energy savings are, in some cases, substantial. Making secondary aluminum requires only 5-10% as much energy as primary aluminum. Steel-mill products made from scrap typically require about 50% as much energy as those made from iron ore. Recycling of paper does not necessarily save energy; it depends on the quality of paper recycled and whether the alternative is burning or landfill (i.e. disposal as solid waste). The economics may depend on whether the landfill costs are included in the analysis.

A Closer Look at Four Materials

Let us examine some of these developments in more detail for four materials: steel, ethylene and derivatives, aluminum, and pulp and paper.

Steel: All the factors mentioned above which contribute to the declining relative role of materials consumption in the U.S. economy can be illustrated with steel. 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, offers a good example 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 at about one for every two persons, and new car sales are not expected to rise much beyond 1975-1978 levels through 1990[1]. The net function of production today is to replace old cars.

Since the mid-1970s, automotive material suppliers have been further affected by minimum automotive fuel economy standards enacted after world oil prices rose sharply. The result has been a general downsizing of automobiles and increased substitution of lighter materials for traditional ones. The weight of the average US-made car dropped from 1727 kg in 1975 to 1469 kg in 1984. The iron and steel contribution dropped from 1139 kg to 802 kg in this period. Industry experts project total vehicle weight to decrease to 1069 kg by 1992, with steel component dropping to 625 kg[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. 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 well over 20% by 1992[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.

There are new markets for steel, but the new markets are largely for special applications involving high value-added products (electronic equipment, medical technology, etc.). The general trend in the US and other industrialized market economies is for growth in less steel-intensive products.

The steel/GNP ratio in the U.S., West Europe and Japan is well below that for most of the rest of the world, as Table 2 shows. However, per capita consumption in the rest of the world is low, so that demand can be expected to increase rapidly there, continuing the recent trend (see Figure 7). For the world as a whole the outlook is for steel demand growing somewhat more slowly than aggregate GNP.

Stagnant domestic demand has helped create the major problem of the U.S. steel industry: the capital in place represents antiquated technology, and the associated institutions and perceptions also tend to be antiquated. Since 1950 only two greenfield, or all new, integrated mills have been built, the last one in the 1960s. Building a greenfield mill doesn't pay in the U.S., because the increase in capital carrying charges exceeds the reduction in operating costs.

Introduction of certain major new components into existing mills is, however, cost-effective. Thus open hearth steel furnaces have been replaced with basic-oxygen shops, continuous casters have replaced much batch casting of ingots, and large blast furnaces have replaced some small old furnaces with low capacity. Unfortunately this kind of modernization has also proceeded slowly in the U.S., and these and other modern equipment items are much more thoroughly implemented in Japan than in the U.S.

Modernization can be largely effectuated in yet another way: through small investment projects and operational changes. The U.S. industry also lags in this area even though very profitable opportunities have been created by computer control developments and by higher energy prices.[6]

In many other countries production costs are lower than in the U.S.,[7] strikingly so, for example, in South Korea. In certain cases, such as in East Asia, plant construction is cheaper. In those countries where the creation of basic manufacturing facilities is a priority of the government, the cost of capital (i.e., the effective interest rate) may be lower. Labor costs are lower in many countries because fewer man-hours are required per ton (in part because work rules are much more flexible), as well as because hourly rates are lower. Ore costs for mills at deep-water ports are lower than the U.S. average, more than compensating for the U.S. advantage in coal costs.[8] In addition, some foreign operations, e.g. at antiquated European mills, are directly subsidized.[9] These advantages and the high overseas buying power of the dollar (some 1/3 above 1970s rates in Europe and Japan) more than make up for the transportation cost differential.

Even if import limitations continue to be in force, it is likely that the cost advantage of a number of foreign producers and the threat of subsidized steel will prevent the major infusion of capital needed to help the U.S. industry be more competitive. Lack of technical effort in the U.S. is increasing the gap. What options are open to the industry?

One strategy the U.S. industry may adopt is to accompany severe retrenchment in the upstream end of the process with imports of rough-shaped steel and modernization of shaping-finishing facilities. However, the Japanese are already modernizing their shaping-finishing facilities, so the U.S. industry will face stiff competition in this area as well. Nevertheless, revolutionary changes in these technologies are now imminent[10]. If U.S. manufacturers can make sound decisions on these new technologies and invest heavily, they could leapfrog many other steelmakers. This strategy has merit, but it leaves unresolved the problems of the front end of the process, the crude steel production. In a way this strategy also begs the question, since the integrated industry in the U.S. does not have a strong technological orientation and so is unlikely to adopt such a strategy.

A different strategy may be appropriate: joint ventures with Japanese firms in order to acquire technical expertise and to secure technically-oriented capital. The Japanese are taking steps to invest in foreign production facilities. They are interested in exporting manufacturing equipment in mature industrial sectors, realizing that the potential for growth in exports of the materials is limited by protective policies.

The question for such ventures is whether they could compete with production in LDCs. The labor-cost disadvantage would still apply even with Japanese engineering; and the current high value of the dollar slams the door. The hope would be that through skillful modernization of existing mills and with an end to the U.S. fiscal policies that cause the overvaluation of the dollar, the better mills would become competitive.

One part of the American steel industry is in robust condition. The secondary steel industry, mini-mills which melt scrap, was growing ten percent per year to 1981, and produced 18% of the steel in the U.S. in 1983. In products where the secondary industry has concentrated, imports are being driven out![8] (Figure 8) A key strategy of the industry has been to select products which can be produced with low unit capital costs and low labor requirements. Experts disagree on the prognosis for further growth of this industry.[8,11] The industry's favorable position is largely built on the economic advantages of scrap compared to virgin material. If the industry continues to be limited to scrap it may continue to be primarily restricted to products, such as bars and light structural sections, which can be made of steel containing significant impurities, especially copper (see Figure 9). The problem is that copper is a common contaminant in post-consumer scrap and copper tends to cause cracks in high-temperature forging, e.g. in hot rolling of sheet steel. If such limitations are not overcome, the secondary industry's growth rate would rapidly decline. On the other hand, new shaping and finishing technologies may enable the making of higher-quality products out of steel with considerable copper content. In that case, for example, sheet steel to make automobiles could be made from automobile scrap. (This development might also become possible through changes in auto design or changes in scrapping procedures.) Then these secondary producers could continue their rapid growth and take a substantial part of the remaining market from the present integrated producers. A different possibility, which has been widely discussed, is that the mini-mills could use direct-reduced or sponge iron as well as scrap as their input. It is not clear that this would provide any economic advantage. In any case, the sponge iron would probably not be manufactured in the U.S. Since the favored technology for producing sponge iron uses natural gas, the primary areas for growth in sponge iron production are now disposing of gas, i.e. flaring it,[12] or have partly unexploited gas resources (such as Mexico, the Middle East and Nigeria).

Ethylene and Derivatives: Ethylene is a very modern basic material which came into wide use only after World War II. In the 25 year period between the end of World War II and the first oil shock the production of ethylene in the US grew almost 5 times as fast as GNP. Since the early 1970s, however, the production of ethylene has been growing only about as fast as GNP (see Figure 5), and the trend since the late 1970s suggests the approach to saturation, in both production and consumption (see Figure 10).

Ethylene is a major building-block for a number of intermediate chemicals, so that ethylene is a good surrogate for organic chemicals generally. As for ethylene, the consumption of organic chemicals is growing only about as fast as GNP in the U.S., with plastics used in packaging and construction leading the way[13]. Although markets for plastics continue to grow, a variety of developments signal an end to tonnage growth faster than GNP, including changing process technologies and maturing product markets.[1]

The introduction of linear low density polyethylene (LLDPE) plastic in the late 1970s, a stronger plastic than conventional low density polyethylene (LDPE), has allowed the use of thinner films in plastic products -- saving up to half the resin formerly required, while still providing equivalent strength. LLDPE now accounts for over 35% of all LDPE produced, and the fraction is expected to grow to near 60% by 1990.

Also, markets for many ethylene-derived products are maturing. About 60% of ethylene oxide (which accounts for about 20% of all ethylene use) goes into antifreeze production and most of the rest to the manufacture of polyester fibers. Ethylene demand in these markets has been slowed by the maturation of the automobile market and the downsizing of cars discussed earlier, and by maturation in the markets for synthetic fibers. The consumption of ethyl benzene, used largely to produce styrene, a basic component of styrene-butadiene rubber (SBR) used in tires, was significantly affected by both the down-sizing of cars, which has been accompanied by a shift to smaller tires, and the introduction in the 1970s of radial tires, which last about twice as long as ordinary bias-ply tires.

West Europe and Japan consume ethylene and derivatives per dollar of GNP at about 80% of the U.S. level, as shown in Table 2. The rest of the world consumes ethylene and derivatives at a much lower rate. The growth rate for the world will continue to be faster than that for GNP.

Substantial capacity to produce ethylene and basic derivatives such as polyethylene and other polymers, ethylene glycol and ethyl alcohol is under construction or has recently been built near markets in the Far East and, to a greater extent, near resources in the Middle East, Canada and Mexico.[14] Huge facilities are just now starting production in Alberta and Saudi Arabia. Although the recent severe recession led to a stretching out of some of the planned construction, much of the planned capacity will be built.

Ethylene is made primarily from ethane, propane and middle distillates; and major expansion in the use of heavier petroleum components as the feedstock has been contemplated. Ethane, a light hydrocarbon associated with oil and natural gas production, provides the cheapest route to ethylene (in terms of value added). Storage and transportation of ethane is costly, so there are good arguments for converting ethane for petrochemicals at the point of supply. Moreover a producer requiring a material like ethane, but not in control of a supply, can be very uncomfortably dependent on a few suppliers, because there is not a well developed market for the material.

Completion of planned ethylene-production facilities would substantially reduce the U.S. share of production. In the medium term, U.S. exports of basic ethylene derivatives are likely to decline sharply. More important, the realization that large new plants can be built elsewhere to produce ethylene cheaply will dramatically inhibit the building of new plants here. Expectations of a continuing expansion of U.S. capacity will probably prove incorrect. New capacity based on heavy oils or crude oil will probably be long delayed.

What is true for ethylene and derivatives is also true for other basic organics. Materials which can be made fairly directly from natural gas, like methanol and ammonia derivatives, are especially likely to be manufactured near isolated gas fields. Much gas is still flared.[12] Other gas formations are not being exploited because the gas is too costly to move to markets.

<u>Aluminum</u>: The use of aluminum in the U.S. grew rapidly as steel consumption

approached saturation levels in the 1940s, 50s, and 60s, reflecting the increasing use of aluminum as a substitute for steel and other heavier materials (Figure 5). However, the consumption per dollar of GNP began to decline in the early 1970s, a trend which has been accelerating in the 1980s. Moreover, per-capita demand appears to have leveled off in the late 1970s.

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, maturing markets and more efficient use of material in existing applications are both contributing to saturating demand.[1]

An examination of specific markets shows only packaging and transportation applications growing faster than GNP in the 1970s, and only packaging in the 1980s[15]. Other materials are competing fiercely with aluminum in both of these markets.

The largest single market for aluminum is containers and packaging, accounting for about 30% of all U.S. shipments, 80% of which goes into making beverage cans. Aluminum cans first appeared in consumer markets in the early 1960s, and their use has grown phenomenally since. By 1981, they accounted for nearly 90% of all beverage cans.

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. 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 in the average new car in the U.S. has been dropping steadily since the mid-1970s, a trend that industry experts expect will continue. Compounding this decreased rate of growth is the approaching saturation in car ownership noted earlier.

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. 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.

Aluminum consumption per unit of real GNP in other highly industrial nations is some two thirds of that in the U.S. (Table 2). Packaging applications make up most of that difference, and it is not clear how much that market will grow in those countries. On the other hand the low aluminum-GNP ratio in LDCs indicates faster growth of aluminum than GNP. The situation suggests world aluminum demand growth slightly faster than or comparable to that of world GNP.

Primary aluminum production in the U.S. will decline with respect to domestic consumption for two reasons: (1) Secondary production will continue growing rapidly; it grew from 25 to 50% of primary production from 1970 to 1983.[15] (Figure 11) (2) The domestic primary industry will shrink as imports of primary aluminum increase.

Aluminum smelters are being built in Australia, Canada and Brazil[16] where new power plants have been, or are being, built which supply power at under 2 cents/kWh.[17] The sources are hydropower in Canada (e.g. the huge new James Bay project) and in Brazil and remote surface coal in Australia.

Unexploited natural gas is also a source of cheap electricity for new smelting capacity. Power contracts held by existing smelters outside the U.S. provide for prices even lower than 2 cents/kWh. Meanwhile the price of electricity in the U.S. is moving sharply upward, albeit with important regional differences, toward the cost of power from new coal and nuclear plants of 5 cents/kWh and more. Roughly speaking a 1 cent/kWh price increase corresponds to a 10% increase in the cost of producing primary aluminum. In the Gulf states, where 17% of the aluminum capacity is located, some smelters have already been closed as gas-fired power has become too expensive. Nuclear power investments and overcapacity have brought the price of power from the Tennessee Valley Authority (TVA) to smelters to 3.7 cents/kWh. In the Pacific Northwest the price to smelters is 2.7 cents/kWh (although some power is temporarily available at a lower price). There the subject of who should enjoy the benefit of low cost hydro and who should pay for costly new plants is being fiercely contested by consumers. In the Ohio valley, low growth may hold the real cost of coal-based power to smelters near the present 2.5 cents/kWh average for some years.

In the next few years it is likely that much more smelting capacity will be closed on a regional basis. U.S. aluminum firms are joining in foreign projects, are increasing their role in secondary aluminum (where the recycling of aluminum cans is an important success story) and are upgrading their domestic finishing operations.

Paper: The changing role of paper in the U.S. economy is reflected in the recently declining ratio of consumption to GNP (Figure 5), which was preceeded by a steady rise up to about 1940, and an extended period during which this ratio changed very little. Per capita consumption is continuing to grow, but distinctly more slowly since the early 1970s.

Recent improvements in material efficiency in the production of large-volume products can be found in many sectors of the paper industry.[1] Newsprint, which accounted for about 30 percent of paper (or about 17 percent of total paper and paperboard) consumption in 1982, 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, and the industry is currently contemplating a further decrease to 28 lbs (20.7 kg/m^2). Coated papers accounted for about 14 percent of paper consumption in 1982, with number 5 coated groundwood, the lightest weight coated paper, accounting for about half the total tonnage. 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: In 1968, less than 6% of all No. 5 paper had basis weights of less than 36 lbs (26.7 kg/m^2), but by 1972 the fraction had grown to 17% and had reached 27% in 1979. In the last decade, the average density of bleached paperboard, widely used in food and pharmaceutical packaging applications and accounting for about 12% of all paperboard consumed, dropped some 15 to 20% due to process innovations permitting higher strength-to-weight ratios to be attained.

Maturing markets for particular paper and paperboard products are also playing a role in determining overall consumption patterns. For example,[18] the strongest growth market in the 1950s and '60s was shipping containers (corrugated boxes), but by the early 1970s the market was saturated. Thus, where few goods were so packaged for shipment in 1950, essentially all but large and bulk goods were so packed in 1970.

For U.S. producers, paper is the bright spot among the basic materials. Although aggregate use of paper is not growing as rapidly as GNP, it is growing absolutely (see Figure 5). Moreover, some product sectors are strong, especially printing papers, such as computer and copying papers.[19] The paperless office is still a scheme for the future. More important, the U.S. and Canadian industries are strong because of their raw materials base. Since wood logs or chips are relatively costly to ship, it pays to locate pulp mills near the wood resources. In many cases it also pays to locate large paper and board mills at the same site, although some drying and shipping of pulps is typically required to obtain the desired blend of materials. The U.S. is unique in combining the forests, which can (with more intensive scientific management including fertilization) support greatly expanded harvests, with the needed skills and infrastructure.[20] There is also a relatively large potential for increased recovery of waste paper.

Strong growth in world demand is expected and will create major opportunities for growth in net exports. At present, Scandinavian producers have the advantage in international pulp and paper trade because of the very high valuation of the dollar, but Scandinavian wood resources and, therefore, pulp and paper production are limited. Most countries have their own paper industries and supply much of their needs. They import primarily linerboard, the high-strength facing from which corrugated shipping containers are made, and high-quality pulp which they use to make a wide variety of products in their own papermills. The U.S. industry has focused primarily on these two exports. Sharply increased world demand and aggressive product development and marketing would lead to growth in exports of a variety of paper products by the U.S.

Aggregate Materials Trends

The discussion of the effects on energy demand of (1) the declining importance of basic materials use in the economy of the United States and (2) the export of some of the materials production, can be simplified by constructing from historical data, aggregate indices of materials consumption and production using fixed energy intensities as weights. Tonnages of paper, steel, aluminum, petroleum refinery products, cement and a combination of 20 large-volume industrial chemicals, weighted by the energy-of-manufacture intensities from the late-1970s, were chosen to represent the energy-intensive materials. Data and definitions are given in the Appendix.

The consumption index is based on the apparent supply of each material: shipments from domestic factories plus net imports. The production index is more complicated for steel and aluminum, in order to separate the upstream reduction of metal ores from the downstream finishing operations. As the contribution of recycling increases as a fraction of output, production activity then decreases with respect to output of finished products.

An important aspect of the production index for the energy analyst is that the manufacturing activity described is significantly narrower in scope than that encompassed by manufacturers broadly classified in, e.g., paper and allied products [Standard Industrial Classification (SIC) 26] or chemicals and allied products (SIC 28). The production index refers to only the energy-intensive upstream manufacturing which takes place in, e.g., pulp and paper mills or basic chemical plants. Only about 11% of industrial value added is in such energy-intensive materials manufacture.

Results for 1960-1984 are shown in Figure 12. As for the eight materials shown in Figure 5 and for the same reasons, the aggregate materials-GNP ratio has suffered a major decline since the early 1970s. One can see how the 1974-1975 and the 1980-82 recessions were occasions for restructuring of the composition of GNP, since the ratio recovered only slightly from the recession lows.

Throughout the 1960s and into the early 1970s, consumption is seen to have grown slightly faster than production. Little more happened in this respect until about 1982. In the past three years there is some evidence that the difference between consumption and production is growing, for the reasons indicated in the case studies of the four materials.

After rising sharply for several decades into the 1960s, the index of materials use per capita appears (except for the prominent troughs in 1975 and 1982) to have been roughly constant in the 1970s. The evidence is also consistent with the onset of a declining role for materials per capita.

The Recent Decline of the Industrial Energy/GNP Ratio

The ratio of energy used by industry to GNP in the U.S. declined 32% between 1973 and 1984. We have analysed this trend in terms of two developments: (1) a shift of production from energy-intensive manufacture of materials to lighter industry, and (2) reductions in energy intensity.

The results of this analysis are presented in Table 3.* The average 3.6% per year decline in the ratio of industrial energy to GNP for the period 1973-1984 is shown to have been caused almost equally by the relative reduction in production of materials (1.6%/yr) and the decline in energy intensity (2.0%/yr). The decline in energy intensity is similar for both the materials sector and the rest of industry.

Industrial Energy Demand in the Year 2000

While several aspects of a projection of energy use by U.S. industry are very uncertain, some issues involved in making projections can be illustrated by making one.

Consumption of industrial products can be related to a projection of GNP. If GNP were to grow an average of 2.5% per year from 1984 to 2000,[23] then we project that all industry will grow 0.83 x 2.5 = 2.1% per year, following its historical relation to GNP.[21] The most important message of

---

* Industry is assumed to consist of two sectors: a materials sector and "other." The ratio of energy use by industry to GNP is:

$$E = E_m + E_o = e_m P_m + e_o P_o,$$

where e_m and P_m are, respectively, the energy intensity and production/GNP ratio for the materials sector and e_o and P_o are the corresponding quantities for other industry. The change in energy use over any time interval for each sector, i, is separated into a term describing changes in production plus another term describing changes in energy intensity:

$$\Delta E_i = \bar{e}_i(\Delta P_i) + \bar{P}_i(\Delta e_i)$$

where $\bar{P}_i$, $\bar{e}_i$ are averages of production/GNP and energy intensity, respectively. We represent production of materials by the index discussed in the previous subsection. Total production is represented by the constant-dollar contribution of industry to GNP.[21] The evolution of the energy intensity of the materials industries is obtained from trade-association data presented elsewhwere.[22] (The history of the energy intensity is not known in detail, but the overall change is known.) The evolution of the energy intensity for other industry is inferred from the other quantities.

this report is that energy-intensive materials consumption will not grow this fast, because this consumption is not closely related to income.

A reasonable assumption, which reflects the recent trends shown in Figures 5 and 12 and the factors underlying these trends, is that materials consumption will grow only as fast as population (projected by the Bureau of the Census to grow about 0.8% per year). While macroeconomic models of the U.S. economy usually make higher projections, we believe that such models (based on regression analyses of the past 30 years and on a fixed input-output table of the 1970s economy) exaggerate the future role of materials.

The next step in our projection concerns the rise in net imports of materials. Materials manufacturing is capital-intensive so the shift away from energy-intensive manufacturing in the U.S. will take time. Over a decade or so another 25% of the primary metals industry in the U.S. may be shut down. The organic chemicals industry may see its net export balance turn into a corresponding net import balance. The most certain development is that new facilities to manufacture the upstream products from virgin materials will not be built in the U.S.

For paper, the bright spot of the U.S. basic materials sector, the opportunities for continuing export strength are good, and would be improved with further technical development and a more favorable exchange rate. This more rosy outlook is part of a larger strength. Soil and climate, infrastructure, and some technical virtuosity make the agricultural and forestry sectors and those industries based on them very strong in the U.S.

Shifts of basic materials manufacture along these lines, when weighted by energy of manufacture, roughly imply zero growth for aggregate materials production in the U.S., for the period to 2000.[24]

While future trends in energy intensity cannot be confidently predicted, the aggregate 20% reduction since the first oil shock must be regarded as modest in relation to the 3.3-fold increase in the inflation-corrected average price of energy for industrial customers in the U.S. in the period 1972-1981[25]. Most of the opportunities to reduce energy intensity which have been created by higher energy prices and require signficant investments remain to be exploited; and investments to achieve energy conservation are continuing to occur even where prices are no longer rising. In addition, thermodynamic limits are remote compared to present manufacturing practice, when viewed in terms of overall change from inputs to outputs (except for reduction of metal ores and feedstocks for organic chemicals).

On the basis of detailed analyses for the steel industry and for petroleum refining[26], it seems reasonable to consider two cases: (a) a continuation of the recent rate of decline in energy intensity averaging 2% per year to 2000 and (b) an average decline of 1% per year to 2000. For case (a), absolute industrial energy use in 2000 would be 0.86 times that in 1984; for case (b), 1.01 times as large.

This analysis thus indicates that, with a healthy economy and in the absence of powerful new public policies or events affecting industrial energy use, energy use by U.S. industry will continue its gradual decline or, perhaps, be roughly constant.

There are of course uncertainties underlying this projection. Slightly faster GNP growth, and slightly slower decline of consumption of materials with respect to GNP, would not be surprising, but much slower GNP growth and much faster expansion of net import of materials would also not be surprising. Similarly, still higher energy prices and possible new public policies over a period of this length could induce a larger reduction in energy intensity than assumed for case (a). It is hard to imagine, however, an energy intensity reduction less rapid than for case (b) above. Thus, the uncertainties are such that it is reasonably likely that future energy use will be substantially less than projected and unlikely that it will be substantially higher than projected.

Postscript

The stagnation in the basic materials industries in the U.S. economy has many parallels with the decline of British industry in the late nineteenth century, the scholarship of which has been reviewed by Francois Crouzet[27].

In Britain the decline of basic manufacturing was overshadowed by the growth of services (banking, insurance and shipping). While the great steelmaking inventions were made in Britain, the initial investments in factories using these techniques were made in Germany and the U.S. Basic manufacturers had shifted from their earlier technical perspective to a financial perspective. British banks and investors were preoccupied with investment outside basic manufacturing, in areas such as in housing and in overseas projects. The banking communities in competing countries were, on the other hand, very interested in manufacturing and took the lead in organizing some ventures.

There are also some differences: The wages of skilled workers in Britain were low, so their competitors in Germany and the U.S. did not reap an advantage in this respect. (This suggests that commentators may have exaggerated the importance of current high labor costs in the U.S. as a fundamental cause of the difficulties of U.S. heavy industry.) British technical education was very limited indeed; nothing analogous to the U.S. boom in high technology is evident from the historical studies of Victorian Britain.

Despite the differences, the similarities of the past British and present U.S situations are striking, and it seems reasonable to speculate that, as in Britain one hundred years ago, heavy industry in the United States is not just temporarily stagnating but has entered a period of long-term decline.

Acknowledgments

One of us (MR) wishes to acknowledge the support of the Special Projects and Industrial Applications Group, Energy and Environmental Systems Div., Argonne National Laboratory; the others (EDL, RHW), support from the Alida and Mark Dayton Charitable Lead Trust and the World Resources Institute.

Table 1
COST POSITION OF EXPORTERS AND POTENTIAL EXPORTERS TO THE UNITED STATES (PARTIAL LIST)

	Cost Advantage*	Rationale
STEEL[a]		
Japan	significant	high technology
East-Asia Rim	major	low-cost labor[b]
Canada, South Africa	marginal	
Brazil	significant	low-cost labor
Europe	uncertain	subsidies
Mexico, Venezuela	uncertain	low-cost labor, gas
PAPER		
Canada	similar costs[c]	
Scandinavia	disadvantage	limited resources
Brazil	significant[d]	natural resources
USSR	uncertain	natural resources
ETHYLENE		
Canada	significant	natural resources
Mid-East	significant	natural resources
Mexico, Venezuela	significant	natural resources
East-Asia Rim	uncertain	
Indonesia, Australia	uncertain	natural resources
ALUMINUM		
Canada	major	hydropower
Brazil	major	hydropower
Australia	significant	coal,[e] gas
USSR	uncertain	hydropower
Other	uncertain	hydropower, flared gas

*Relative to the U.S. The present high value of the dollar also provides an advantage.
[a]All these countries have some or many modern, more productive, mills than in the U.S., although Europe also has many antiquated mills.
[b]Relatively skilled labor and good infrastructure provide a major advantage.
[c]The potential for expansion is more limited than in the U.S.
[d]Expansion will be slow and only hardwood pulp is involved.
[e]Low-quality coal unsuited for export. Some analysts see significant cost advantages in Australia. Others see the opportunity dependent on help, e.g. capital subsidies.

Table 2

CONSUMPTION OF STEEL, ALUMINUM, ETHYLENE AND PAPER IN SELECTED REGIONS OF THE WORLD

	Consumption Per Unit GNP (lbs/100$)*			Annual Consumption Per Capita (lbs pc)		
	U.S.	West Europe & Japan	Asia, Africa & Latin America[a]	U.S.	West Europe & Japan	Asia, Africa & Latin America[a]
Steel[b]	12.8	12.3	16	1380	1040	90
Ethylene[c]	1.24	1.00	~0.3	133	85	~2
Aluminum[d]	0.60	0.39	~0.2	66	33	~1
Paper[e]	7.6	3.5	3.0	620	290	17

*GNP in U.S. dollars from Statistical Abstract of the United States, 1983-84.
[a] Excluding Japan and USSR.
[b] Crude steel basis, United Nationas Statistical Yearbook.
[c] Production, Chemical & Engineering News, June 13, 1983.
[d] Aluminum Statistical Review," Aluminum Association.
[e] "Pulp & Paper Review," Data Resources Inc., Feb. 1983.

Table 3

SOURCE OF DECLINE IN INDUSTRIAL ENERGY USE PER UNIT OF GNP (1973-1984)
(Rate of decline in percent per year)

	Energy Use by All Industry	Energy Use by Basic Materials Industries
Reduced Relative Production of Materials	1.6	2.7
Reduced Energy Intensity	2.0	2.1

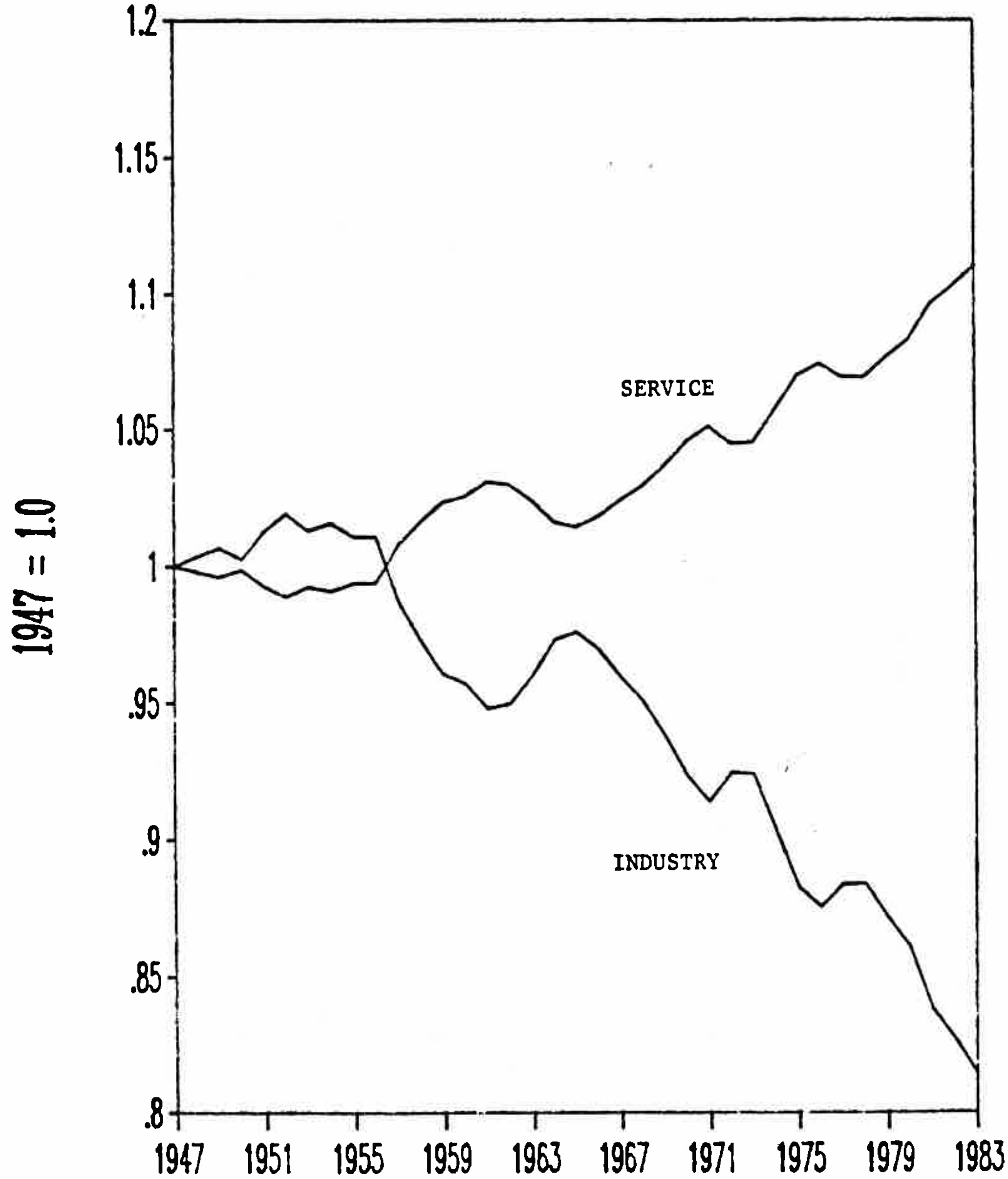

Figure 1. Constant Dollar Value-Added to GNP Ratios by Sector in the U.S.

The value-added measure used here is gross product originating (GPO). Industry includes the manufacturing, mining, agriculture, and construction subsectors. Services includes all the rest. Three year running averages are plotted. Figure taken from ref. 1.

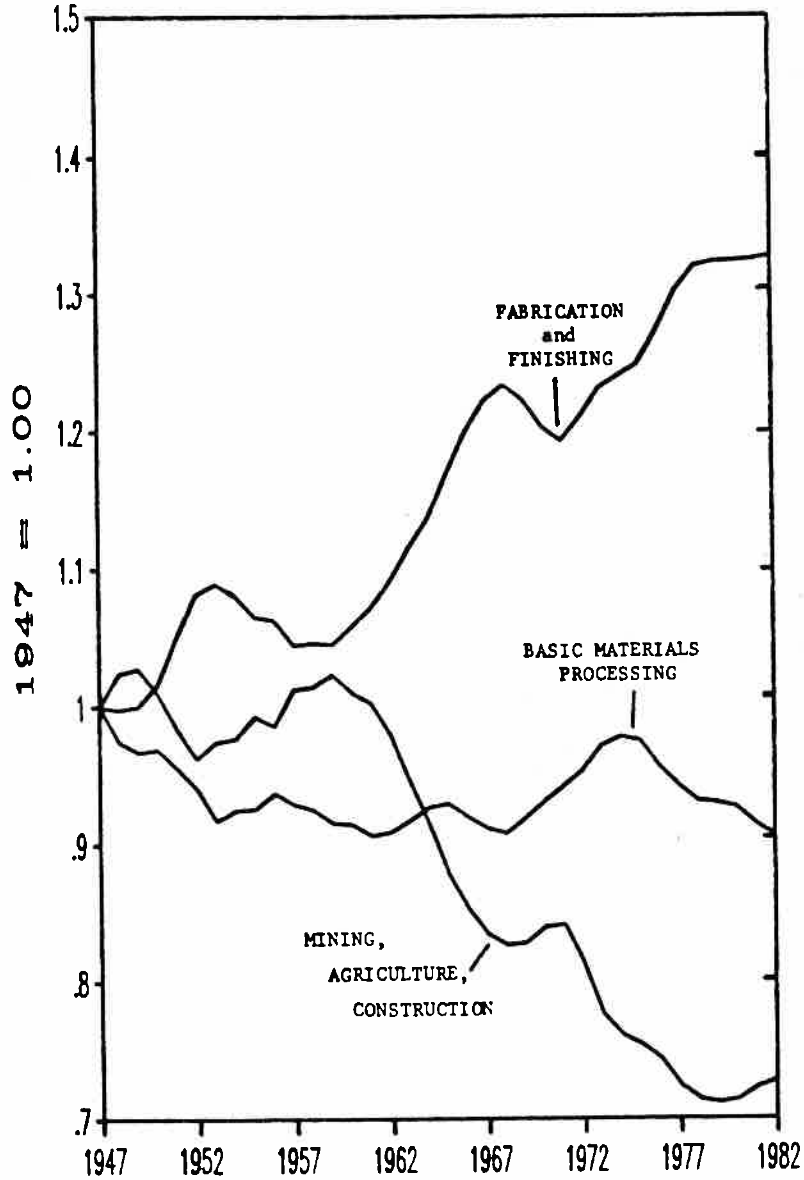

Figure 2. Ratios of GPO by Industrial Subsectors to GPO by All Industry

Within manufacturing, the basic materials processing industries their 2-digit Standard Industrial Classification (SIC) codes are taken to be 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 includes all SIC categories from 20-31, excluding the basic materials processing industries. Three year running averages are plotted. Figure taken from ref. 1.

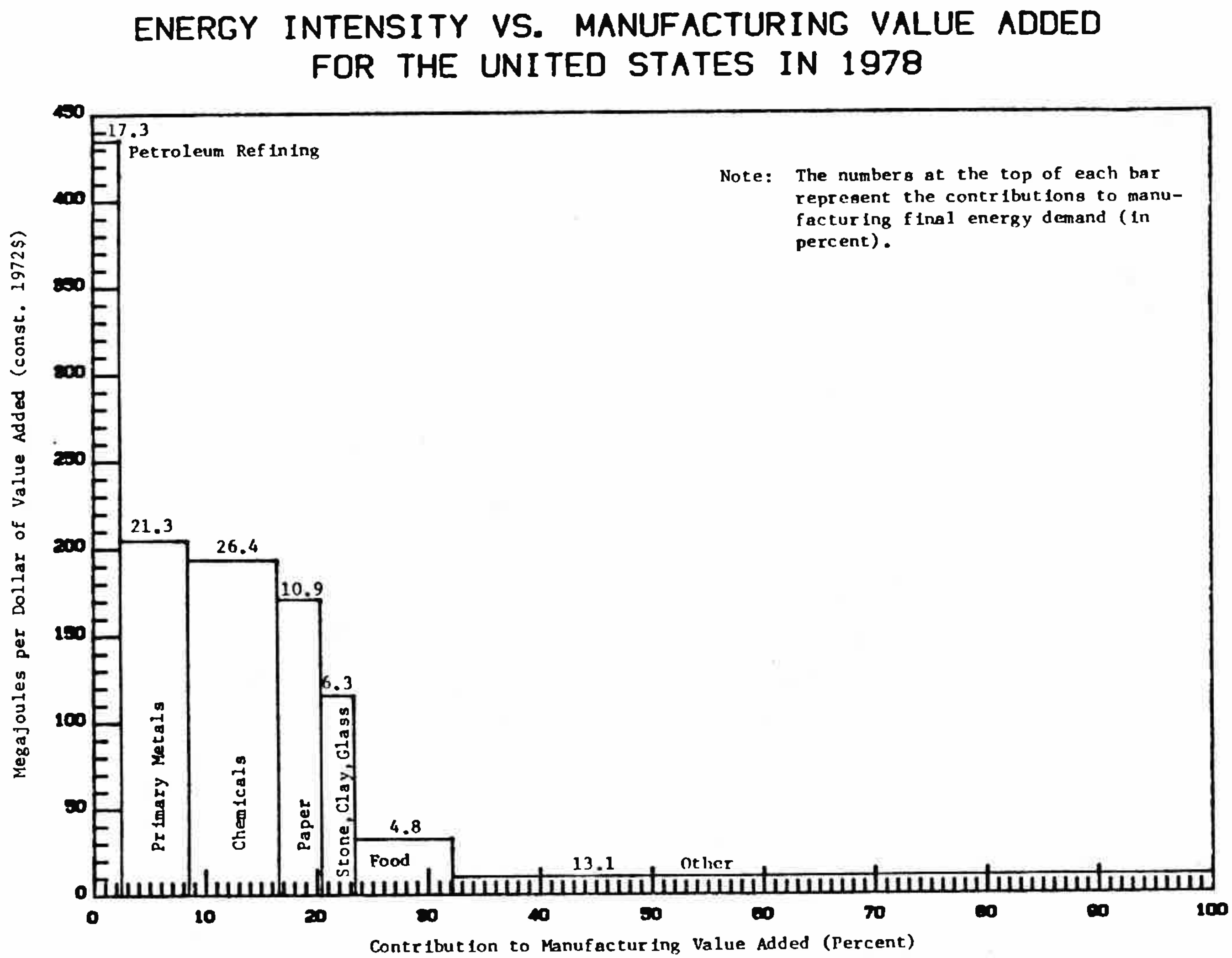

Figure 3. Final-Energy Intensity vs. GPO for U.S. Manufacturing Industries in 1978. (Figure is from reference 1.)

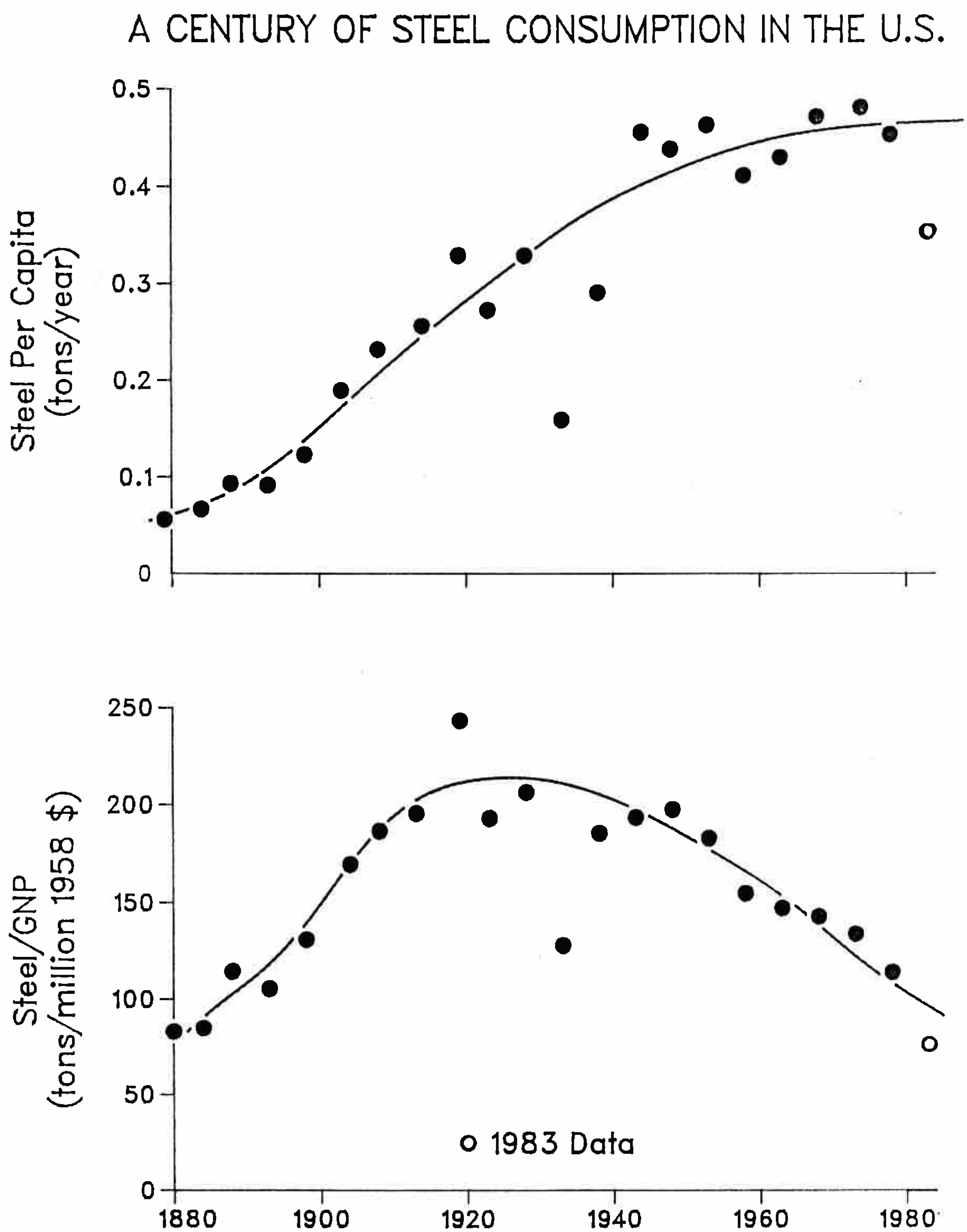

Figure 4. See reference 3.

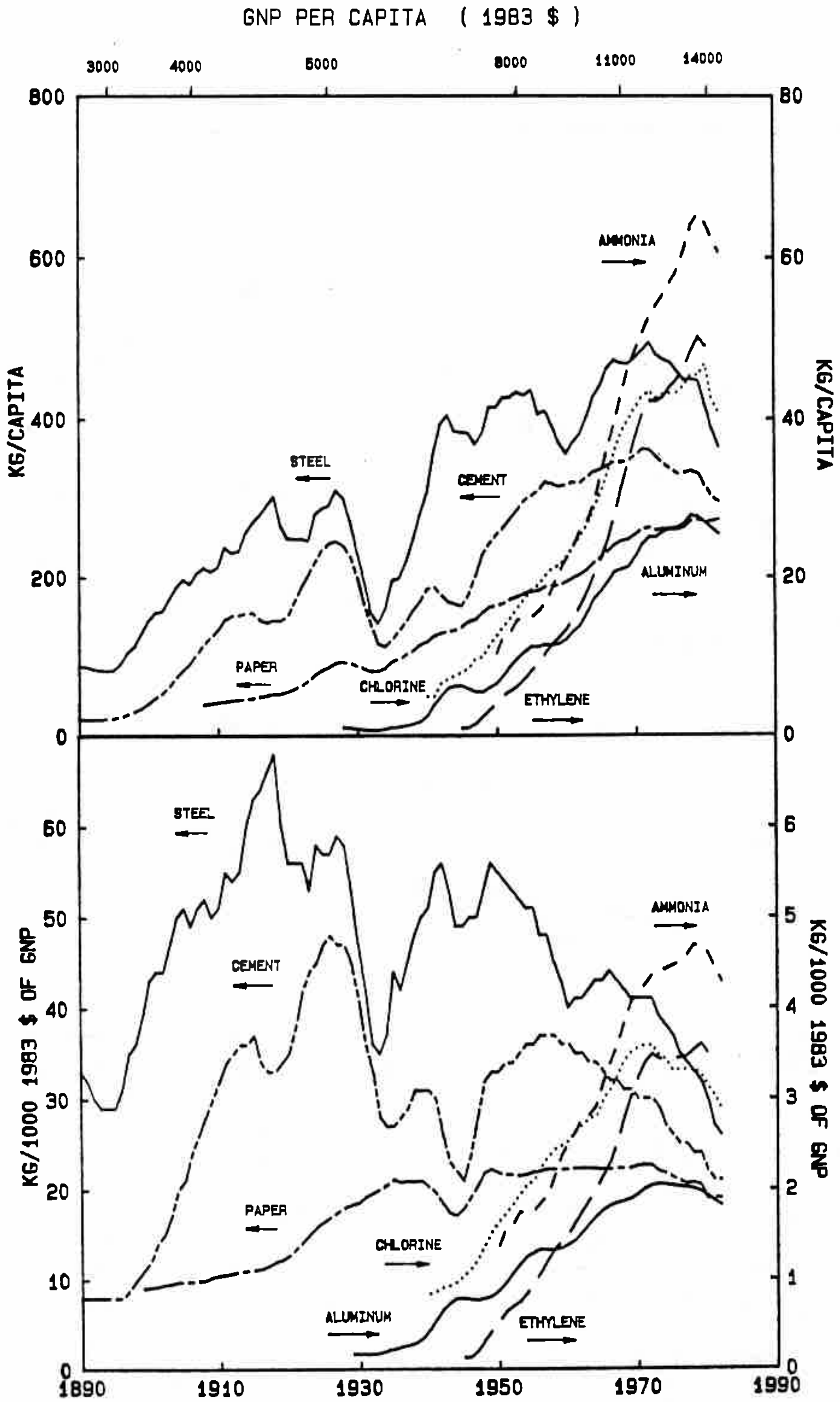

Figure 5. <u>U.S. Trends in Materials Consumption</u>.

All data are apparent consumption -- production plus net imports. Data on final consumption -- apparent consumption plus net imports of material embodied in finished products -- are generally not available. However, because the U.S. economy is relatively closed, the difference between apparent and final consumption is generally not significant. In the case of steel, for example, final consumption in the U.S. was within ± 1-2% of apparent consumption from 1962 to 1979. (See final citation in reference 3.) See Fig. 10 for further discussion of the ethylene data. Five-year running averages are plotted. This figure is adapted and updated from reference 1.

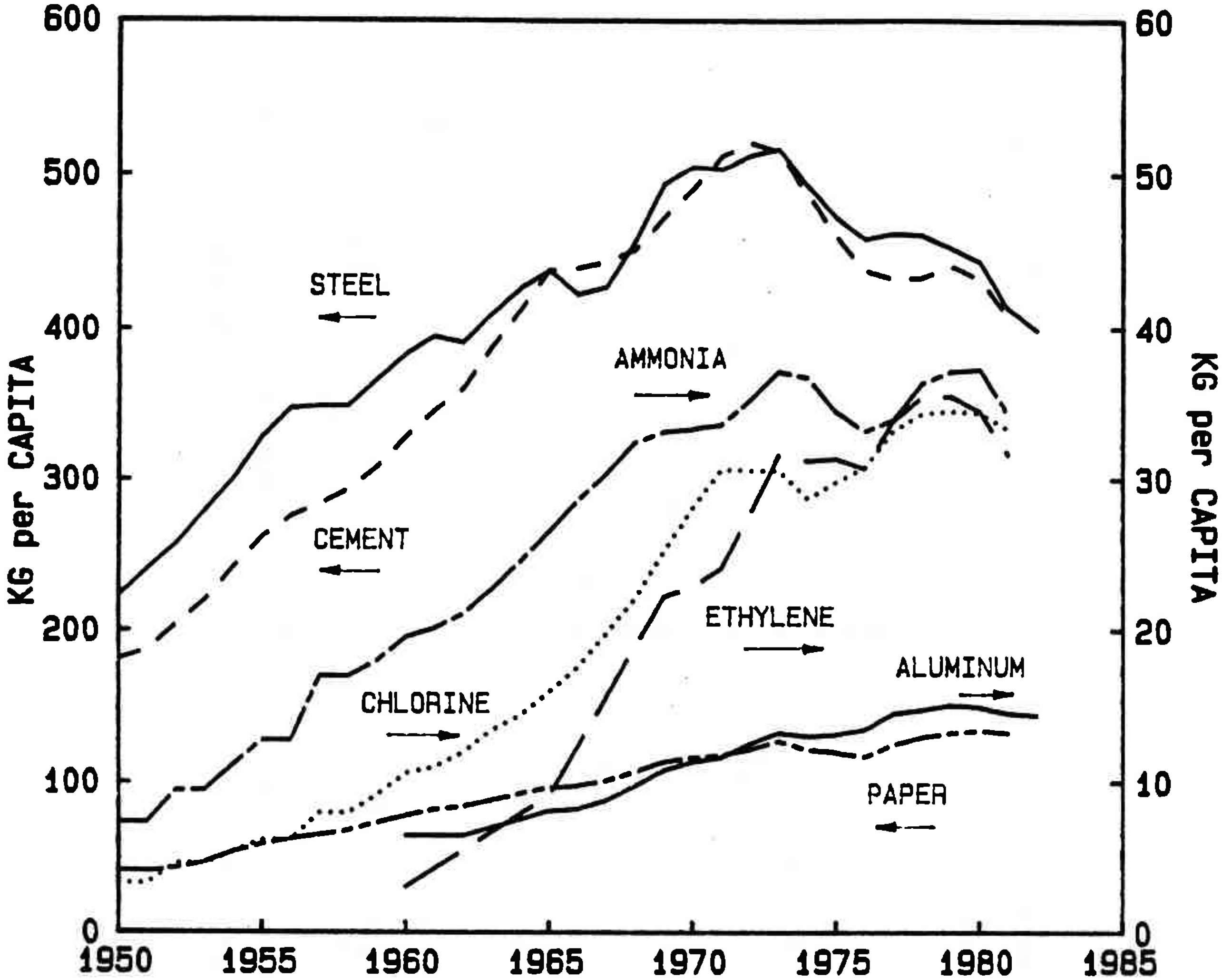

Figure 6. Trends in Materials Consumption in Western Europe.

Plotted are 3-year running averages of aggregates of apparent consumption data for Germany, France, and the U.K. The ammonia data include only Germany and France. Data sources are as follows. **Steel:** 1950-51, U.N. Statistical Yearbook, United Nations, New York, 1952; 1952-80, Iron and Steel, 1952-1982, Eurostat, Office of Official Publications of the European Communities, Luxembourg, 1983; 1980-83, Quarterly Iron and Steel Bulletin, Vol 3, Eurostat, Statistical Office of the European Communities, Luxembourg, 1984. **Cement:** 1950-72; The Cement Industry in Europe, Organization for European Economic Cooperation, Paris, various years; 1973-1982, Annual Bulletin of Housing and Building Statistics for Europe, Economic Commission for Europe, United Nations, New York, various years. **Paper:** 1950-1972, Pulp and Paper, Organization for Economic Cooperation and Development, Paris, various years; 1973-1982, Quarterly Statistics of Pulp and Paper, Vol. 3, OECD, 1984. **Aluminum:** Aluminum Statistical Review, Aluminum Association, Washington, D.C., various years. **Chemicals:** Annual Review of the Chemical Industry and (in earlier years) Market Trends and Prospects for Chemical Products, Economic Commission for Europe, United Nations, New York, various years. **Population:** 1950-63, U.N. Demographic Yearbook, United Nations, New York, 1970; 1964-82, National Accounts, 1953-1982, OECD, Paris, 1984; 1983, Main Economic Indicators, OECD, Paris, March 1985.

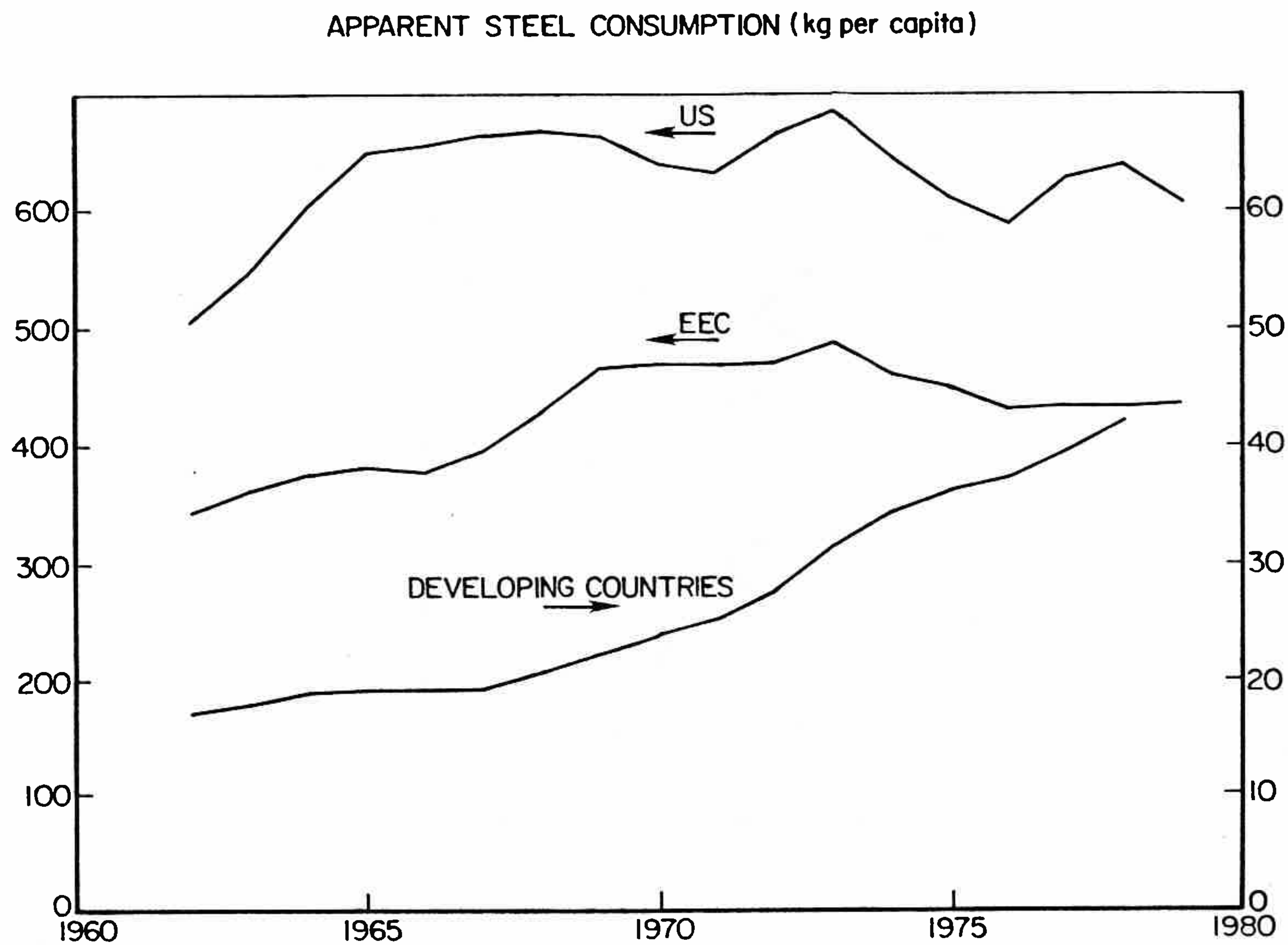

Figure 7. <u>Apparent Steel Consumption in Three Regions of the World</u>.

Data are from <u>U.N. Statistical Yearbook</u>, United Nations, New York, various years.

THE PERCENT SHARE HELD BY IMPORTS IN THE MINIMILL MARKET AND IN THE TOTAL MARKET

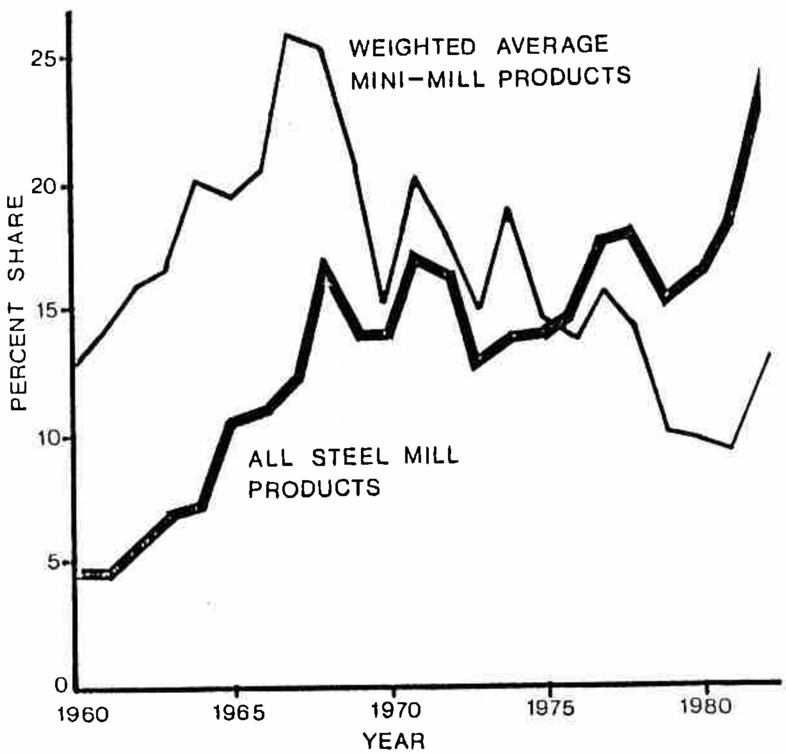

Figure 8. From reference 8.

THE MAXIMUM FRACTION OF A PRODUCT MARKET WHICH CAN BE SERVED WITH STEEL CONTAMINATED WITH COPPER

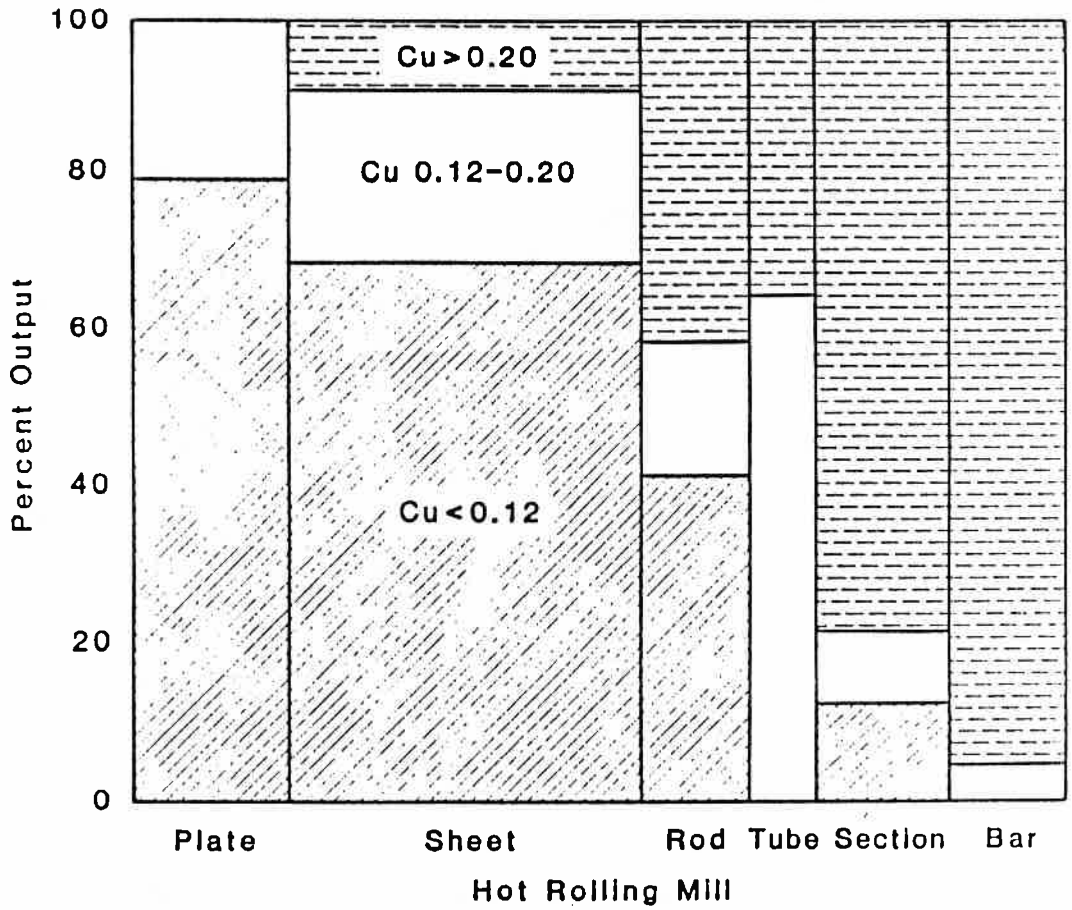

Figure 9. From reference 11.

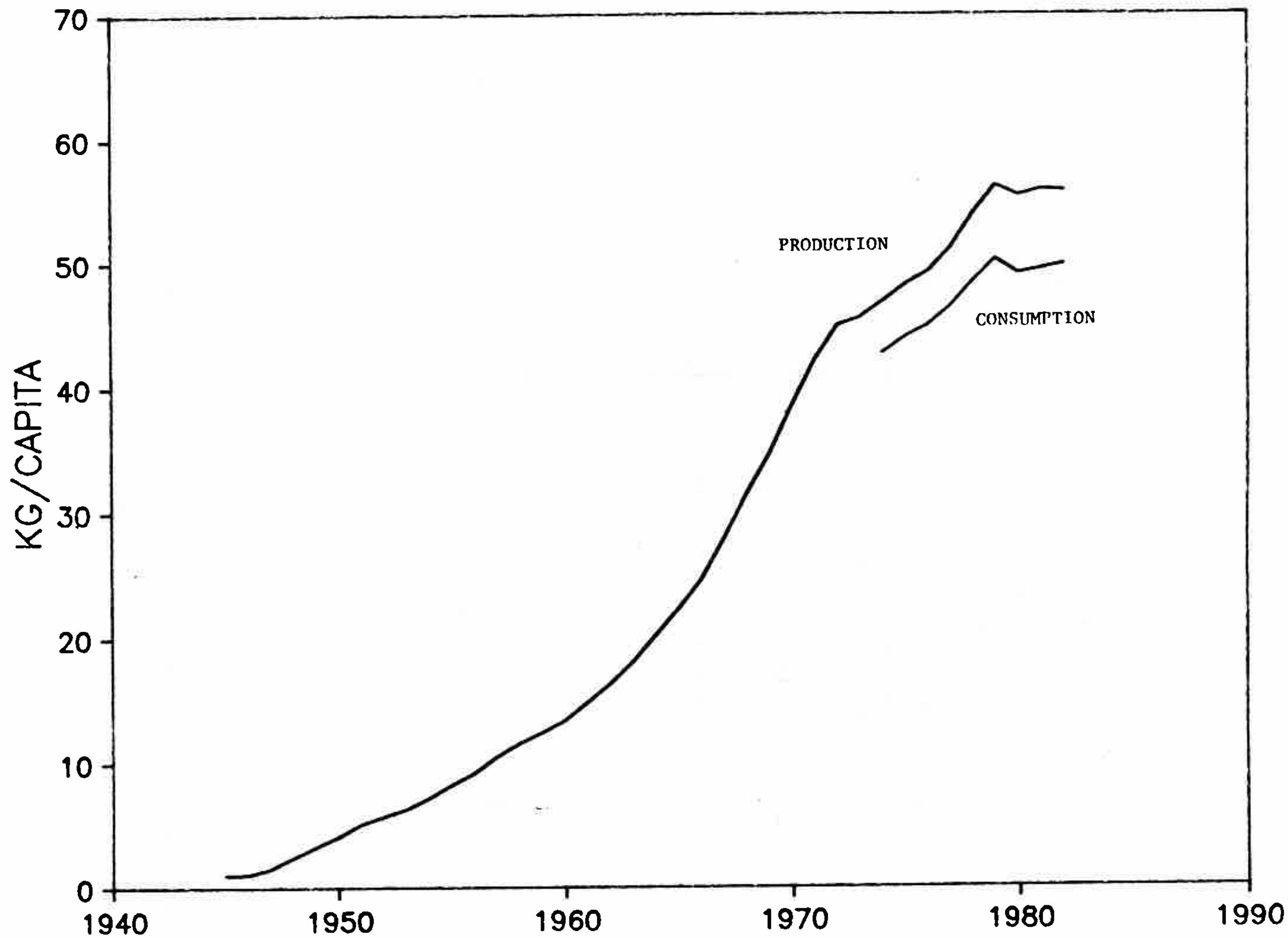

Figure 10. U.S. Ethylene Production and Consumption.

Production data are from "Facts and Figures of the Chemical Industry," Chemical and Engineering News, annual statistical review of the chemical industry, various years. Consumption was determined by multiplying production by (1 - \$E/\$S), where \$E and \$S are the values of net exports and total shipments, respectively, of organic chemicals and plastics & rubber, data for which are taken from U.S. Industrial Outlook, 1985, Bureau of Industrial Economics, Department of Commerce, Jan. 1985.

THE RATIO OF PRODUCTION OF ALUMINUM FROM SCRAP

TO PRODUCTION OF PRIMARY ALUMINUM

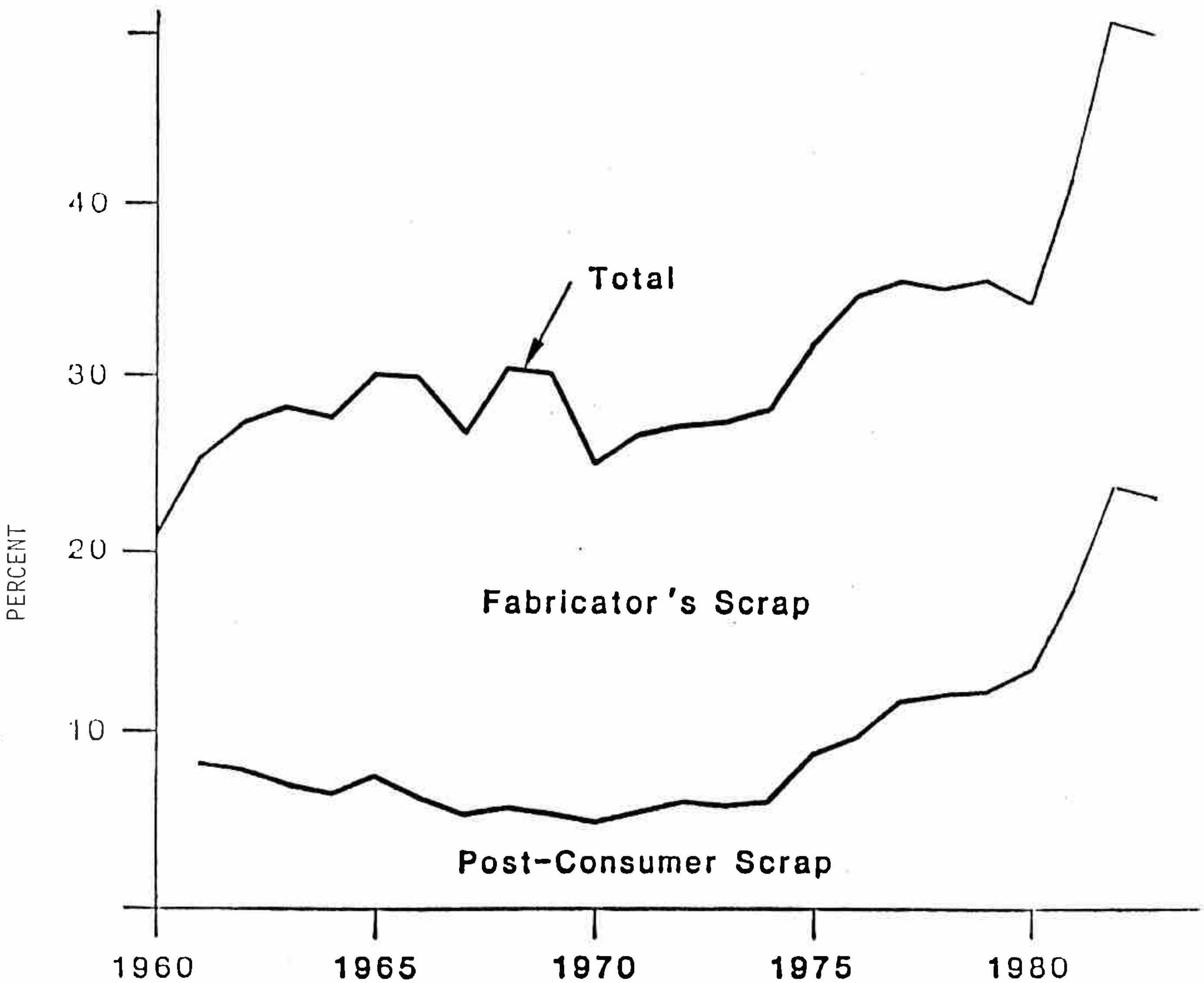

Figure 11. Data are from reference 15.

MATERIALS IN THE UNITED STATES ECONOMY

1967 : 100

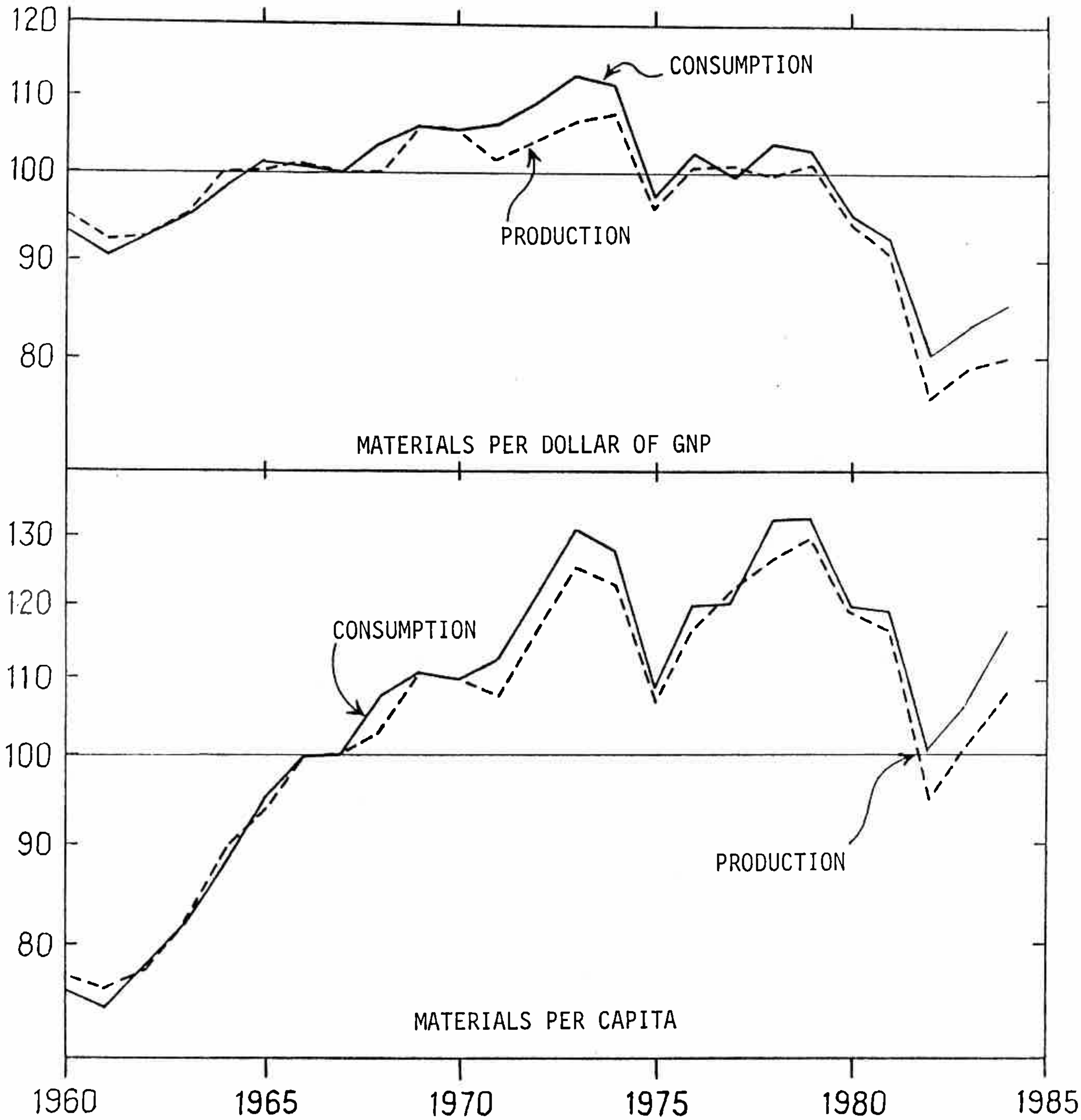

Figure 12.

References

1. Eric D. Larson, Robert H. Williams, and Andrew Bienkowski, "Material Consumption Patterns and Industrial Energy Demand in Industrialized Countries," Center for Energy and Environmental Studies Report No. 174, Princeton University, Princeton, New Jersey, December 1984.

2. Simon Kuznets, Secular Movements in Production and Prices, Houghton Mifflin, 1930; Donella H. Meadows et al., Limits to Growth, New American Library, 1972, p. 110 ff.; W.W. Rostow, The World Economy: History and Prospect, Univ. of Texas, 1978; Wilfred Malenbaum, World Demand for Raw Materials 1985 and 2000, E/MJ Mining Information Services, McGraw Hill, 1978; Wm. S. Humphrey and Jos. Stanislaw, "Economic Growth and Energy Consumption in the United Kingdom, 1700-1975," Energy Policy, p. 29, March 1979; Louis A. Girifalco, "Malthus Modified," Journal of Resource Management and Technology 12, p. 191, 1983.

3. Apparent consumption of steel mill products (net shipments plus net imports) from American Iron and Steel Institute from 1954. In earlier years, production of mill products from Historical Statistics of the U.S. from Colonial Times to 1970, series P270. Five year averages are shown except for the latest points for 1983. The curves are for illustration; they are not the result of explicit computations. Indirect trade in steel products, e.g. imports of steel in the form of cars, are not included. The net indirect imports of steel increased the trend in consumption about 0.5 percent per year during the '60s and '70s. Thus, e.g., total steel consumption by final consumers was about 10% higher in 1980 relative to 1960 than shown. Committee on Economic Studies, International Iron and Steel Institute, "Indirect Trade in Steel -- 1962 to 1979," I.I.S.I. Brussels, 1982.

4. Charles Kindelberger, Foreign Trade and the National Economy, Yale University Press, 1966.

5. Ray Vernon, Two Hungry Giants, The United States and Japan in the Quest for Oil and Ores, Harvard University Press, 1983.

6. Industrial Investment in Energy Efficiency: Opportunities, Management Practices, and Tax Incentives, Alliance to Save Energy, Washington, 1983.

7. Robert W. Crandall, The U.S. Steel Industry in Recurrent Crisis, The Brookings Institution, 1981.

8. Donald F. Barnett and Louis Schorsch, Steel: Upheaval in a Basic Industry, Ballinger, 1983.

9. William T. Hogan, World Steel in the 1980s: A Case of Survival, Lexington, 1983.

10. Julian Szekely, "Some Thoughts on Steelmaking Technology in the Year 2000," Steel Times, p. 551, Nov. 1983.

11. C. C. Schueppert, "How Far Can the Minimill Go in Terms of Product," The British Steelmaker, vol. 48, p. 10, June 1982.

12. The International Energy Annual, Energy Information Administration, U.S. Department of Energy, DOE/EIA 0219, 1983.

13. Facts and Figures of the Plastics Industry, The Society of the Plastics Industry, New York, 1980.

14. "HPI Construction Boxscore," Hydrocarbon Processing, Feb., Oct. 1983.

15. Aluminum Statistical Review, The Aluminum Association, Washington, 1981.

16. Rhea Berk, et al., Aluminum: Profile of the Industry, Metals Week, McGraw-Hill Inc., 1982.

17. Prices for electricity to aluminum smelters are from direct contact with utilities, from Battelle Pacific Northwest Laboratories, "The Direct Service Industries: Their Contributions to the Northwest Power Systems and Economy," a report prepared for Direct Service Industries Inc., Portland, Oregon, April 1983; and from "Aluminum: A Vital U.S. Industry in a Highly Competitive World Market," The Aluminum Association, Washington, 1983.

18. Marc H. Ross and Arthur H. Purcell, "Decline in Materials Intensiveness: The U.S. Pulp and Paper Industry," Resources Policy, V. 7, p. 235, Dec. 1981.

19. Statistics of Paper, Paperboard and Wood Pulp, American Paper Institute, New York, 1983.

20. Office of Technology Assessment, Energy from Biological Processing, U.S. Congress, 1980; Harold E. Young, "Forests are Finite, of Variable Biomass Productivity, But Renewable," Proceedings of the Ninth Cellulose Conference, Part II, p. 549, Journal of Applied Polymer Science, Applied Polymer Symposium 37, 1983.

21. See, e.g., Table 738, Statistical Abstract of the United States, 1984. The growth of this value-added measure tracks that of GNP. We take its growth rate to be 0.83 times that of GNP.

22. Marc Ross, "Industrial Energy Conservation and the Steel Industry," presented at the Soviet-American Symposium on Energy Conservation, Moscow, June 6-12, 1985. The energy-weighted rate of decline of the energy intensity of materials manufacture is taken to be 2.1% per year. Fuel used as feedstock in organic chemicals manufacture is not included in this evaluation so that part of industrial energy use is included in the "other" sector of our 2-sector model.

23. We choose 1984 as the base year for our projection. We believe that this year is not too close to the recession year 1982 to be misleading. As shown in Fig. 12, there was rapid growth in 1983 and 1984, but it seems unlikely that 1985 will show similar growth.

24. We assume a 1.4% per year decline in primary metals production from virgin materials, relative to consumption, for an overall 25% decline 1984-2000. We assume a 1.0% per year decline in basic chemicals and petroleum refining, relative to consumption, for an overall 15% decline. Net exports of paper are assumed to grow at 0.2% per year relative to consumption. An energy-weighted combination of these growth rates implies a decline of 1% per year.

25. Energy Information Administration, US Department of Energy, State Energy Price and Expenditure Report 1970-1981, DOE/EIA-0376(81), June 1984.

26. Marc Ross, "Industrial Energy Conservation and the Steel Industry," presented at the Soviet-American Symposium on Energy Conservation, Moscow, June 6-12, 1985, and William Larsen & Marc Ross, "Energy Conservation and Petroleum Refining," prepared for the Soviet-American Symposium on Energy Conservation, Moscow, June 6-12, 1985.

27. Francois Crouzet, The Victorian Economy, Columbia University Press, 1982, Chapter 12.

APPENDIX

The energy-weighted indices of production (based on primary energy used by manufacturers in 1980) were defined for the following materials:

Paper: 26.3P

Steel: 22BF + 15SMP

Aluminum: 190PAL + 37MP + 15ALA

Chemicals: 6500CI(t)/CI(1980)

Petroleum Refining: 0.633CRS

Cement: 6.02C

where

P = paper and board production in million short tons (American Paper Inst.)

BF = blast furnace production in million short tons (American Iron & Steel Inst)

SMP = steel mill products (shipments corrected for inventory changes) in million short tons (AISI and Survey of Current Business)

PAL = primary aluminum production in million short tons (Aluminum Assn)

MP = aluminum mill products (excluding imported products) in million short tons (Aluminum Ass'n.)

ALA = alumina production in million short rons (Minerals Yearbook)

CI = chemicals index determined in Marc Ross, "Measuring Trends in the Production of Chemicals," Univ. of Michigan Report (1984)

CRS = crude oil processed by U.S. refineries in million barrels

C = cement production in million short tons

The unit for the production indices so defined is trillion Btu. The results are shown in Table A1.

TABLE A1

ENERGY WEIGHTED PRODUCTION INDICES

	Steel	Aluminum	Paper	Chemicals	Petroleum Refining	Cement
1984	2192	1162	1870	6440	2794	485
1983	2076	1013	1765	5807	2701	430
1982	1795	923	1607	5414	2719	393
1981	2980	1228	1694	6426	2880	437
1980	2731	1280	1677	6500	3114	462
1979	3409	1279	1698	6718	3387	517
1978	3428	1220	1636	6166	3406	515
1977	3127	1154	1583	5997	3374	482
1976	3298	1082	1538	5468	3102	448
1975	3009	959	1344	4932	2874	420
1974	3695	1238	1557	5493	2804	499
1973	3832	1171	1561	5303	2874	527
1972	3375	1054	1512	5037	2709	509
1971	3044	995	1399	4521	2589	483
1970	3403	996	1360	4382	2513	459
1969	3554	999	1393	4210	2456	483
1968	3295	857	1319	3718	2388	470
1967	3233	829	1225	3514	2267	441
1966	3386	792	1228	3264	2182	450
1965	3354	726	1143	2833	2089	445
1964	3213	667	1077	2551	2040	433
1963	2739	603	1016	2255	2007	413
1962	2505	566	975	2035	1943	393
1961	2429	489	925	1861	1891	380
1960	2548	499	892	1765	1869	370

The energy-weighted index of materials consumption is defined in terms of the following materials:

Paper = 26.3P

Steel = 33.8S

Aluminum = 200A

Chemicals = IKC × 6500 CI(t)/CI(1980)

Petroleum Refining = IKP × 0.633 CRS or 0.098 PCQ after 1972

Cement = 6.02, as for production

where

P = "new supply" of paper and board in million short tons (Table 1, American Paper Inst. Statistics)

S = "apparent supply" of steel mill products in million short tons (Table 1A, AISI Annual Statistical Report)

A = "net shipments, U.S. consumers" in million short tons (Shipment Table, Aluminum Association, Aluminun Statistical Review)

CI = chemical production index (see production index).

IKC = net import correction for chemicals industry in form of (1 + (net import $)/sales $) from Survey of Current Business

IKP = 1 + (net import petroleum products)/(production U.S. refiners)

CRS = crude runs to stills in million barrels

PCA = petroleum consumption in quads, Monthly Energy Review

C = cement production in million short tons

The unit for the consumption indices is trillion Btu. The results are shown in Table A2.

TABLE A2

ENERGY WEIGHTED CONSUMPTION INDICES

	Steel	Aluminum	Paper	IKC	Chemicals	Petroleum Refining
1984	3191	1130	2036	.964	6208	3038
1983	2822	1056	1880	.953	5534	2945
1982	2582	912	1707	.940	5089	2963
1981	3563	1203	1791	.933	5995	3129
1980	3219	1201	1768	.925	6012	3352
1979	3886	1384	1840	.934	6275	3638
1978	3943	1368	1786	.952	5870	3720
1977	3666	1227	1693	.951	5703	3638
1976	3417	1160	1634	.962	5260	3447
1975	3009	912	1426	.964	4755	3208
1974	4043	1280	1668	.963	5290	3279
1973	4142	1376	1710	.955	5064	2314
1972	3602	1149	1632	"	4811	3107
1971	3464	987	1511	"	4318	2907
1970	3281	895	1472	"	4185	2807
1969	3472	982	1510	"	4021	2687
1968	3639	933	1429	"	3605	2544
1967	3165	829	1353	"	3356	2427
1966	3346	845	1371	"	3117	2326
1965	3398	758	1270	"	2706	2208
1964	2972	659	1196	"	2436	2144
1963	2664	591	1130	"	2154	2096
1962	2456	536	1095	"	1943	2029
1961	2275	464	1043	"	1777	1927
1960	2417	412	1013	"	1685	1931

Cement as in production table.