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Trends in the Consumption of Energy-Intensive Basic Materials in Industrialized Countries and Implications for Developing Regions

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ABSTRACT

The tonnage consumption of most energy-intensive bulk materials (steel, cement, aluminum, chlorine, ammonia, etc.), as well as of other energy-intensive materials (copper, lead, tin, zinc, etc.) has saturated in industrialized countries. This phenomenon appears to be explained by three main factors: improvements in the efficiency of material use, saturation of bulk markets for materials, and shifts in consumer preferences at high income levels to less materials-intensive goods and services. This paper reviews these trends and underlying causes and discusses their implications for the evolution of basic materials processing industries and industrial energy use in developing regions of the world, where materials use levels are still small by comparison to industrialized countries.

1. INTRODUCTION[1]

Industry accounts for 50% of total energy use in developing countries and in Eastern Europe [3] and 30-40% in most OECD countries. Within industry, the largest energy users are the basic-materials processing industries: steel, paper, cement, non-ferrous metals, glass, chemicals, food, textiles, etc. For example, in Brazil the energy-intensive basic materials industries account for over 85% of industrial energy use [4]

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[1] Sections 1 through 3 of this paper draw heavily on [1] and [2].

and over 70% of industrial electricity use [5]. In the US, these industries account for nearly 60% of industrial energy use. Thus, understanding the prospects for the development of basic materials industries is important to understanding possible future industrial energy use. Since the *demand* for materials is what fundamentally drives the evolution of these industries, the analysis here focusses on the consumption, rather than production, of materials. Earlier analyses of trends in basic materials consumption in industrialized countries [1,2] are reviewed and updated here, and the analysis is extended to consider implications of these trends for developing countries and European economies in transition.

2. BASIC MATERIALS CONSUMPTION IN THE U.S. AND WESTERN EUROPE

A key point of departure for an analysis of the impact of basic materials consumption patterns on energy use is the recognition that physical units (kilograms) are more useful indicators than economic measures (dollars). Economic measures are often not sufficiently disaggregated to identify shifts in consumption patterns to higher value-added products, and physical units are more directly related to energy.

Historical data on the tonnage consumption of steel in the US give a clear illustration of the typical lifecycle observed for many basic materials in industrialized countries (Fig. 1). When steel was first introduced into the US economy, its use grew more rapidly than both GNP and population. Steel made an important contribution around the turn of the century to infrastructure building (factories, railroads, buildings, etc.). The rapid growth in demand drove innovations such as the Bessemer process, which reduced costs and encouraged continued expansion. At the end of the heavy infrastructure-building phase (reached in the 1920s in the US) steel began playing a smaller relative role in the economy, causing consumption per unit of GNP to peak and begin a long monotonic decline (except in the late 1930s, when it rose following the precipitous and anomalous drop caused by the Great Depression). Steel use per dollar of GNP in the US is now at about the same level as it was in 1880.

In contrast to steel use per dollar of GNP, per-capita consumption continued to grow beyond the 1920s (Fig. 1), as markets for steel consumer goods such as cars and household appliances continued to develop. With increasing affluence, these consumer markets approached saturation in the 1950s, causing per-capita growth in demand to slow. No new bulk markets developed, and by the late 1960s, per-capita steel demand leveled off. Demand fell through the 1970s. Today's demand level is at 3/4 of the peak reached in the 1970s. Saturation in per-capita demand at higher income levels has been elegantly noted elsewhere, e.g. in a cross-country, multi-material analysis by

Strout [6] (Fig. 2) and more recently in cross-country correlations for steel and cement prepared by the US Office of Technology Assessment [7] (Fig. 3).

Similar matured-lifecycle behavior is evident for most large-volume basic materials, both traditional materials such as steel and cement and more recently introduced materials such as ammonia, chlorine, and aluminum, as shown for the US in Fig. 4 and Western Europe in Fig. 5. For all these materials, consumption per unit of GNP peaked in the early 1970s (in the 1920s in the case of cement), followed by a leveling off of per-capita demand. The major exceptions to these trends are paper and ethylene (a major building block for plastics and other chemicals), both of which are showing strong per-capita growth. In both the US and Europe, however, paper consumption per unit of GNP appears to have peaked already and is currently flat or slowly declining. Ethylene consumption per unit of GNP is climbing after a hiatus in the 1970s. In Europe aluminum use is also growing in both per-capita and per-unit-GNP terms. (Per-capita use in Europe is about 25% lower than in the US today.)

3. UNDERLYING CAUSES

An analysis of the underlying causes of the observed trends in consumption strongly suggest that fundamental structural changes are occurring in industrialized economies away from intensive use of basic materials [1,2,8]. The trends can be attributed to three primary factors: more efficient use of material in a given application, saturation of markets, and shifting consumer preferences at high per-capita income levels.

Design changes that involve more efficient or longer-lived use of materials have come about in some cases to help cope with increased production costs, in some cases as part of the process of technological innovation, and in other cases due to competition from lighter, stronger and/or durable substitutes. Rising energy costs in the 1970s and 1980s have been an important consideration [9]: natural gas for fuel and feedstock accounts for about 3/4 of the cost of producing ammonia; electricity accounts for about 1/3 of the cost of making aluminum. A good example of technological innovation leading to improvement in strength and durability is the locomotive. The weight to power ratio for a typical locomotive in the early 1800s was 1300 kg/kW. It declined steadily to less than 20 kg/kW by 1980 (Fig. 6). Competition from substitutes has been visible in the composition of automobiles. The use of specialty steels, such as stainless and high-strength steel, in the average US-made car tripled from about 3% of total material content in 1975 to 9% in 1990, while total steel use fell from 1139 kg (65% of total material) to 711 kg (54%) [10]. The use of plastics and composites doubled from 4% of total material use in 1975 to 8% in 1990.

Even for materials that are continuing to show demand growth, efficiency improvements are evident. For example, plastic films are thinner and stronger today, in part due to the introduction in the late 1970s of linear low-density polyethylene to replace low-density polyethylene [8]. The demand for ethyl benzene, used largely to produce styrene, a basic component of the styrene-butadiene rubber used in tires, was significantly affected by both the downsizing of cars and the introduction of radial tires in the 1970s: tires weighed an average of 25% less in 1983 than in 1972, and radial tires last about twice as long as ordinary bias-ply tires [8]. There has been general downward pressure on the basis weights of paper (the weight of a fixed number of sheets of standard size), since area (not volume) is of greatest interest to end users, while production and transport costs are directly related to volume [11]: over the last decade, the average density of bleached paperboard (widely used for food and pharmaceutical packaging) has dropped 15-20% owing to process innovations that have yielded higher strength-to-weight ratios [1]. External factors have also been driving down basis weights. For example, increasing postal rates have contributed to lower weights for No. 5 coated groundwood paper used for magazines and direct-mail advertizing [12].

The second factor underlying the trends in Figs. 4 and 5, the saturation of traditional markets for bulk materials, is especially evident for cement and steel. Infrastructure building is essentially complete. In the case of the US, railroads are shrinking, and highway construction slowed in the 1960s as the interstate road system was completed. The only area where demand for steel and cement continues to be relatively strong is the market for commercial buildings, which is not a large one for these materials. Furthermore, ownership of basic consumer goods is also saturating due to affluence: most households are now equipped with stoves, refrigerators, washers, and cars. Thus, in infrastructure-related and consumer-goods markets, the function of new production is largely to replace rather than expand the size of the stock. And even where replacement occurs, the replacements often involve less material use than the objects they replace. For example, steel girders used in repairs to the Eiffel Tower in the mid-1980s weighed 1/3 of those they replaced [13].

Saturation is also seen in major markets for some of the more recently-introduced materials. For example, in the US the use of nitrogen fertilizer, which accounts for about 80% of ammonia produced, increased more than six-fold from 1955 to 1980. Future growth is likely to be relatively slow because most cropland is already being fertilized and the current average application rate per hectare, if increased, would produce diminishing returns in increased yield (Fig. 7).

The third factor behind the trends in Figs. 4 and 5 is a relatively more recent shift in consumer preferences accompanying higher income levels. Marginal income is being spent not on the same, but rather on a wide range of products characterized by a low ratio of material content to price (items such as home entertainment systems, personal computers and software, and financial, medical, recreational and other services). The shift to less materials-intensive goods is also apparent in the markets for capital goods--the factories and machineries needed to make consumer goods. For the product areas in which growth is most probable, production is likely to be less capital-intensive, and/or the capital less materials-intensive, than in the past. For example, in 1977 the cost of construction and machinery for factories to produce a dollar's worth of electronic computing equipment was roughly one-third less than that required to produce home appliances. Meanwhile, a dollar's worth of electronic computing equipment involves less than one/fourth as much steel and two-thirds as much aluminum as the production of machine tools and dies for metal forming [1].

4. IMPLICATIONS FOR DEVELOPING REGIONS

Industrial and Economic Development

In contrast to the situation in industrialized countries, the consumption of most basic materials in developing countries, Eastern Europe, and the USSR is low (Table 1). Thus, strong growth in demand for such materials can be expected in these regions, particularly in developing countries. For example, steel production in China grew 9% per year from 1975 to 1987 [14]. In the early-1980s, paper demand was being projected to grow to the year 2000 by 5.9% per year in Latin America, 7.3%/yr in developing countries of Asia, 8.5%/yr in Africa, 5.1%/yr in the USSR and only 1.9%/yr in North America and 1.4%/yr in Western Europe [15].

Because material demand levels are low in developing countries, most basic materials processing industries there are in a state of relative infancy. Thus, these countries are largely in a position to choose their industrial development path. Although they might wish to choose the path followed by industrialized countries, the situation in which developing countries find themselves today is fundamentally different from that of industrialized countries at a comparable stage in their development. This has both positive and negative implications for the development of industries--the basic materials processing industries in particular--and economies more generally.

On the positive side, there have been many technological developments that should make it possible for developing countries to achieve higher standards of living with less capital, energy, and materials use than in industrialized countries. The evolution of refrigerator technology provides a case in point. Since the 1940s, the cost of manufacturing refrigerators has fallen by a factor of five in the US (Fig. 8a) and electricity use in refrigerators has fallen substantially since the early 1970s after steadily climbing from 1950 (Fig. 8b). The average material content of refrigerators per unit of service provided has also been falling.[2] Such trends should allow developing countries to manufacture and use refrigerators much earlier in their development than was the case for industrialized countries. Simultaneously, energy and material demands could be kept lower. That higher standards of living can be achieved in developing countries with less energy use than has been the case in industrialized countries is suggested more generally by a comparison of maximum energy intensities (total energy use per unit of GNP produced) reached by different industrializing market economies. These intensities have been falling over time, as shown in Fig. 9. This trend is extrapolated in Fig. 9 to suggest a possible future trend for developing countries. The present and formerly planned economies of the USSR, China and Eastern Europe have already reached much higher energy intensities than industrialized market economies, reflecting extreme inefficiencies in these economies rather than the supply of higher levels of services [16]. The high energy intensities imply a large potential for efficiency improvements.

On the negative side, the slowing demand for basic materials in industrialized countries means that the rate of demand-driven technological innovation in these industries in these countries will slow. (For example, only one new large integrated steel mill has been built in the US in the last 25 years [14].) Historically such innovation has reduced energy intensity by 1% to 2% per year [17] while increasing overall productivity. Moreover, the tightening industrialized-country markets for basic materials will be more difficult to penetrate, so that developing countries wishing to tap industrialized-country markets will need cost-cutting innovation more than ever. Additional factors make the need for innovation in developing countries that much

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[2] For example, the typical weight of 450-480 liter (16-17 ft^3) refrigerators made by Frigidaire (a major US appliance manufacturer), fell from 114 kg in 1970, to 107 kg in 1980, to 91 kg in 1990 (private communication from W. Willison, Plant Manager, Frigidaire Refrigerator Division, Greenville, Michigan, October 1991). The weight reduction has been due in part to the replacement of batt insulation with rigid foam. The latter provides some structural support, permitting a decrease in steel support material. Also, plastic has largely replaced steel used in the inside liner.

greater: energy is no longer cheap, capital is more expensive, and sensitivity to the environment has increased.

Energy Use in the Basic Materials Processing Industries

Many of the technologies used in basic materials production in developing countries today are dated. (See Table 2 comparing energy use in three industries.) Typically, they represent energy and capital-intensive technology developed in industrialized countries during periods of cheap energy and low-cost capital. Even the best process technologies available in industrialized countries today are sub-optimal from energy use, capital cost, and/or environmental impact perspectives. For example, the energy used in the production of most basic materials is still far higher than that needed according to laws of thermodynamics. In fact, the production of most basic materials, with the exception of metals reduction, requires little or no energy in principle [9].

<u>More Energy-Efficient Components</u>. A good starting point for reducing energy use in basic materials production is the systematic application of more efficient component technologies to today's best process technologies. A particularly important class of technologies relates to motor drive systems, since motor drive accounts for the largest share of electricity use in industry generally and in the basic materials industries in particular, as illustrated by Tables 3 and 4 for Brazil and Thailand, respectively. Pump and fan systems are particularly big industrial electricity users, as indicated in Table 5 and as discussed by Nilsson [18]. The variable speed drive is another important technology, the use of which can produce large, cost-effective electricity savings [19].[3]

In industrialized countries, the potential for cost-effectively reducing electricity use in motor-drive and other applications at existing industrial sites is very large relative to reductions that have been achieved to date [9,20,21]. This is an auspicious fact for developing countries, since many of the technologies that make economic sense in retrofit applications will be even more attractive in new installations [22]. At expected growth rates of industries in developing countries, new equipment will account for most of the industrial energy use within a decade. Thus, paying close attention to

[3] It is interesting to note that most variable speed motor applications in heavy industries in India today rely on direct-current synchronous motors (private communication from S. Anand, Tata Energy Research Institute, New Delhi, October 1991). Replacing these with alternating-current motors and electronic variable speed drives would substantially reduce the material content needed to achieve the same variable control capability.

the use of energy-efficient equipment in new installations can improve the competitiveness of industries in developing countries while lowering energy supply needs.

Installing high-efficiency equipment need not mean increasing technology imports. Many developing countries have the capability to manufacture energy efficient component technologies, as illustrated by Fig. 10, which shows that the performance of both standard-efficiency and high-efficiency motors made in India are comparable to those in the USA. There are often strong economic reasons for manufacturing locally, e.g. lower labor and shipping costs. Unfortunately, the less efficient equipment is often sold domestically and more efficient models are exported. For example, one Brazilian company assembles and exports high-efficiency air conditioners containing imported compressors and sells in Brazil less efficient air conditioners containing domestically made compressors [23]. Brazilian compressor manufacturers have the capability to produce high efficiency compressors, but have not had sufficient incentive to re-tool for this.

Fundamental Process Change. Fundamental process changes will often yield even more substantial benefits than upgrading equipment piecemeal, and the benefits will often go beyond energy alone [17,24]. Innovations which raise overall productivity tend, for example, to decrease energy consumption more than "add-ons" designed solely to reduce energy use of existing technologies. Three examples illustrate this point.

1. Direct steel making. Steel is conventionally made by first producing iron from pelletized ore in a blast furnace by adding coke produced from coal. Steel is then formed by removing carbon and impurities from the iron while in molten form in a basic oxygen converter. A new process, direct steel making, has been proposed to greatly simplify steel production [25]: powdered ore, coal, and flux would be injected into the molten bath of iron to achieve reduction of the iron oxides, removal of impurities, and thus direct steel production. If it is successfully developed, this process would use only one reactor vessel, capable of continuous operation, in place of four major batch processes: pelletization of the ore, production of coke from coal, blast furnace, and basic oxygen converter. It is not clear that energy use per tonne of steel with this technology would be much lower than with *best* conventional technology,[4] but direct steel making would achieve comparable performance for a much lower capital

[4] The energy required for iron and steel making with *best* practice today is about twice the minimum predicted by thermodynamics for the reduction of iron oxides [14]. Since this minimum is unachievable in practice, today's *best* technology is probably close to the most energy-efficient achievable.

investment and the elimination of environmental problems associated with coking [14]. Pilot-scale efforts to develop this technology are ongoing in several industrialized countries.

2. Gasification chemical recovery. In producing kraft pulp for paper making, black liquor, the lignin-rich byproduct of cellulose extraction from wood, is used as a source of both energy and chemicals. In kraft mills today, black liquor is burned in Tomlinson recovery boilers, a technology commercialized in the early 1900s. Steam is raised (usually to drive a steam turbine cogeneration system) and a chemical smelt rich in sodium carbonate and sodium sulfide is produced. The smelt is processed to recover the chemicals for re-use in the cellulose extraction stage. The large scale, high capital costs, smelt-water explosion risks and sulfur pollution problems associated with Tomlinson boilers, as well as an interest in increasing the electrical output of pulp-mill cogeneration systems have motivated efforts to develop black liquor gasification systems for energy and chemicals recovery. In systems under development, the black liquor is gasified to produce a low-heating value gas and a dry or liquid chemical effluent [26,27]. Since smaller volumes of gas are involved than the combustion products from a Tomlinson boiler, sulfur cleanup is simplified. Smelt-water explosion risks are eliminated because the gas can be burned in a separate boiler. Alternatively, the gas can fuel a gas turbine cogeneration system. This option would substantially raise the electricity-to-heat production ratio of a mill's cogeneration system compared to a conventional steam-turbine-based system. This could permit mills to export electricity produced in excess of on-site needs or to reduce use of purchased electricity [28]. Also, since the cost of gasifier-gas turbine systems would be less scale sensitive than Tomlinson boiler/steam turbine systems, smaller plants could be built more economically.

3. Charcoal steel production. Another example of technological innovation that has already become widely used in Brazil is charcoal-based steel production. This case illustrates the effective use of indigenous resources to competitively produce world-class steel, while also addressing important social and economic issues in Brazil. The Brazilian steel industry has adapted the charcoal-steel technology last commonly seen in the industrialized world in the late 1700s. Industrialized countries abandoned this technology with the discovery that coal-based factories could be built considerably larger than charcoal-based units, thereby taking advantage of economies of scale resulting from decreased labor costs relative to total production costs [29]. While coal facilities were generally more capital-intensive, this disadvantage was out-weighed by rising charcoal prices resulting from increased wages paid to workers in the charcoal-making industry. The combination of higher labor and lower capital intensity of charcoal-based steel making, together with the additional employment generated in charcoal production, makes this choice well-suited to the Brazilian context.

Rather than importing metallurgical coal, Brazil devotes some of its large land resources to Eucalyptus plantations to supply the charcoal industry. Most charcoal is made in brick beehive kilns in Brazil today--not the most efficient technology available, but more labor-intensive and 1.8 to 2.8 times less capital-intensive than advanced retort systems [30]. The steel industry has actively worked to develop more efficient beehive kilns and higher yielding species of Eucalyptus. A tar recovery process is now integrated into the beehive technology, raising overall energy conversion efficiencies to near 60%, and test plantations have produced wood yields as high as 98 m^3/ha-yr (46 dry tonnes/ha-yr), more than triple the average in Brazil today [30].

5. CONCLUSIONS

The per-capita demand in industrialized countries for most energy-intensive basic materials is stagnating or declining, while consumption relative to GNP is far below its historical peak and declining. Evidence indicates that developing regions will not need to trace this history. In particular, developing countries will not need to reach the same levels of per-capita consumption to achieve an equivalent or higher standard of living. This would translate into lower industrial energy demands than in industrialized countries at similar stages in their development. Nevertheless, as the basic materials industries grow in developing regions, the demands they will place on energy supply, on capital markets, and on the environment will be large in absolute terms. Thus, it will be important for these regions to adopt process technologies with lower energy use, lower capital or total cost, and/or less environmental impact whenever possible. Such technologies will also often raise overall productivity. Thus, such technologies would help developing regions compete in industrialized-country markets that will be tighter due to slowing demand growth.

To encourage the building of energy-efficient industrial infrastructures, it would be important in the developing regions to adopt policies that encourage use of best available technologies, both at the component level (motors, pumps, fans, etc.) and the overall process level, whenever retrofits are considered or a new factory is built. Special attention should be given to new plant construction, since this will account for the large majority of the industrial energy-using capital stock in developing countries a decade from now. At a minimum, R&D policies need to be structured to promote good judgments when selecting among existing technologies. The Technology, Information

Forecasting and Assessment Council recently established by the Department of Science and Technology in India [31] is a good example of an effort to promote wise technology choice.

Furthermore, with slowing materials demand in industrialized countries, the pace of innovation in these countries in the relevant production processes can be expected to slow. Historically, such innovation has reduced process energy intensities by 1 to 2 percent per year. While some major process innovations are in the pipeline in industrialized countries, developing countries must become the new arena for innovation to ensure continued improvements in the longer term. It seems clear, however, that even a continuation of the historical rate of energy intensity reduction will be inadequate to enable developing countries to raise their material standard of living to industrialized country levels without running up against serious energy supply and environmental constraints.

Thus there is a clear need to accelerate the rate of improvement in industrial energy efficiency. In this regard, it would be important to put in place in developing regions research and development policies that encourage technological innovation. An important idea to consider here is "technological leapfrogging," whereby new technologies are deployed first in developing countries [32]. This approach has been discouraged by most national and international policies. For example, the traditional policy of the World Bank in this area was succinctly stated by one official in the mid-1980s [33]:

> ...In the world of energy, as in many other areas, (the Bank's) role is not to create innovative technical solutions, or to help countries to gamble on new processes, but to identify the best practices that have been fully proven in a developing country situation, and encourage their wider adoption where merited by circumstances...

The World Bank's recent establishment of the Global Environment Facility represents an explicit and welcome recognition of the need for greater technological innovation. More such initiatives are needed nationally and internationally.

Since many countries may not be able to support significant R&D activities on their own, basic-materials processing R&D centers might be established in different geographical regions, drawing on financial resources and expertise from a number of countries that would share the benefits of the research. Such centers could help sustain innovation in basic materials processing technology. Innovation would directly benefit industries in the participating countries and may also be welcomed by non-participating countries, since many innovations will lead to reduced pressure on global energy resources and on the global environment.

Table 1. Per-capita consumption of five energy-intensive basic materials in different countries.

	Steel[a]	*Cement*[b,f]	*Paper*[c,f]	*Aluminum*[d]	*Ethylene*[e,f]
Developing Countries					
Argentina	95	202	31.1	4.1	na
Brazil	99	173	26.0	2.6	na
China	64	173	14.6	0.74	1.39
India	20	46	2.6	0.41	na
Mexico	93	311	40.6	0.79	na
East Europe & USSR					
Czechoslovakia	703	665	81.5	7.0	38.9
(East) Germany	581	748	88.5	13.4	20.4
Hungary	307	391	66.5	18.7	30.5
Poland	422	426	39.5	3.6	7.9
USSR	582	483	35.4	6.3	10.9
OECD Countries					
France	259	423	149	16.1	43.2
(West) Germany	457	414	210	27.7	54.6
Japan	582	587	222	29.5	37.7
UK	259	252	169	11.4	21.2
USA[g]	417	276	307	26.6	64.4

(a) 1987 apparent steel consumption per capita from [34].

(b) 1987 production data from [34].

(c) 1989 apparent consumption from [35].

(d) Apparent consumption per-capita from [36] in 1988 for developing countries and 1989 for East Europe and USSR. Apparent consumption per capita from [37] in 1988 for France, Germany, and the UK, in 1989 for Japan, and in 1990 for the USA.

(e) Apparent consumption data from [38] for China and the USA (1990 data) and Hungary and the USSR (1989 data). All other countries' data are for 1987 from [39]. na indicates not available.

(f) Population data from [40].

(g) Steel and cement numbers do not correspond to those shown in Fig. 4 due to different data sources.

Table 2. Specific primary energy consumption (kg oil equivalent per tonne of product) in selected industries.

Industry	*Model Plant*[a]	*USA Average*[b]	*Developing Countries*
Steel[c]	550	775	900-1015
Pulp & Paper[d]	690	990	1200-1500
Cement[e]	105	145	150-170

(a) Estimated achievable with best currently-used technology.

(b) Mid-1980s.

(c) Energy use per tonne of rolled mill product at an integrated mill. The developing country estimates are for Chinese plants [14]. Energy use in Chinese plants has been corrected to make it comparable to USA numbers by accounting for the very large production of cast-iron products in China, lower use of recycled scrap from outside the steel industry, and much less ambitious shaping and treating of final products. The low estimate is for "key" plants (large units producing 75% of all steel), and the high estimate is an average of all plants in China. The upper estimate also characterizes energy use at one of the more efficient integrated steel mills in India in 1987 [41].

(d) Energy use per tonne of paper, including energy from process by-products. The model plant and US average are from [42] for the pulp and paper mix of the US. The developing country range is from [43] for integrated pulp and paper mills in India.

(e) Model plant and US average are from [44]. The developing country estimates are from [45] for the late 1970s in the Philippines (lower estimate) and India (higher estimate).

Table 3. Industrial electricity end use in Brazil in 1984 [5].[a]

		Fraction of subsector total for each end use (%)					
Industry	*Percent of total industrial electricity consumption*	*Motor*	*Process heat*	*Direct heat*	*Electro-chemical*	*Light*	*Other*
Basic Materials	**72.6**	**32.1**	**8.6**	**23.1**	**7.8**	**1.4**	**0.3**
Nonferrous metal	20.9	32	1	35	32	1	--
Iron and steel	12.4	1	--	98	--	1	--
Chemicals	11.9	79	5	4	9	3	--
Food/beverage	9.0	6	78	16	--	1	3
Paper and pulp	6.5	87	8	2	--	3	--
Textiles	5.3	89	4	1	--	5	--
Ceramics	3.9	65	--	34	--	1	--
Cement	2.7	91	--	6	--	3	1
Other	**27.4**	**16.9**	**1.4**	**8.9**	--	**0.6**	--
Mining/pelletization	5.6	50	--	49	--	1	--
Steel alloys	4.8	7	--	92	--	1	--
Other	17.0	76	2	16	--	5	1
TOTAL	**100.**	**49**	**10**	**32**	--	**2**	--

(a) -- indicates not available or not applicable. Total industrial electricity use was 105 terawatthours.

Table 4. Estimated industrial electricity use by sector and end use in Thailand in 1985 [46].

Industry	*Percent of total industrial electricity consumption*	**Fraction of subsector total for each end use (%)** *Motor*	*Air conditioning*	*Process heat*	*Space heat*	*Lighting & other*
Basic Materials	**87.1**	**63**	**9**	**7**	**2**	**7**
Textiles	24.2	66	26	0	2	6
Food	24.1	77	8	1	3	11
Non-ferrous metals	13.5	77	0	15	0	8
Chemicals	13.1	77	3	6	3	11
Ferrous metals	7.4	36	0	56	0	7
Paper	4.8	97	0	0	0	3
Wood	1.6	92	0	1	0	7
Other	**12.9**	**8**	**0**	**1**	**0**	**3**
Metals fabrication	6.6	55	0	9	4	32
Other	6.3	75	0	10	0	15
TOTAL	**100.**	**71**	**9**	**8**	**2**	**10**

Table 5. Estimated industrial electricity consumption in India by end use in 1989/90 [47].

End use	*Percent of GWh use in industry*
Motors	**73.7**
Pumping	14.1
Fans	8.3
Air compressors	3.6
Refrigeration	3.6
Other	44.1
Lighting	**11.8**
Incandescent	0.3
Fluorescent	6.7
Mercury vapor	1.2
Sodium vapor	0.8
Electrolysis	**11.0**
Chlor-alkali	3.0
Aluminum	8.0
Electric arc furnaces	**2.8**
Other	**3.6**

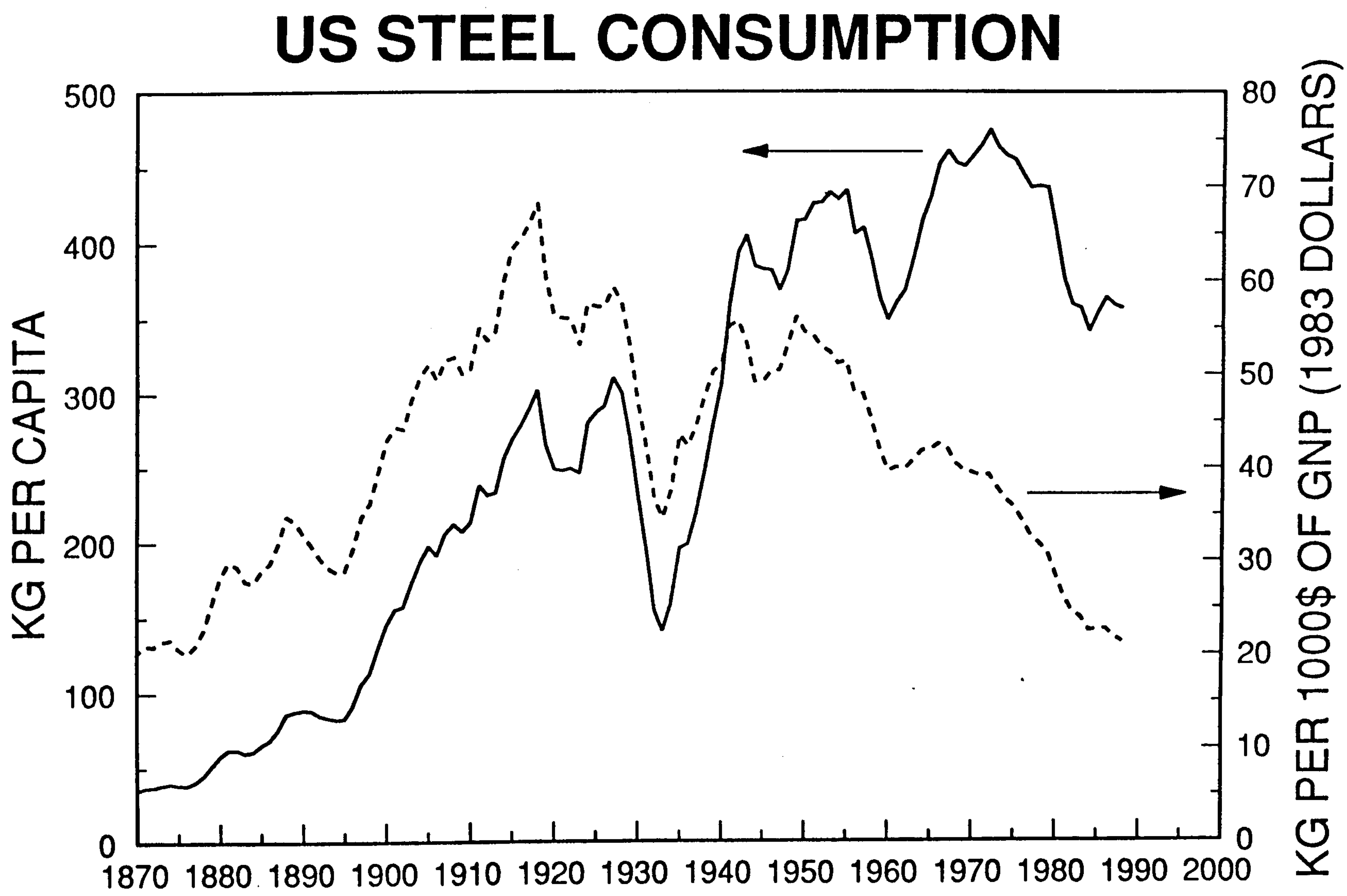


Fig. 1. One hundred and ten years of steel consumption data for the United States illustrate the characteristic lifecycle of a material. Annual data have been averaged over running 5-year periods. The last year for which data are included is 1990. The data are apparent consumption of steel mill products (net shipments plus net imports). Steel embodied in finished products traded (e.g. imported automobiles) is included in the data beginning in the 1960s. This indirect consumption raised steel use about 2% in the late 1970s [48], but a negligible amount prior to the early 1960s. See [1] for original data sources. The large drop in consumption during the 1930s was caused by the Great Depression.

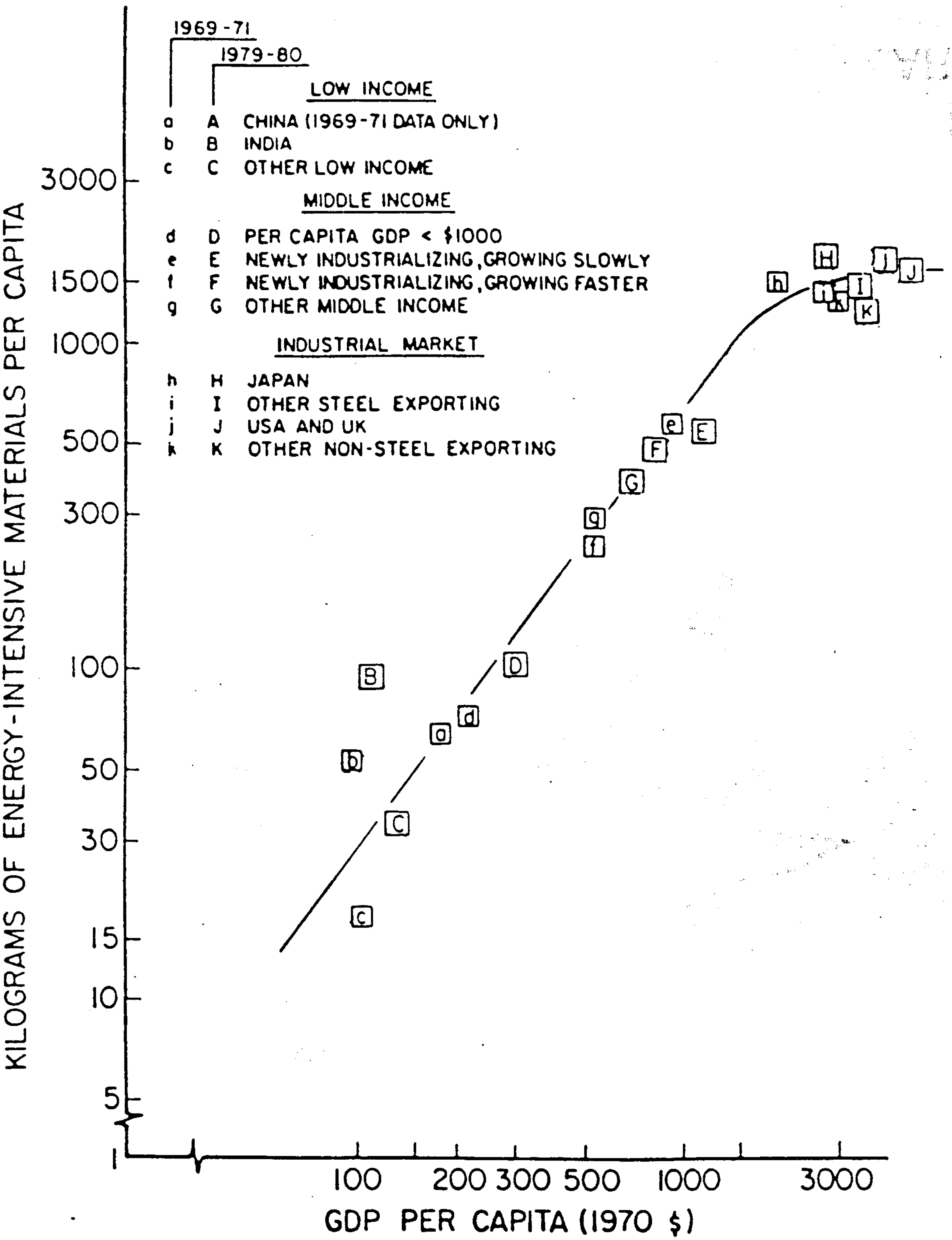


Fig. 2. Materials consumption per capita by region versus per-capita GDP for the following materials: pulp, paper and paperboard, chemical fertilizers, hydraulic cement, steel products, primary copper, primary lead, primary zinc, primary aluminum, and primary tin [6]. These materials have been aggregated using fixed energy-of-manufacture weights (energy per tonne of material) characteristic of US industry in 1967. Countries included here are as follows for: c,C, Bangladesh, Indonesia, Pakistan and Zaire; d,D, Colombia, Egypt, Morocco, Nigeria, Peru, the Philippines and Thailand; e,E, countries with less than 3% annual per-capita GDP growth (Argentina, Chile, South Africa Customs Union and Spain); f,F, Brazil, South Korea, Mexico, Portugal and Yugoslavia; g,G, Algeria, Greece, Malaysia, Turkey and Venezuela; i,I, Australia, Austria, Belgium-Luxemburg, Canada, Finland, France, (West) Germany, Italy, the Netherlands and Sweden; k,K, Denmark, New Zealand, Norway and Switzerland.

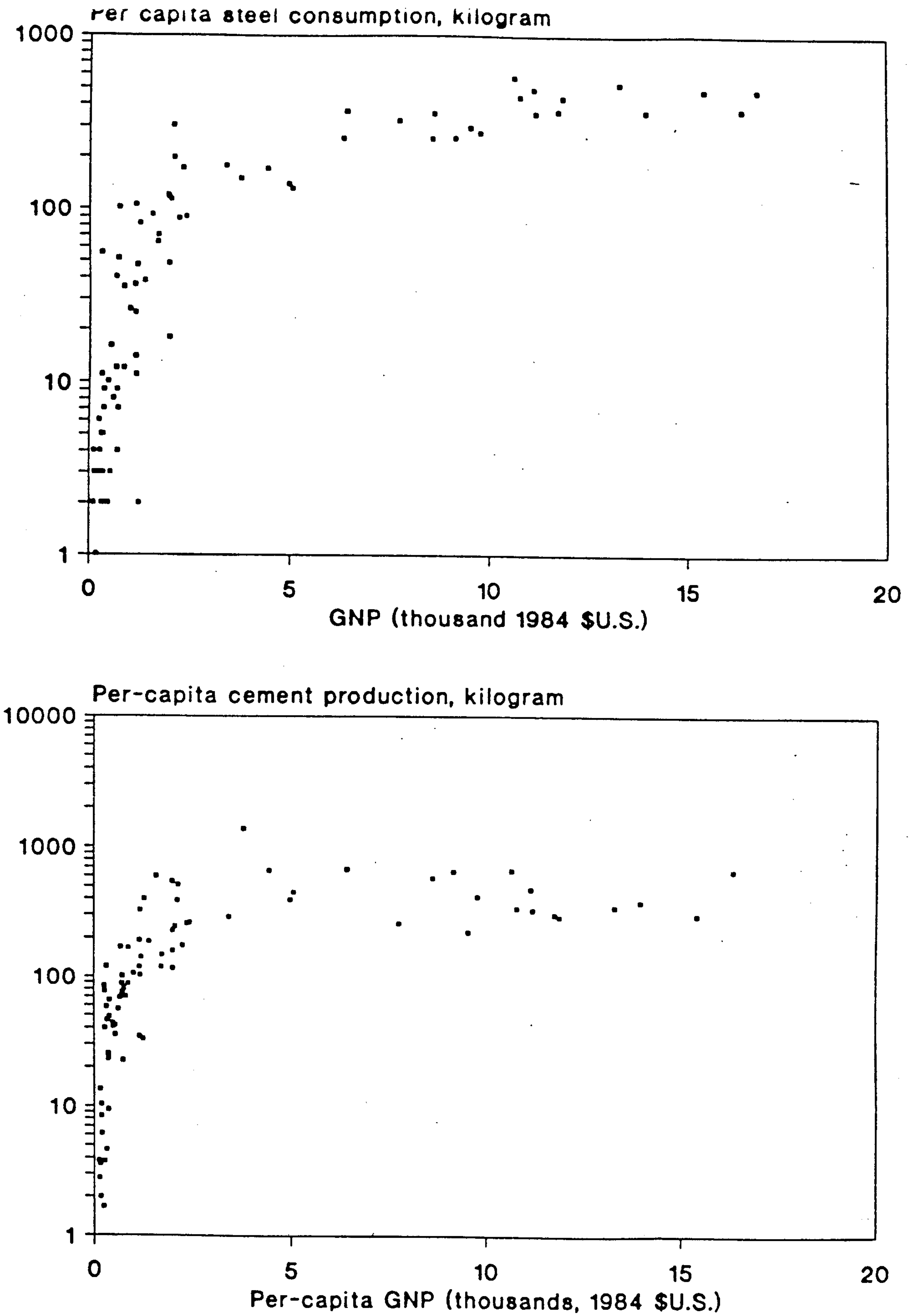
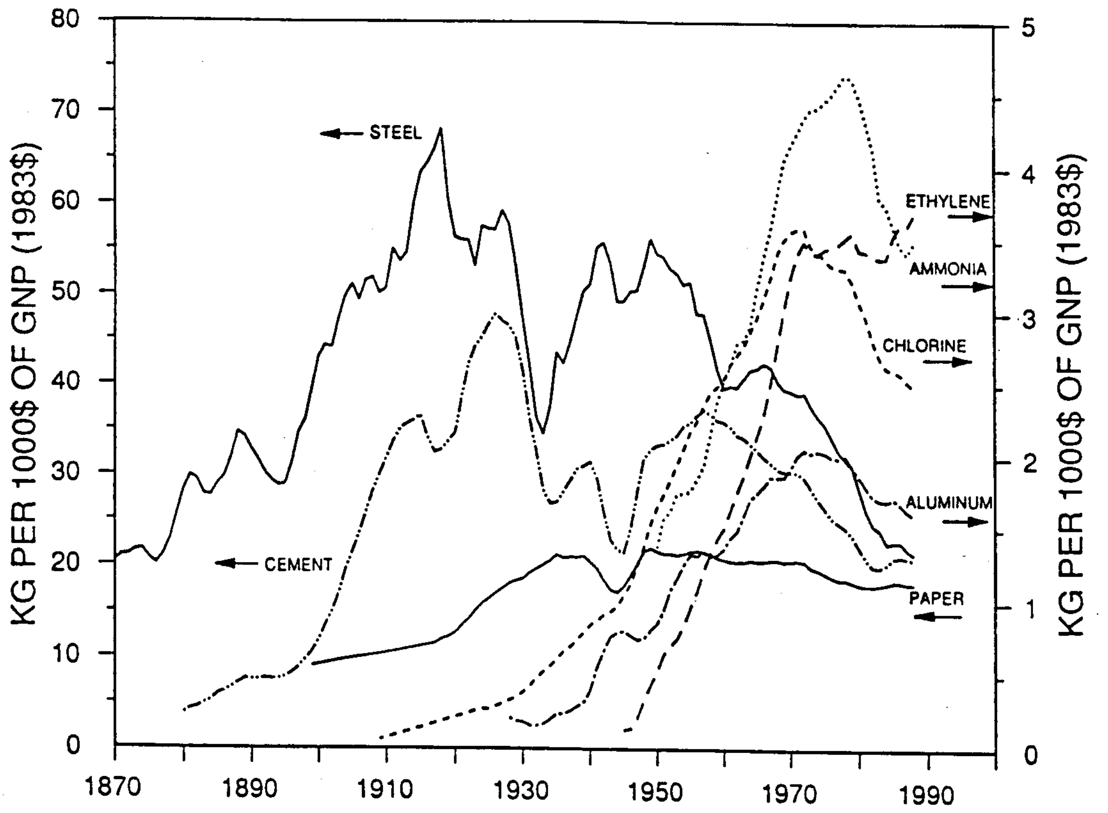


Fig. 3. Per-capita steel consumption and per-capita cement production versus GNP, with each point representing a different country [7].



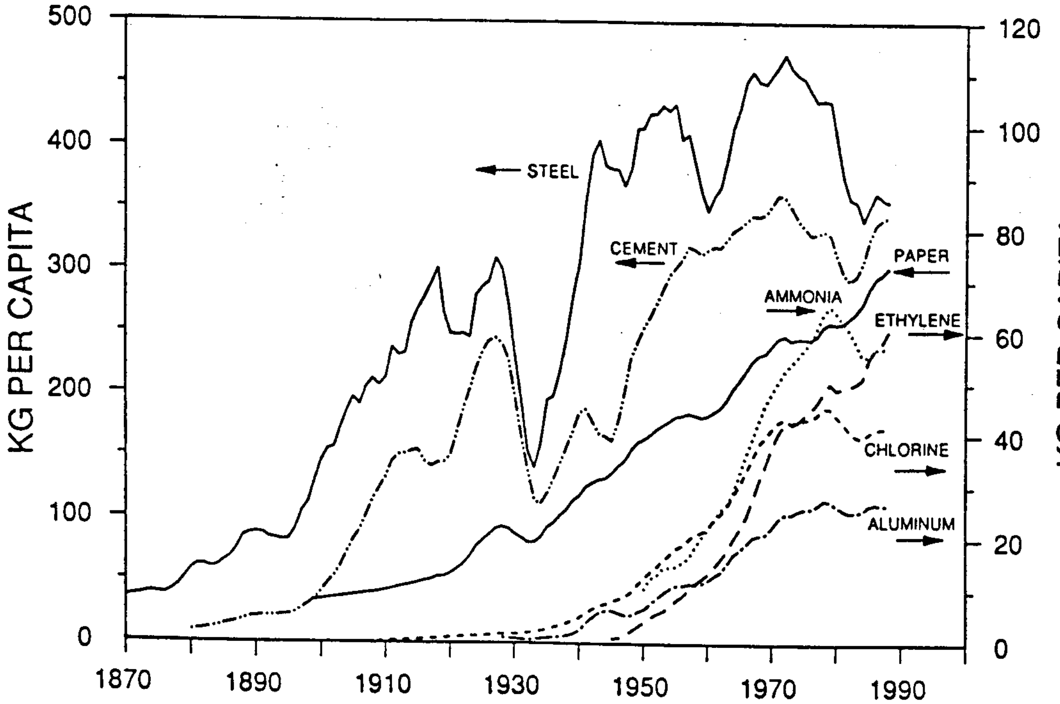


Fig. 4. Trends in the apparent consumption of energy-intensive bulk materials in the US. Shown are five-year averages, including data through 1990. This is an update of Fig. 4 in [1]. See [1] for original data sources.

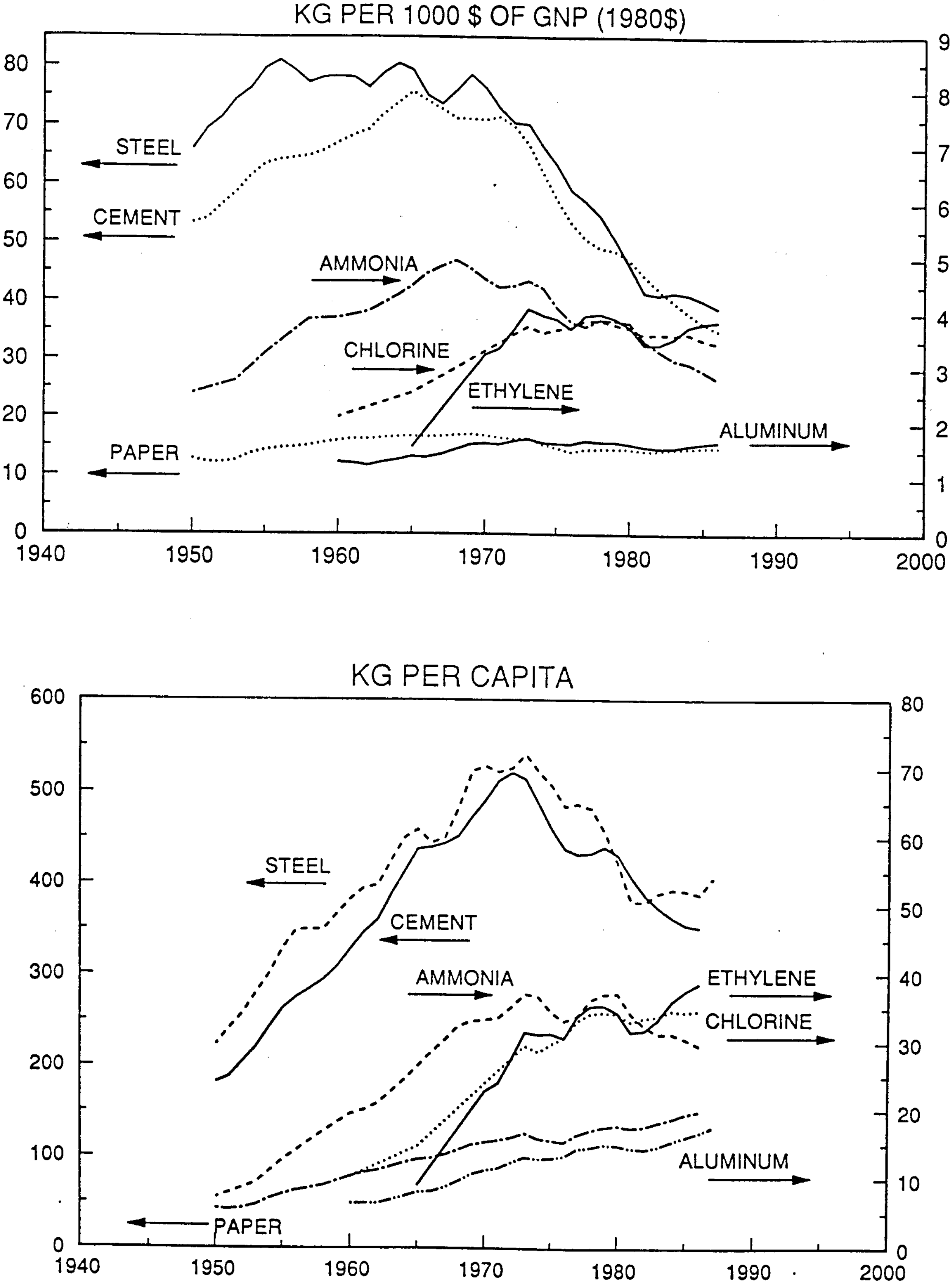


Fig. 5. Trends in the apparent consumption of energy-intensive bulk materials in Western Europe. Shown are three-year averages. The data are aggregates for France, (West) Germany, and the UK. GNP for each of these countries has been expressed in purchasing-power-corrected US dollars based on [49]. Data sources are as follows: population [50], steel [51], cement [52], paper [53], aluminum [37], and chemicals [54].

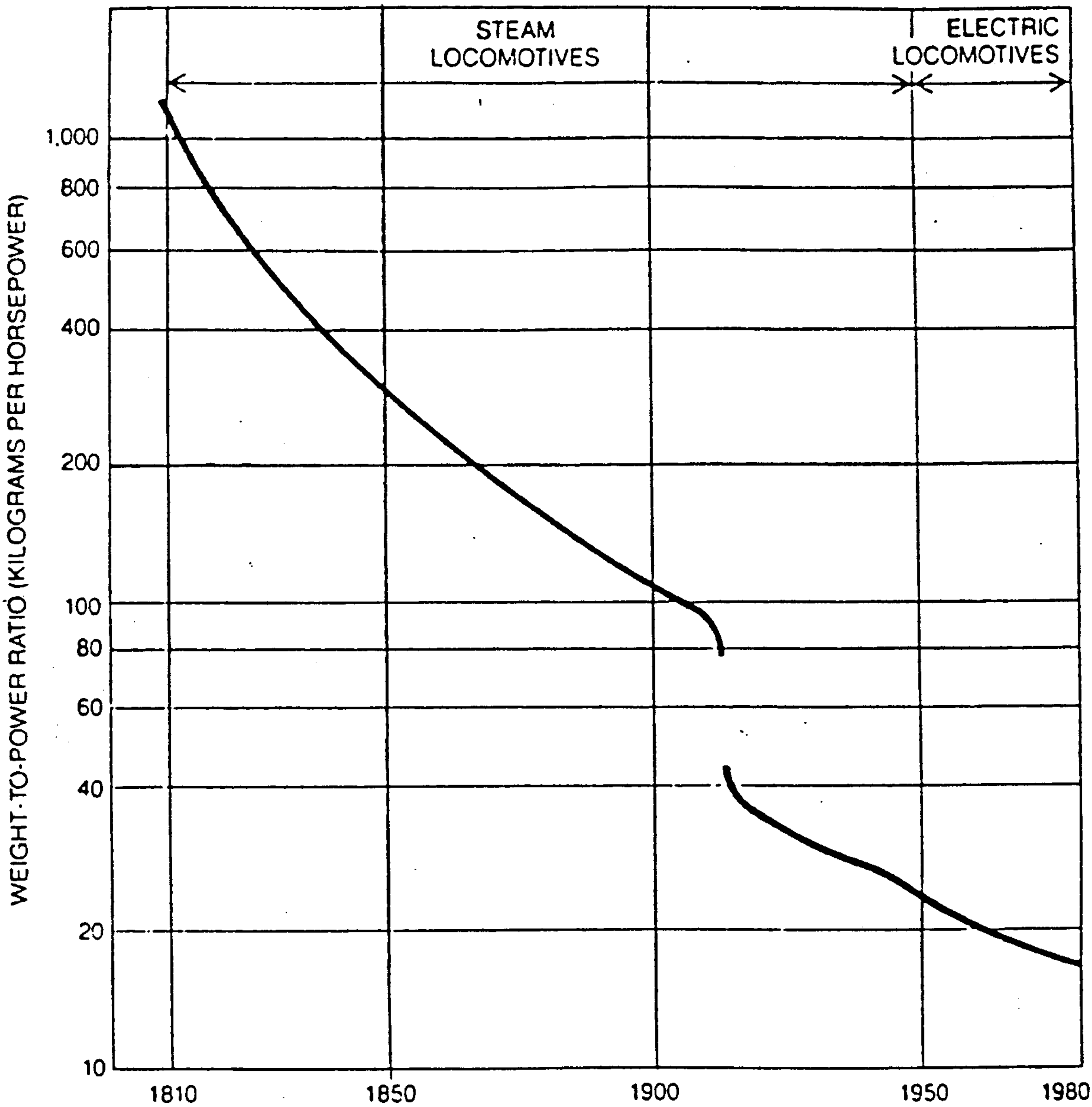


Fig. 6. The weight-to-power ratio of locomotives from 1810 to 1980, based on European data [55]. The gap in the data is a result of disruptions in data collection during World War I.

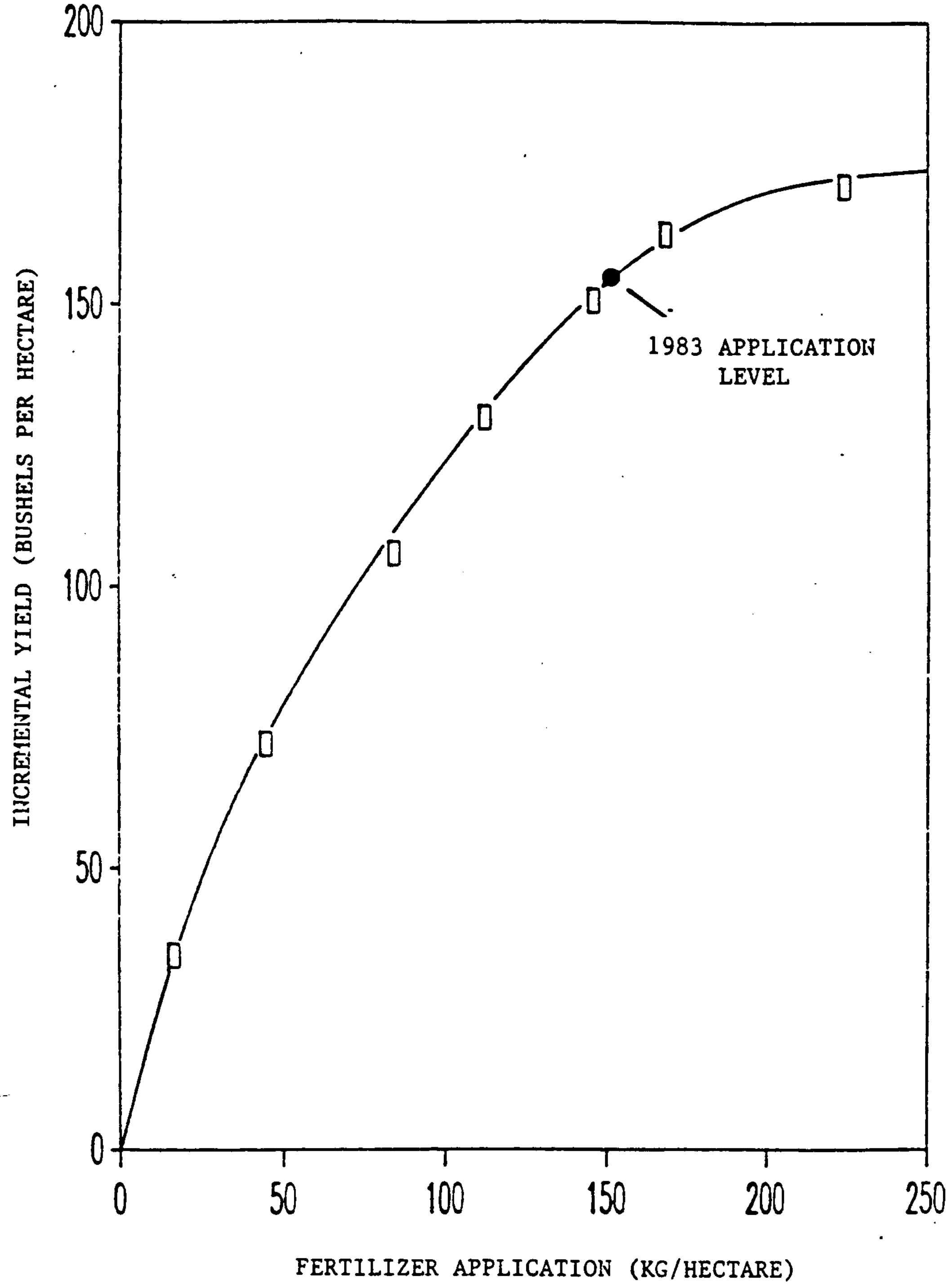


Fig. 7. Incremental yeild of corn with increased fertilizer application. The data (rectangles) represent the average of a number of agronomic experiments conducted at various locations in the "corn belt" of the US [56].

(a)

(b)

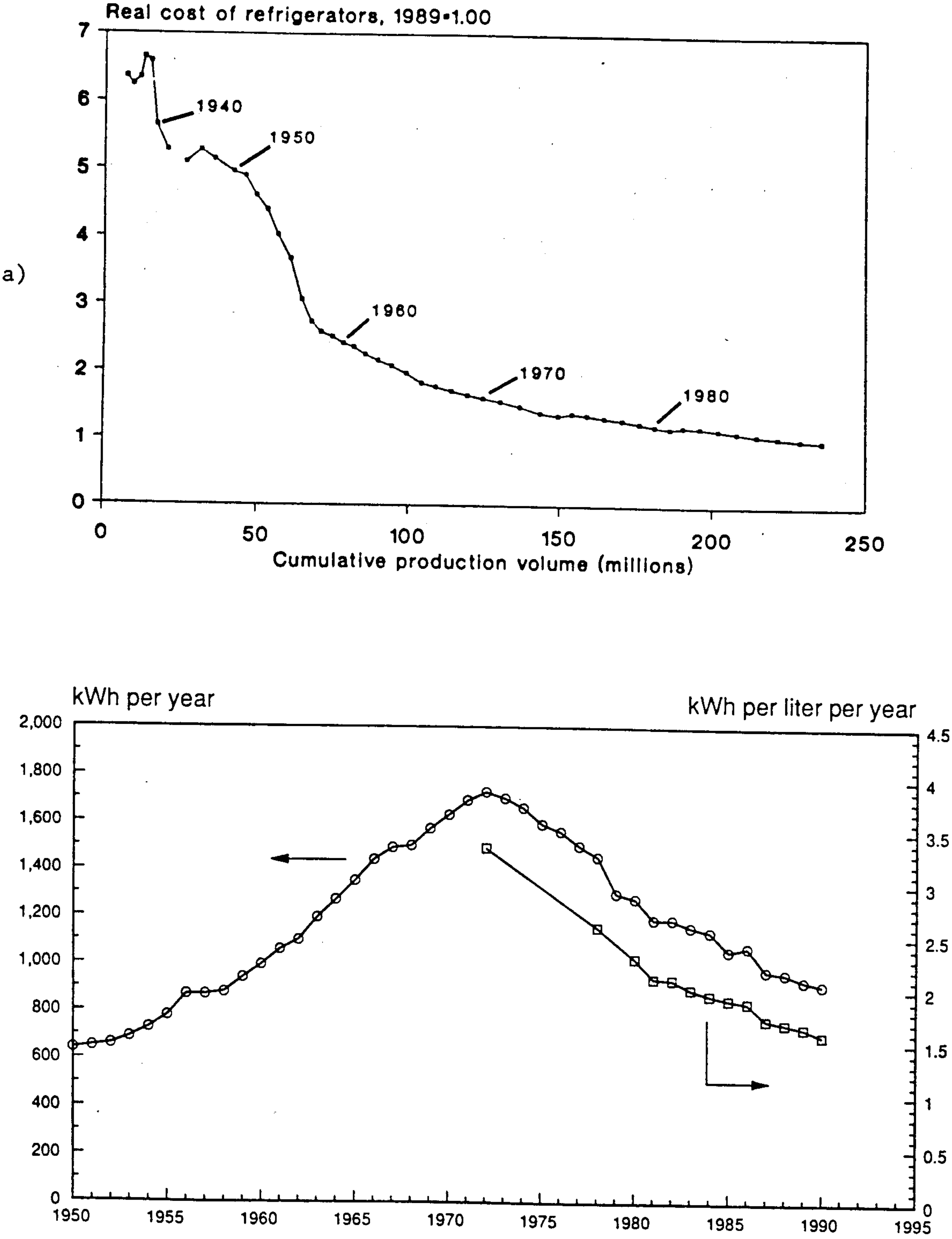


Fig. 8. (a) Reduction in the real cost of refrigerators in the US (1989 = 1) [7]. (b) Average electricity use in new refrigerators sold in the US (private communication from D. Goldstein, Natural Resources Defense Council, San Francisco, Calif., October 1991) and (private communication from Association of Home Appliance Manufacturers, Chicago, October 1991). The kWh/liter/year data are calculated as the average kWh per year per refrigerator weighted by the shipments of different models (manual defrost, auto defrost, top-mount or bottom-mount freezer, etc.) divided by the shipment-weighted average adjusted volume.

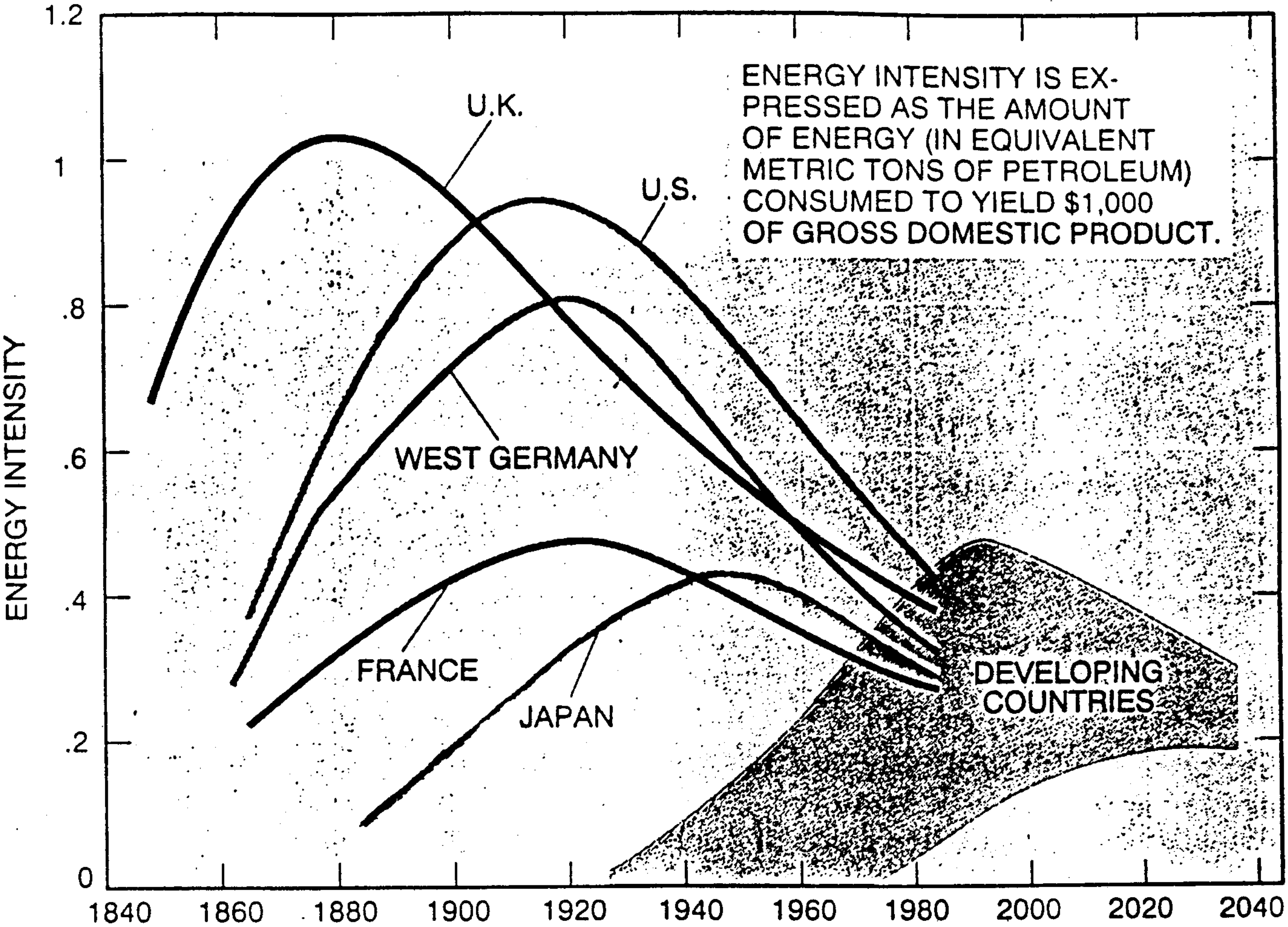


Fig. 9. Evolution of energy intensity in different countries [57].

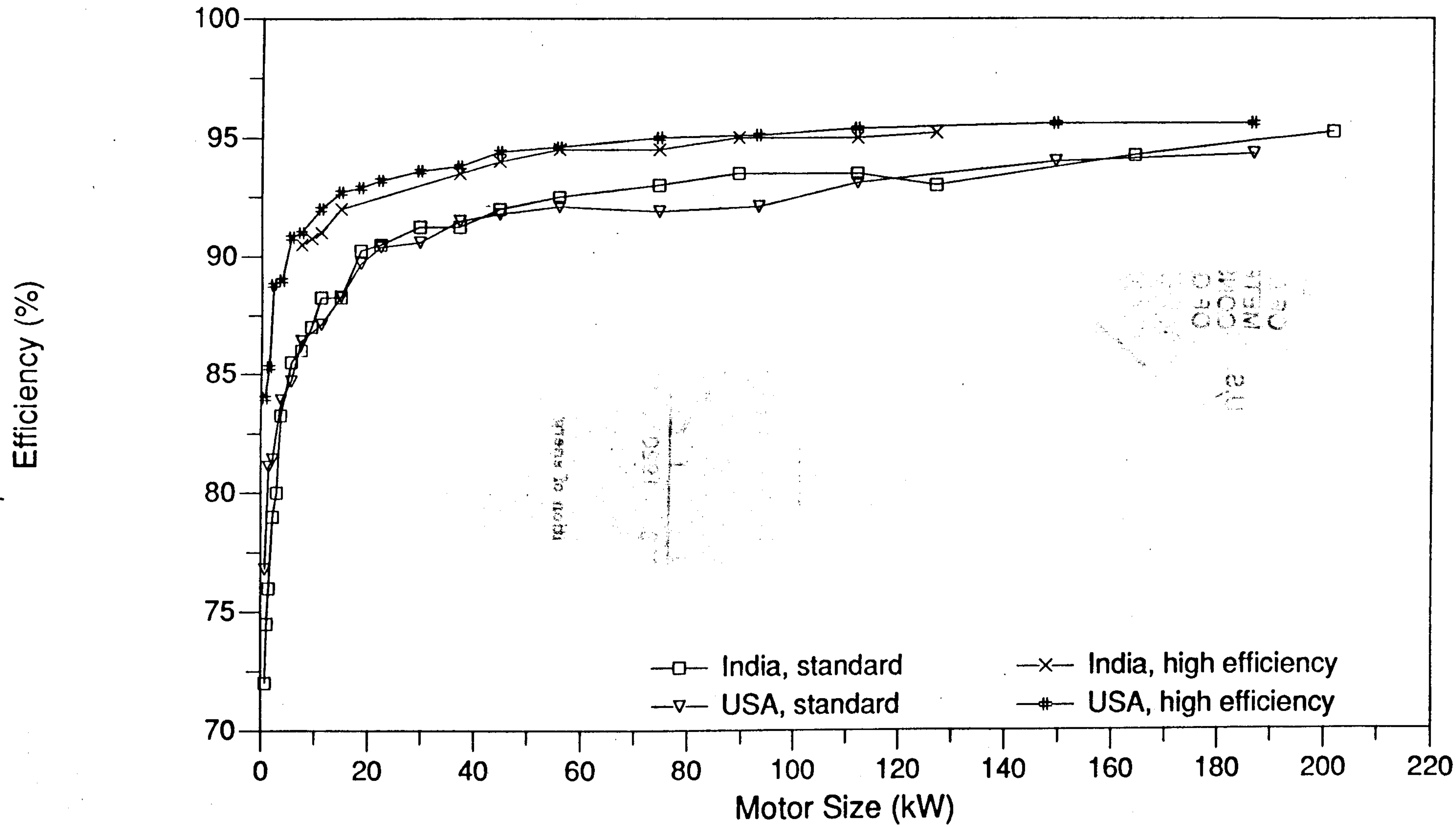


Fig. 10. Performance of standard-efficiency and high-efficiency motors manufactured in India and in the USA [47]. All data are for totally-enclosed, fan-cooled, three-phase, four-pole motors. US data are averages for eight different manufacturers. Indian data are from the database of the National Productivity Council (New Delhi). Motor testing procedures in India and the USA are both based on IEEE Standard 112- Method B, so the efficiency data should be comparable.

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