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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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Development and Transfer of Technology Series

No. 21

THE ECONOMIC USE OF ALUMINIUM

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THE ECONOMIC USE OF ALUMINIUM

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Preface

The present volume of the *Development and Transfer of Technology Series* is based on a study, "The economic use of aluminium" (UNIDO/IOD.335), prepared for the Metallurgical Industries Section of the United Nations Industrial Development Organization (UNIDO) by A. Boker, A. B. Domony and I. Varga of Hungary and reflects largely, but by no means solely, the experience in that country. The study outlined the factors affecting aluminium production and consumption and the main reasons for using this metal; it also described how and under what circumstances aluminium consumption expands in a developing country.

Reference is made to a number of international sources for information on aluminium; additional information can be provided by the Industrial Information Section, UNIDO, Vienna International Centre, A-1400 Vienna, Austria.

EXPLANATORY NOTES

References to dollars ($) are to United States dollars, unless otherwise stated.

References to "pounds" (£) are to pounds sterling, unless otherwise stated.

A solidus (/) between dates (e.g. 1980/81) indicates a financial year.

Use of a hyphen between dates (e.g. 1980-1985) indicates the full period involved, including the beginning and end years.

A point (.) is used to indicate decimals.

A space is used in tables to distinguish thousands and millions.

The following symbols have been used in tables:

Two dots (. .) indicate that data are not available or are not separately reported.
Two dashes (- -) indicate that the amount is nil or negligible.
A dash (—) indicates that the item is not applicable.
Totals may not add precisely because of rounding.

Besides the common abbreviations, symbols and terms, the following have been used in this report:

ACSR	steel-corded aluminium cables
CIDA	International Centre of Aluminium Development
DIN	Deutsche Industrie Norm
GDP	gross domestic product
GNP	gross national product
OECD	Organisation for Economic Co-operation and Development
PVC	polyvinyl chloride

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Introduction

The widespread utilization of aluminium on an industrial scale began in the 1930s. There was a significant rise in aluminium production—particularly in North America and Germany—during the Second World War to meet the increasing demand of the war industries, especially aircraft manufacture. Owing to the scarcity of other strategic materials, aluminium was used in other sectors as well. Electrical engineering and transport-vehicle manufacture were the two most prominent end-use sectors, with chemical engineering and food processing following on a more modest scale.

In the post-war reconstruction period when large stocks of aluminium became available for civilian use, new outlets were soon found, including prefabricated utility houses, shipbuilding and electrical engineering and food-processing equipment. From the second half of the 1950s, the major aluminium manufacturers of the world devised new strategies for boosting aluminium consumption, so as to find new markets for their rising production. During this period new uses were found for aluminium which, in the long run, have proved to be feasible from both a technical and economic point of view. The market position of aluminium at that time was strengthened by the fact that marked shifts in the pricing of other structural materials had taken place in favour of aluminium, a trend that continued in the following years.

The present volume reflects the experience of Hungary in aluminium production, but its experience would be applicable in developing countries that had similar geophysical and economic characteristics—abundant bauxite resources but few heavy non-ferrous metals, little timber and a narrow selection of steel products. In general, setting up an integrated aluminium industry in less industrialized countries calls for certain geophysical and economic factors.

The study is concerned with the interaction of the economic factors that influence the growth of aluminium consumption; it also describes endeavours in the production and consumer sectors. Examples of aspects of design, prototype manufacture and serial production, in Hungary and elsewhere, are cited to illustrate how utmost advantage can be taken of internal resources and how know-how obtained from abroad can be used. Organization, training and scientific policy, all essential in promoting aluminium consumption, are also dealt with. The examples cited do not claim to be a panacea for solving all problems, nor are they fixed patterns that must be strictly adhered to.

I. World use of structural materials

Efforts towards boosting aluminium consumption were first concentrated on developing new technologies and introducing products to replace traditional structural materials (for example, aluminium for copper in electric conductors, foil and collapsible packaging tubes of aluminium to replace tin, aluminium household holloware). In view of shifts in the pricing of non-ferrous metals in the last 40 years, aluminium has become a focus of attention. Of course, the concrete scope and prospects have always depended on local conditions. These include access to raw or structural materials and the extent to which industrial policies and the general economic situation had favoured aluminium. In more recent times, a significant condition giving further impetus to aluminium use has been the higher cost-effectiveness for both the producer and the consumer [1].

Structural materials

In this survey, the term "structural materials" refers not only to ferrous and non-ferrous metals, but also to plastics, wood and cement. By using a multitude of data on past and present aluminium consumption throughout the world, a complex techno-economic index system has been devised to predict future aluminium consumption at different levels of economic development. In method, the present investigation is fundamentally different from that of other authors. In earlier reports correlations were plotted between each specific usage of a material and the gross domestic product (GDP) of a given country; in this study an attempt has been made to synthesize such correlations and to present consumption trends in a more unified manner.

Early in the history of the aluminium industry specialists realized that aluminium was an effective and economical substitute for copper in the conduction of electricity. Soon thereafter, tin disappeared in most types of packaging, which gave way to fresh advances by the aluminium industry. Next in line came chemical engineering and then electrical engineering, where lead could be replaced by aluminium (for tanks and containers and for cable-sheathing). In the transport vehicle industry, aluminium, thanks to its light weight, soon became a competitor for cast iron. By reducing the weight of transport vehicles, considerable power economies could be arrived at, an important consideration in view of the present world energy situation. In the wake of fresh developments in the building trade, traditional designs using wood, reinforced concrete or steel gave way to aluminium (for example, for window and door frames, claddings and load-bearing building structures). Aluminium building components reduced assembly time and maintenance costs and enabled complete building elements to be transported over long distances with ease and assembled within the shortest possible time on site (e.g., cold-storage rooms). Thanks to its high resistance to weathering, aluminium has also become a highly effective substitute in a variety of other fields (e.g., building, transport vehicle and food packaging), and its corrosion resistance compares favourably with that of tin plate or zinc-coated steel. With continuing shortages of some heavy non-ferrous metals such as tin and zinc, this trend is expected to continue. This survey includes plastics so as to assess their potential impact on aluminium consumption over the long term.

Production and consumption trends

The rate of growth of aluminium consumption has been high in the last 40 years, well ahead of that of traditional structural materials (see tables 1 and 2). This growth was especially strong during the period 1960 to 1970. Although after the increase of oil prices this trend declined slightly, in comparison to other structural materials aluminium consumption shows extremely high growth rates.

This unprecedented steady growth is based on a high standard of systematic research and development throughout the world, relying, in turn, on effective co-operation between producers and consumers, irrespective of the economic system or extent of industrialization in a given country.

With the aid of a set of calculations, an attempt has been made to forecast future aluminium consumption based on the data released in earlier studies. In order to do this, the first step was to compare the consumption of principal

TABLE 1. WORLD CONSUMPTION OF STRUCTURAL MATERIALS, 1935-1980

(Millions of tonnes)

Structural material	*1935*	*1950*	*1960*	*1965*	*1970*	*1975*	*1976*	*1977*	*1978*	*1979*	*1980*
Aluminium (primary)	0.3	1.5	4.5	6.5	10.2	11.3	13.1	15.0	14.6	15.2	16.0
Copper	1.8	3.2	5.0	6.1	7.6	7.5	8.5	9.0	9.2	9.4	9.4
Lead	1.4	1.8	2.7	3.1	4.0	3.9	4.3	4.9	5.0	5.6	5.3
Tin	0.2	. .	. .	0.2	0.22	0.23	0.25	0.25	0.24	0.24	0.24
Zinc	1.4	2.1	3.2	4.1	5.2	5.0	5.8	5.8	6.0	6.5	6.6
Steel	124.0	187.0	343.0	458.0	588.0	646.3	681.8	677.0	. .	746	717.0
Plastics	0.22	1.3	6.87	14.69	30.36	37.0	43.0	. .	. .	. .	. .
Wood[a]	. .	210.0	337.3	374.3	404.2	423.7	. .	441.0	442.0	447.0	. .
Cement	66.2	133.0	314.2	430.5	578.0	702.0	727.0	. .	. .	711.0	806.0

[a] Timber in millions of cubic metres.

TABLE 2. WORLD CONSUMPTION GROWTH INDICES OF PRINCIPAL STRUCTURAL MATERIALS

Material	*1977/1935*	*1970/1960*	*1977/1960*	*1977/1970*	*1980/1970*
Aluminium	50.0	2.2	3.3	1.47	1.56
Copper	5.0	1.5	1.8	1.18	1.24
Lead	3.5	1.5	1.8	1.22	1.32
Tin	1.2	1.0	1.3	1.35	1.09
Zinc	4.1	1.6	1.8	1.11	1.25
Steel	5.5	1.7	2.1	1.14	1.22
Plastics	195.5[a]	4.4	6.3[b]	1.42[c]	. .
Wood	. .	1.2	1.3[d]	1.05[e]	1.10[f]
Cement	11.0[a]	1.9	2.3[b]	1.28[c]	1.39

[a] 1976/1935.
[b] 1976/1960.
[c] 1976/1970.
[d] 1975/1960.
[e] 1975/1970.
[f] 1979/1970.

structural materials to GDP in a number of selected countries at various levels of economic development.

For the purposes of this survey, those countries whose per capita GDP had been compared in a special study conducted by the Hungarian Institute of Economic Planning have been used [2]. The per capita GDP ratio has been used throughout as an index of economic development,* notably for comparisons in terms of time to be made, taking 1970 prices as a basis. For the sake of comparability GDP values have been converted into United States dollars and corrected. The corrections taken into account modified rates of exchange and use 43 indices measured in "natural" units. This correlation was also made by the Institute of Economic Planning [2].

In the calculations data from 23 industrialized countries, 8 centrally planned economies and 7 developing countries—Argentina, Brazil, Chile, Egypt, India, Mexico and Peru—have been considered. The scope is large enough to permit general conclusions to be reached for the benefit of other countries as well.

Aluminium consumption, 1937-1976

In the present survey aluminium consumption is classified according to the International Centre of Aluminium Development (CIDA) nomenclature adopted by the countries members of the Organisation for Economic Co-operation and Development (OECD) in 1973. The principal headings of the classification are:

Domestic primary aluminium consumption
Domestic secondary aluminium consumption
Domestic consumption of imported semi-manufactures

Consumption under the above headings, of course, does not include exports of semi-manufactures. In more detailed statistical returns semi-manufacture exports are listed in a separate line, permitting a direct read out of domestic aluminium consumption. Such detailed statistics, however, are not always available and the comprehensive figures released usually include exports of semi-manufactures as well. In view of this, these figures have been accepted at face value for inclusion in tables and figures presented here. Such incomplete data, however, had no significant bearing on the trend calculations; in dealing with a large amount of data, small margins of error usually balance out.

In figure I, the 1976 per capita aluminium consumption of 29 selected countries is plotted against their per capita GDP. The year 1976 may be regarded as a more or less stable one from an aluminium consumption point of view. No new aluminium outlets calling for large tonnages emerged during that year.

Over the period 1937-1968, the situtation was entirely different. In figure II the consumption vs. GDP curves for four characteristic years are

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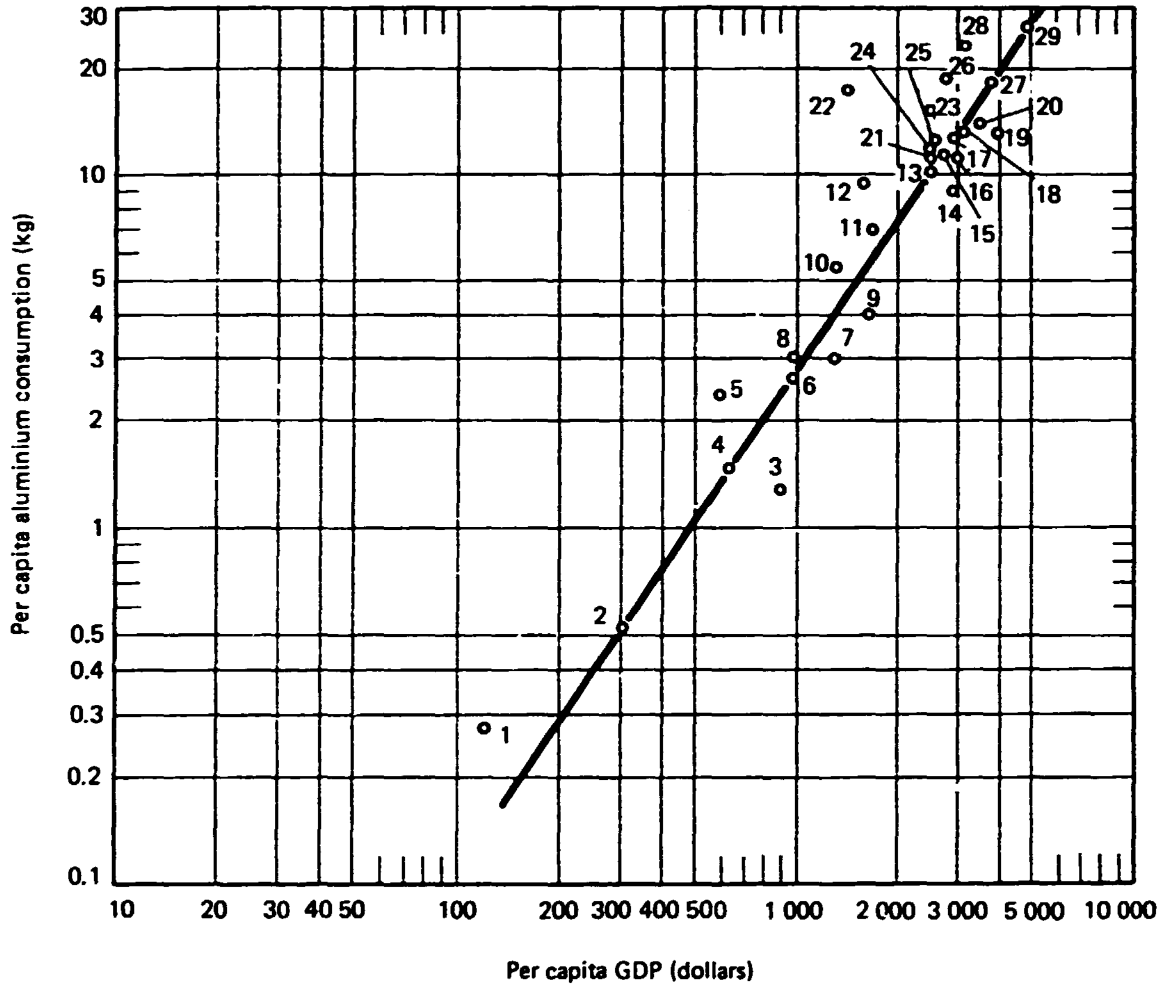
*The per capita gross national product (GNP) ratio can also be used as an index of economic development, but certain difficulties arise when comparing industrialized and developing countries

Figure I. Per capita aluminium consumption in 29 selected countries plotted against their per capita GDP, 1976

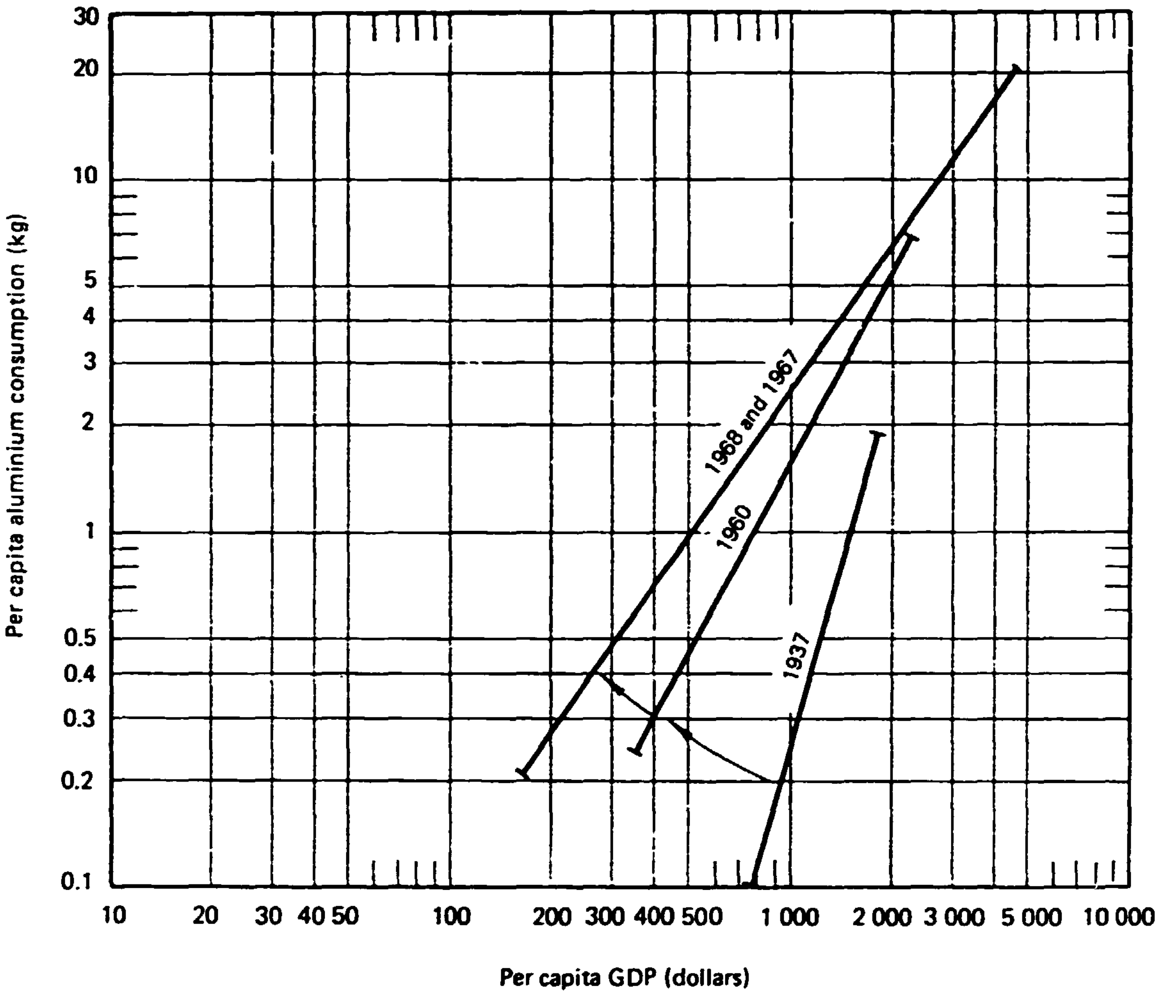


Key:
1 India
2 Egypt
3 Portugal
4 Mexico
5 Brazil
6 South Africa
7 Argentina
8 Greece
9 Ireland
10 Spain
11 Israel
12 Italy
13 Austria
14 New Zealand
15 Belgium
16 Denmark
17 United Kingdom
18 Netherlands
19 Canada
20 Australia
21 France
22 Hungary
23 Japan
24 Finland
25 Switzerland
26 Germany, Federal Republic of
27 Sweden
28 Norway
29 United States

displayed in a single graph, so as to permit a comparison of growth trends in the long term. Above a given level of economic development, per capita consumption in the long run continued to grow. For example, at $500 GDP per capita, per capita aluminium consumption rose from 0.5 kg in 1966 to 1 kg in 1968. The curve for 1968 coincides with that for 1976, suggesting that further growth was no longer anticipated unless the relative pricing of aluminium dropped considerably or a number of new volume-intensive aluminium outlets were found.

The growth of aluminium consumption in each of 10 selected countries is illustrated in figure III. Here the lines connect points plotted for each of the four years under survey (1937, 1960, 1968 and 1976). The line for each country tends towards the median line for 1968 and 1976. A full convergence in the median line, of course, may not be anticipated, because of the annual fluctuations of data. But the amplitude of fluctuations has in the past visibly narrowed and the trend towards convergence is expected to persist in the future.

Figure II. Aluminium consumption vs. GDP curves for the 29 countries, 1937, 1960, 1968 and 1976



A few points on the median line of figure III are given numerically in table 3 to demonstrate that aluminium consumption tends to rise much faster than GDP. How much faster is given by the slope of the line in figure III, called the elasticity coefficient, which is 1.43.

Hence, if future trends of GDP or GNP are known, trends of aluminium consumption may be forecast. For countries whose position on the graph in figure III is located below the median line, the use of a higher, and for those located above the median line, the use of a lower, elasticity coefficient is advisable. Assuming normal economic growth, in both cases the relative positions will tend to converge.

Consumption of other structural materials

Figure IV compares the per capita consumption and per capita GDP of steel, copper, timber, cement and plastics in 29 selected countries for various years. Each of these materials is discussed below.

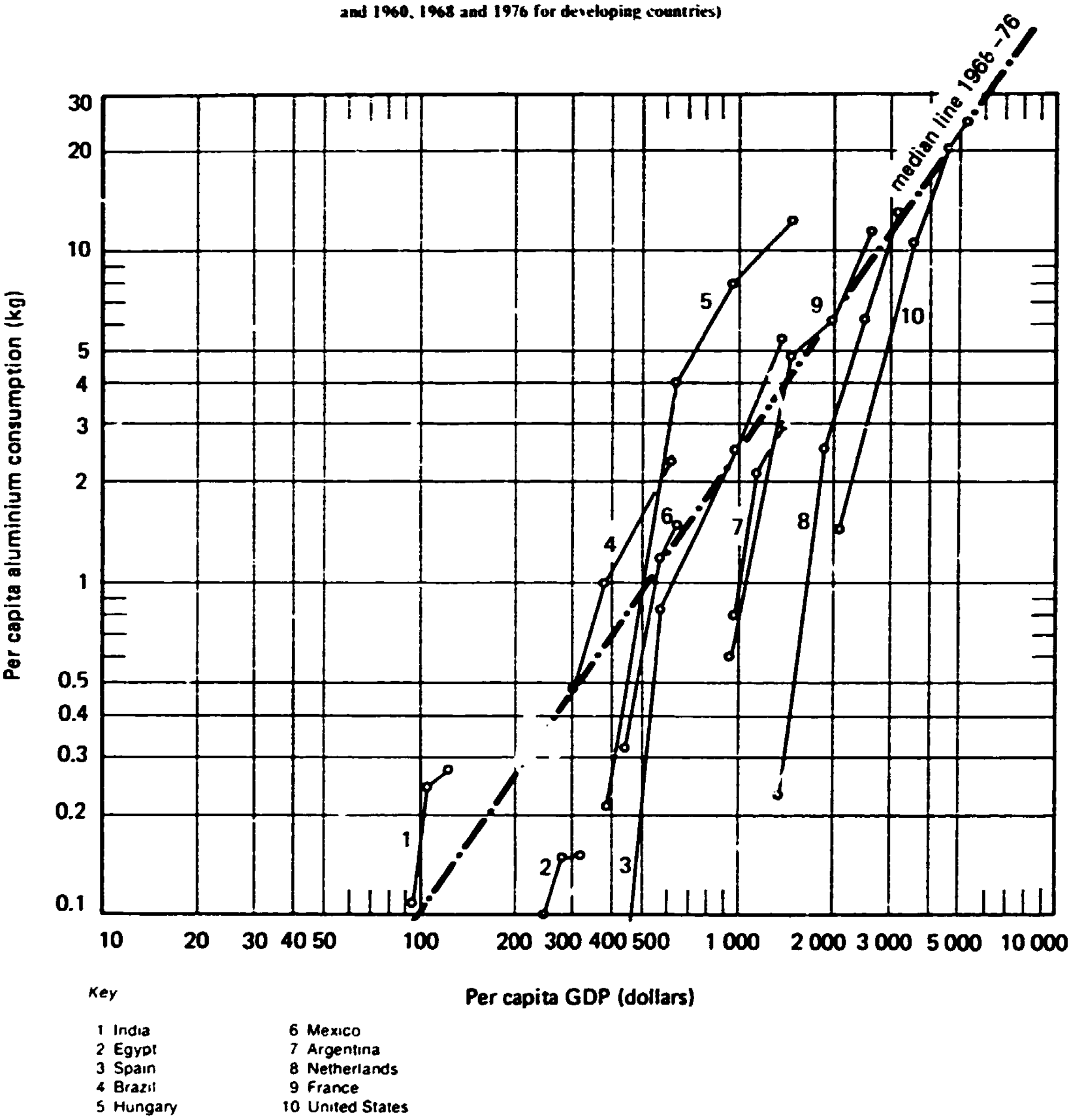
TABLE 3. PER CAPITA GDP IN RELATION TO ALUMINIUM CONSUMPTION

Per capita GDP (US dollars)	*Aluminium consumption (kg)*	
	Per capita	*Per $US 1,000 GDP*
300	0.50	1.66
500	1.00	2.00
1 000	2.6	2.6
2 000	6.75	3.38
4 000	17.5	4.38

Steel

In contrast to aluminium, it is a characteristic feature of steel that international mainstream consumption trends expressed by the median have

Figure III. Aluminium consumption in 10 selected countries, various years (1937, 1960, 1968 and 1976 for industrialized countries and 1960, 1968 and 1976 for developing countries)



not changed since 1937 (see figure IV*(a)*). Steel consumption tends to keep to a traditional consumption pattern with an elasticity coefficient of 1.5 per cent, despite the fact that new and competitive materials such as aluminium and plastics have made heavy inroads on the steel market. Obvious reasons for this stable figure are the large volumes of steel consumed in areas where there is little scope for substitution and technical advances in the steel industry [3].

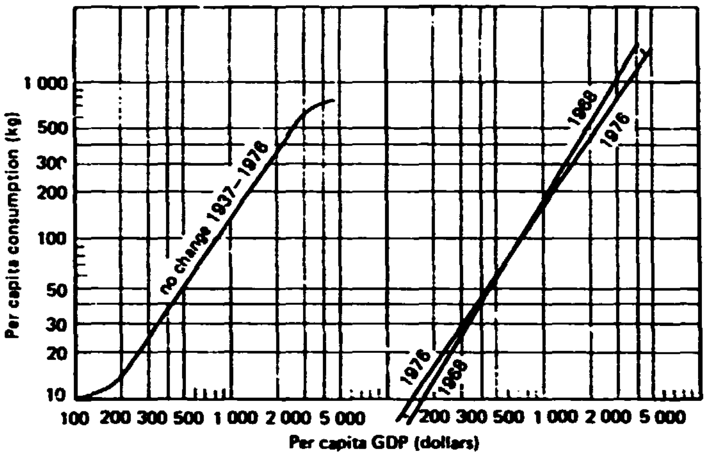
Copper

Data for refined copper consumption are available only for the years 1968 and 1976 (figure IV*(b)*). From 1968 to 1978, the median of copper consumption remained about the same at the $620 per capita mark. Where it went over this level (all developed countries and some developing countries), per capita copper consumption dropped to 1.5 kg, corresponding to that of steel.

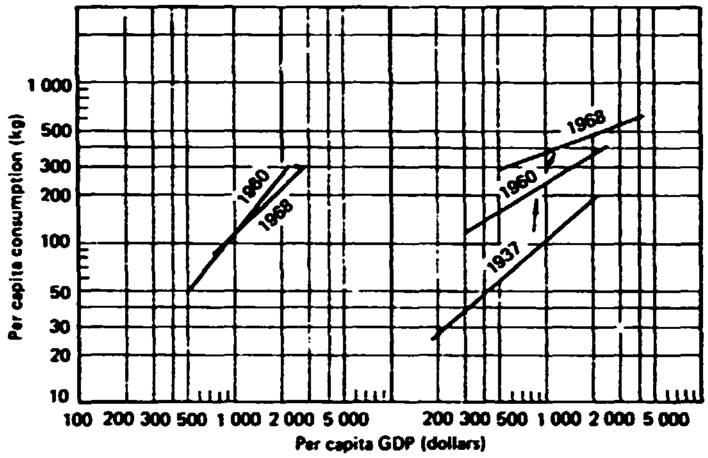
In 1976 aluminium consumption per kg of copper was 1.4-1.8 kg in developed countries on the average, 6.2 kg in Hungary and 15 kg in Norway.

Hungary, with its 2.1 kg per capita consumption, is one of the world's most modest copper consumers. This is obviously due to the country's very high aluminium consumption in relation to

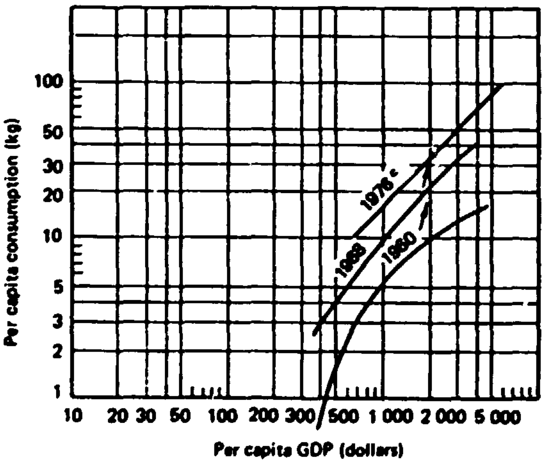
Figure IV. Per capita consumption and per capita GDP of some structural materials in 29 selected countries,[a] various years



(a) Steel (b) Copper



(c) Timber[b] (d) Cement



(e) Plastics

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[a] See the key to figure I.

[b] Excluding the developed countries.

[c] Excluding developing countries, for which no data were available.

its economic development. Countries of similar economic development, by contrast, have accounted for about 5 kg copper consumption per capita.

While the price of aluminium is a disadvantage in its competition with steel, for copper the situation is the reverse. For many end-uses, copper could be replaced by aluminium. Further encroachment of aluminium on the copper market seems largely limited by only technological considerations (e.g., flexibility of electrical coil wire).

Timber

Half of the world's wood consumption may be accounted for as fuel, with the other half being used for industry. One third of the latter is timber, the product being discussed here. Accurate data were available only for Europe covering the period 1950-1970.

In the past the more developed countries consumed more timber than the less developed ones. Nowadays, however, per capita timber consumption in developed countries may no longer grow although per capita GDP is constantly rising. This may be because in the past timber was used almost exclusively in wood-growing areas.

The shortening of the medians and the steepness of their gradients in figure IV*(c)* clearly indicate that timber consumption by the less developed countries tends to approximate that of the more developed ones.

Cement

For cement (figure IV*(d)*) numerous data were available for 1937, very few for 1968 and none for 1976. In consequence, the medians may be less accurate than those for the other materials.

Over the period 1937-1968 the medians tend to attain higher and higher levels revealing more and more pronounced gradients. Accordingly, per capita cement consumption related to GDP has a strong tendency to rise, with its elasticity coefficient tending to drop, e.g. at a $100 per capita level from 0.8 in 1937 to 0.3 in 1968.

Plastics

The median for each year is higher than for the preceding year. The 1960 median is curved (figure IV*(e)*). Of course, no data were available for 1937 when the plastics industry was still in its infancy. Also, no 1976 data were available in respect of developing countries.

The medians plotted from available data in figure IV*(e)* point, at a constant per capita GDP level, to a rising trend in per capita plastics consumption, implying that this vigorous material has a great variety of end-uses (a reverse picture of that of timber). The increase in plastics consumption, though in some specific fields—cable manufacture, heat-insulated sandwich panels, packaging etc.—simultaneous with and a corollary of that of aluminium, may at times also adversely affect aluminium marketing interests, e.g., in the building trade, the transport vehicle industry and the manufacture of some consumer goods. It is indeed often hard to say whether the two industries are co-operating partners or competitors. However, with the median of aluminium rising less steeply than that of plastics, it seems that in industrialized countries plastics tend more and more to expand their markets to the detriment of aluminium.

Forecasts

The period covering the 1950s, the 1960s and the first half of the 1970s witnessed an exponential growth of world economy. World population, industrial production and the consumption of raw materials have shown congruently growth trends of exponential character (see tables 1 and 2). Among raw materials, the increase of aluminium metal consumption was particularly spectacular—between 1950 and 1970 the average annual growth rate attained 9.7 per cent on world scale.

As a result of the first petroleum crisis in 1973, the dynamic growth of world economy became interrupted, thus partially justifying economists who had called for more restraint. *Limits of Growth*, a volume of studies prepared for the Club of Rome and printed in 1972, was one of the best-known publications in this category. In view of predictions of the Club of Rome and of alarming developments in world economy, Nobel Prize laureate economist Wassily Leontief was appointed by the United Nations to elaborate a coherent model designed to be instrumental in creating a new international economic order. Professor Leontief and co-authors elaborated their ideas in a comprehensive study titled *The Future of the World Economy* [4]. Their initial supposition was a future gradual decrease of world population growth, especially in the developing countries. This could lead to a decrease in the growth of industrial production, the per capita consumption of goods on world scale could grow at a pace that would not lead necessarily to an early exhaustion of world raw material resources and a world disaster caused by environmental pollution could be also avoided. Reasonable housekeeping with energy and raw material resources, improved and increased efficiency in utilizing raw material resources and intensive recycling from wastes appear as key tasks for development. Keeping in mind the above, a world model—broken down by economic regions and enabling the calculus of GDP and its growth rates—was made.

Leontief's calculations provided the basis for sectoral forecasting between 1978-1980 for individual raw and structural materials. These forecasts, compared with previous ones, show much more modest development rates for the period up to the year 2000.

Leontief was soon followed by M. F. Dowding, the president of the British Metals Society, who elaborated updated consumption forecasts specifically for metals and other structural materials [5]. The forecasts were analysed on the basis of the expected values of gross national product (GNP) (see tables 4 and 5).

TABLE 4. AVERAGE ANNUAL GROWTH RATES OF GNP: FORECASTS TO 2000

(Percentage)

Economic grouping or country	*1980-1985*	*1985-1990*	*1990-2000*
Developed market economies (excluding Japan)	3.5-3.0	3.4-3.3	3.0-2.5
Centrally planned economies	5.0	5.0	4.5
Japan	5.5	5.0	4.5
Developing countries	7.5-6.0	6.5-5.7	5.5
World total	4.7	4.4	4.2

Source: [5]

TABLE 5. WORLD CONSUMPTION OF THE MOST IMPORTANT METALLIC STRUCTURAL MATERIALS BY DECADES TO 2000

(Millions of tonnes)

Material	*1971-1980*	*1981-1990*	*1991-2000*
Steel	6 900.3	10 200	13 800
Aluminium	130.0	218	358
Copper	82.5	136	206
Zinc	58.0	79	102
Lead	48.0	50	61

Source: [5].

Keeping in view the data presented in table 4, Dowding prepared forecasts of consumption related to the main metallic structural materials (table 5).

The gross total consumption of primary and secondary aluminium was elaborated in detail, and a 5 per cent average annual growth rate was anticipated (see table 6).

The breakdown of aluminium consumption by economic grouping has been worked out on the basis of Dowding's calculations for a study by UNIDO, prepared in 1978 (see tables 7 and 8) [6]. A rough halving of the previous annual growth rates (which amounted between the years 1960-1970 to 8-10 per cent) was taken into account in the calculations.

It seems highly probable that the share of developing countries in aluminium production and consumption will grow considerably in the years ahead. According to S. Moment [7], in the period 1975-1985, aluminium production in developed market economies is expected to double roughly, from 9.1 million tonnes to 19 million tonnes. During the same period, aluminium smelter capacities of the developing countries are expected to grow fivefold, expanding from 0.8 million tonnes to 4 million tonnes annually. The reality of this forecast seems to be confirmed by available contemporary data, shown below:

Year	*Capacity (Thousands of tonnes)*
1960 [8]	88.6
1970 [8]	538.2
1975 [7]	842
1977 [9]	1 104
1978 [9]	1 318
1985 [7]	4 000
2000 (estimated)	7 000-9 000

By 1985 the share of developing countries in world aluminium smelter capacity may reach 17 per cent of total installed world smelter capacity. Under these circumstances, the target suggested at the Second General Conference of the United Nations Industrial Development Organization held at Lima, Peru, in March 1975, that at the turn of the century developing countries should account for 25 per cent of total world industrial production, appears to be a thoroughly

TABLE 6. GROWTH OF WORLD ALUMINIUM CONSUMPTION BY ECONOMY TYPE, 1978-2000

(Millions of tonnes)

Economy type	*1978*	*1985*	*1990*	*2000*
Market	15.7	22.0	28.3	46.0
Centrally planned	4.3	6.0	7.7	12.0
Total	20.0	28.0	36.0	58.0

Source: [5].

TABLE 7. GROWTH OF WORLD ALUMINIUM CONSUMPTION BY ECONOMIC GROUPING, 1978-2000

(Millions of tonnes)

Economic grouping	*1978*	*1985*	*1990*	*2000*
Developing countries	1.2	3.0	4.8	10.0
Centrally planned economies[a]	4.3	6.0	7.7	12.0
Developed market economies	14.5	19.0	23.5	36.0
Total[b]	20.0	28.0	36.0	58.0

Source: [6].

[a] Including China.

[b] Gross value including secondary aluminium.

TABLE 8. FORECAST OF ALUMINIUM CONSUMPTION ANNUAL GROWTH RATES

(Percentage)

Economic grouping	*1978-1985*	*1986-1990*	*1991-2000*
Developing countries	14.0	10.0	8.6
Centrally planned economies[a]	4.9	5.1	4.8
Developed market economies	3.9	4.5	3.9
World average	5.0	5.1	5.1

Source: Based on the figures in table 7.

[a] Including China.

fair percentage that can be reached by developing countries as far as the share in world aluminium smelter capacities is concerned [10].

The second "explosion" of petroleum prices and the ensuing recession called into doubt the reality of forecasts that were prepared in the second half of the 1970s. Estimates of global growth rates and of the relative values of structural materials and, consequently, of their potential for substitution by each other had become doubtful. Simultaneously it also became clear that the economic future of developing countries would not be as uniform as previously supposed. A group of "well-off" developing countries—consisting mainly of the countries of Latin America—emerged. In addition to natural resources, this group of countries also has trained labour, an essential condition of development. In extremely low-income countries, however, agricultural and industrial development targets could not be met even when natural resources were more or less available. Lack of trained personnel was the main obstacle.

Recent economic forecasts include those by Interfutures [11] and a report prepared for the President of the United States (1980) [12]. The GNP-related data of the latter report are summarized in table 9. Forecasts dealing with future demand of structural materials and aluminium all agree on the existence of a correlation between GNP and the consumption of some of these materials. According to more recent forecasts, the elasticity quotient of GNP and growth in aluminium consumption has a general tendency to decrease and is becoming increasingly differen-

TABLE 9. GNP AND GROWTH RATES, 1975, 1985 AND 2000

Economic grouping, region or country	*GNP, 1975 (billions of 1975 US dollars)*	*Predicted annual growth rate, 1975-1985 (percentage)*	*Projected GNP, 1985 (billions of 1975 US dollars)*	*Predicted annual growth rate, 1985-2000 (percentage)*	*Projected GNP, 2000 (billions of 1975 US dollars)*
World	6 025	4.1	8 991	3.3	14 677
Economic grouping					
Developed countries	4 892	3.9	7 150	3.1	11 224
Developing countries	1 133	5.0	1 841	4.3	3 452
Eastern Europe and USSR	996	3.3	1 371	2.8	2 060
North America, Western Europe, Australia, Japan and New Zealand	3 844	4.0	5 691	3.1	8 996
Regions					
Africa	162	5.2	268	4.3	505
Asia and Oceania	697	4.6	1 097	4.2	2 023
Europe					
Eastern	330	3.3	454	2.8	682
Western	1 598	4.0	2 366	3.1	3 740
Latin America	326	5.6	564	4.5	1 092
Selected countries					
Bangladesh	9	3.6	13	2.8	19
Brazil	108	5.6	185	4.4	353
China	286	3.8	413	3.8	718
Egypt	12	5.6	20	4.4	38
India	92	3.6	131	2.8	198
Indonesia	24	6.4	45	5.4	99
Japan	495	4.0	733	3.1	1 158
Mexico	71	5.6	122	4.4	233
Nigeria	23	5.4	43	5.4	94
Pakistan	10	3.6	14	2.8	21
Philippines	16	5.6	27	4.4	52
Republic of Korea	19	5.6	32	4.4	61
Thailand	15	5.6	25	4.4	48
USSR	666	3.3	917	2.8	1 377
United States	1 509	4.0	2 233	3.1	3 530

Source: [12]

tiated by economic regions. For the industrially developed countries this quotient, which was 1.2 to 1.3, will decrease by the year 2000 to 0.9 to 1.0. The expected quotient will be 1.3 to 1.4 for Latin America [13]; 1.4 to 1.5 for the least developed countries and 1.0 for the centrally planned economies.

The model, which was published on the occasion of the Second International Symposium on Aluminium Transformation Technology and its Applications, Buenos Aires, August 1981 [14], relies partly on published sources [11] and [12] and partly on unpublished papers of W. Leontief. This model surveys the consumption of main structural metals up to the year 2000. The author estimates that world total primary aluminium consumption will be 32 to 33 million tonnes by the year 2000, if current technological conditions still prevail. If aluminium recycling is developed world-wide, a lot of material and energy could be saved and world primary aluminium consumption could be reduced by the end of this century to some 27 million tonnes. The expected rate of growth for steel, copper, lead and titanium was also estimated. Reduced consumption estimates may result from technological development and in recycling.

The final conclusions of these calculations for primary metals are presented in table 10 and figures V and VI. The consumption figures given for primary metals should be increased by the volume of secondary metal recycled from scrap, which may be 20 to 30 per cent of the primary metal for aluminium.

TABLE 10. GROWTH OF WORLD CONSUMPTION OF MAIN PRIMARY STRUCTURAL METALS TO THE YEAR 2000

(Millions of tonnes)

Metal	*1980*	*1990*	*2000*
Aluminium	15.2	22	32
Copper	9.6	13	17
Lead	5.2	6	7
Steel	720.0	1 000	1 138

Source: [14].

A feeling of some uncertainty emerges from figure VI, based on Varsavsky's projections [14] and from the forecast prepared by Interfutures [11]. In addition to the status of the world economy, the future demand of structural materials will depend on such unknown conditions as the rate and efficiency of recycling from scrap; new technological achievements in production and processing, especially as related to their impact on capital and energy requirements; innovations, product quality characteristics and material savings; and, finally, material substitution possibilities.

A model to forecast gross aluminium consumption, both primary and secondary, with an arbitrary division into main economic regions was constructed. Gross volumes of aluminium consumption are shown in table 11, and the relevant annual growth rates are shown in table 12. The

Figure V. Projected world consumption of several primary metals (relative index) [14]

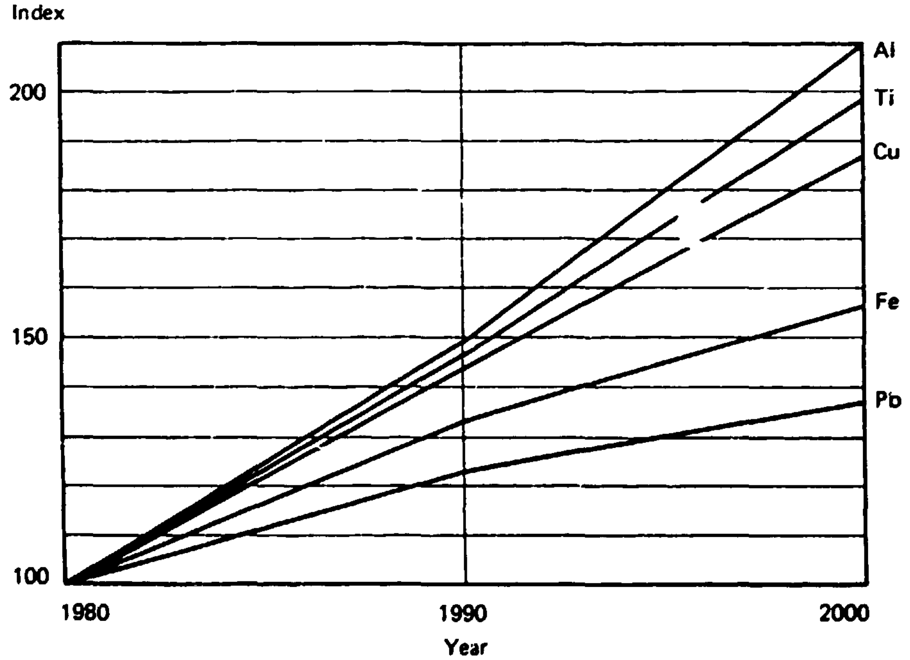
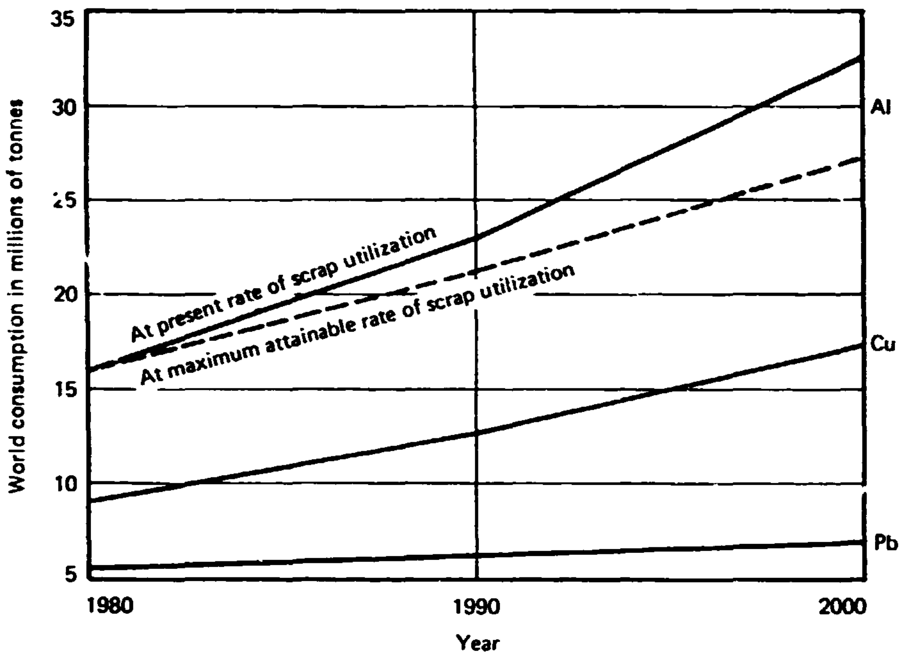


Figure VI. Projected consumption of some primary non-ferrous metals [14]



volume of metal to be recycled from scrap by the year 2000 was estimated at 20 per cent of primary metal, an estimate similar to that of Varsavsky. As a result world demand of primary aluminium by 2000 can be put at some 30 million tonnes. This figure is corroborated also by Kapolyi [15], whose analysis of forecasts of the 1970s concluded that projected growth rates tend to decrease.

The decrease in aluminium consumption growth rates can be attributed to the following factors:

(a) Growth increments of GNP in developed countries originate mainly from industrial sectors that are not intensive consumers of aluminium, e.g., electronics and telecommunications. For developing countries, intensive electrification pro-

TABLE II. GROSS CONSUMPTION OF PRIMARY AND SECONDARY ALUMINIUM, 1970-2000

(Millions of tonnes)

Economic grouping, region or country	*1970*	*1975*	*1979*	*1980*	*1981 (estimate)*	*Forecast* *1985*	*Forecast* *1990*	*Forecast* *2000*
Market economies of Western Europe	3.2	3.5	5.7	5.6	5.3	6.5	7.5	9.9
Japan	1.4	1.6	2.3	2.1	2.0	2.5	2.9	3.8
United States	4.2	4.2	6.6	6.2	6.4	7.1	8.1	10.7
Other developed market economies	0.5	0.8	1.0	1.0	1.0	1.2	1.5	1.8
Total, developed market economies	9.3	9.5	15.6	14.9	14.7	17.3	20.0	26.2
Latin America	0.2	0.4	0.6[a]	0.7[b]	0.7	1.0	1.3	2.1
Petroleum-producing countries	0.1	0.2	0.3	0.3	0.3	0.4	0.5	0.8
Total, Latin America and petroleum-producing countries	0.3	0.6	0.9	1.0	1.0	1.4	1.8	2.9
Least developed countries of Asia,[c] Africa[d] etc.	0.3	0.4	0.6	0.6	0.6	0.8	1.0	1.7
European centrally planned economies[e]	1.7	2.6	3.0	3.1	3.0	3.6	4.2	5.5
China and other centrally planned economies[e]	0.3	0.4	0.6	0.6	0.6	0.8	1.1	1.8
Total, centrally planned economies[e]	2.0	3.0	3.6	3.7	3.6	4.4	5.3	7.3
Total	11.9	13.5	20.7	20.2	19.9	23.9	28.1	38.1

[a] Metal Bulletin's Second Aluminium Congress, Madrid, September 1980.

[b] *Aluminium*, vol. 58, No. 1 (1982) p. 73.

[c] Excluding China and Japan and petroleum-producing countries

[d] Excluding petroleum-producing countries and South Africa

[e] Estimate

TABLE 12 AVERAGE ANNUAL INCREMENTS OF GROSS PRIMARY AND SECONDARY ALUMINIUM CONSUMPTION

(Percentage)

Economic grouping, region or country	*1970-1975*	*1975-1980*	*1980-1985*	*1985-1990*	*1990-2000*
Market economies of Western Europe	2.0	5.8	3.1	2.8	2.8
Japan	2.5	4.1	3.2	2.8	2.8
United States	- -	3.9	2.8	2.8	2.8
Other developed market economies	9.8	7.1	4.5	3.0	3.0
Average, developed market economies	0.5	4.5	3.0	2.9	2.8
Latin America	14.5	13.0	7.2	5.4	4.8
Petroleum-producing countries	14.5	11.8	5.2	4.8	4.7
Average, Latin America and petroleum-producing countries	14.5	12.6	7.0	5.1	4.8
Least developed countries of Asia,[a] Africa[b] etc.	6.0	7.0	6.0	5.3	5.8
European centrally planned economies	8.9	5.9	3.3	3.8	2.8
China and other centrally planned economies	6.0	7.0	5.0	5.0	5.0
Average, centrally planned economies	8.5	6.4	3.5	3.7	3.8
Overall average	2.5	5.5	3.4	3.4	3.7

[a] Excluding China and Japan.

[b] Excluding petroleum-producing countries and South Africa.

grammes and an industrial structure similar to that of the developed countries between 1960 and 1970 result in a higher specific demand for aluminium;

(b) Capital costs for investments to create new primary aluminium production capacities are steadily increasing owing to increases in the costs of infrastructure and energy, increasing production unit size and pollution control standards;

(c) Few new uses for aluminium are being discovered, except in air transport and road vehicles;

(d) The rise in the price of aluminium compared to that of other structural materials, especially alloyed steels and some plastics, has shifted to the detriment of aluminium. As an example, the world market price of aluminium in 1979 was 2.32 times the 1972 level; alloyed steel prices were 1.68 times the 1972 level.

Table 13 presents forecasts of world steel consumption, and table 14 shows the relevant annual increments as percentages [16]. The structure of these tables and the inherent uncertainties and possibilities of error are similar to those of tables 11 and 12 on aluminium consumption forecasts.

Tables 15 and 16 show comparative shares of aluminium and steel consumption by economic grouping between 1970 and 2000. The share of developed countries decreases for aluminium and steel. The share of centrally planned economies stays level for aluminium and shows a decrease for steel for the final years. The share of developing countries shows a spectacular increase for steel and a more modest, but still significant, increase for aluminium. Least developed countries show a pattern similar to that of developing countries but at a much lower level. In summary, an increase in the demand for aluminium appears possible in the developing countries. However, this will require well-organized marketing, competent technical information and advisory services and efficient transfer of technology. In addition, the increasingly keen competition by plastics and alloyed steels, which are today advancing on a broad front just as aluminium did between 1955 and 1970, must be kept in mind.

The structure and sectoral breakdown of aluminium consumption by regions, or by individual countries, depends on the general economic situation and on the structures of local industries. It is tempting to use comparative analysis of aluminium end-uses by regions in the preparation of elaborate forecasts. However, lack of sufficient data and the complicated and changing nature of economic patterns makes it impossible to provide more than an estimate of some fundamental tendencies. The following general conclusions emerge:

(a) The four main economic groupings display distinct types of end-use patterns. In developed market economies most consumption comes from transport, construction and packaging. In semi-industrialized developing countries electrical industries have a large role, domestic utensils show a decrease and production of transport goods grows; packaging (where there are food industries) and construction (depending on local climate) may also have a potential for growth. The bulk of aluminium consumption in the least developed countries is in the household goods and electrical industries sectors. In the centrally planned economies (independent of their respective levels

TABLE 13. WORLD STEEL CONSUMPTION, 1970-2000

(Millions of tonnes)

						Forecast		
Economic grouping, region or country	*1970*	*1975*	*1979*	*1980*	*1981*	*1985*	*1990*	*2000*
Market economies of Western Europe	120	120	130	130	128	130	130	140
Japan	80	90	100	100	90	95	105	115
United States	120	108	120	100	108	120	125	140
Other developed market economies	36	52	60	60	54	55	60	65
Total, developed market economies	356	370	410	390	380	400	420	460
Latin America	13	18	40	40	43	55	70	140
Petroleum-producing countries	2	6	15	15	17	20	40	100
Total, Latin America and petroleum-producing countries	15	24	55	55	60	70	110	240
Least developed countries of Asia,[a] Africa[b] etc.	16	16	16	17	18	40	60	150
European centrally planned economies[c]	180	195	213	203	208	220	230	250
China and other centrally planned economies[c]	32	42	52	52	47	65	80	150
Total, centrally planned economies[c]	212	237	265	255	255	285	310	400
Total	599	647	746	717	713	800	900	1 250

[a] Excluding China, Japan and petroleum-producing countries.

[b] Excluding petroleum-producing countries and South Africa.

[c] Estimate.

TABLE 14. AVERAGE ANNUAL INCREMENTS OF STEEL CONSUMPTION

(Percentage)

Economic grouping, region or country	*1970-1975*	*1970-1980*	*1980-1985*	*1985-1990*	*1990-2000*
Market economies of Western Europe	- -	1.0	- -	- -	1.5
Japan	2.3	2.1	1.0	2.0	1.9
United States	2.1	1.5	3.5	0.8	1.1
Other developed market economies	7.0	5.0	1.7	1.7	1.6
Average, developed market economies	0.8	1.0	0.5	1.0	1.8
Latin America	6.4	11.0	6.4	4.8	13.3
Petroleum-producing countries	20.0	22.0	5.7	13.3	17.1
Average, Latin America and petroleum-producing countries	22.8	13.5	6.2	7.6	7.4
Least developed countries of Asia,[a] Africa[b] etc.	- -	1.0	5.7	8.0	17.1
European centrally planned economies	1.6	0.8	1.6	0.9	0.8
China and other centrally planned economies	5.0	5.0	4.6	4.1	6.0
Average, centrally planned economies	2.2	1.8	2.2	1.7	2.5
Overall average	1.5	1.8	2.1	2.4	3.2

[a] Excluding China and Japan.

[b] Excluding petroleum-producing countries and South Africa.

TABLE 15. SHARE OF ECONOMIC GROUPINGS IN WORLD ALUMINIUM CONSUMPTION, 1970-2000

(Percentage)

Economic grouping	*1970*	*1980*	*1985*	*1990*	*2000*
Developed market economies	78	74	72	72	69
Semi-industrialized developing countries	3	5	6	6	8
Least developed countries	3	3	3	3	4
Centrally planned economies	16	18	19	19	19
Total	100	100	100	100	100

TABLE 16. SHARE OF ECONOMIC GROUPINGS IN WORLD STEEL CONSUMPTION, 1970-2000

(Percentage)

Economic grouping	*1970*	*1980*	*1985*	*1990*	*2000*
Developed market economies	60	54	50	47	37
Semi-industrialized developing countries	2	8	9	12	20
Least developed countries	2	2	5	6	12
Centrally planned economies	36	36	36	35	31
Total	100	100	100	100	100

of industrial development), where the market is not saturated, electrical engineering is the main civil consumer;

(b) As a result of world-wide industrial development it appears probable that end-use patterns of all main economic groupings will gradually approach the present patterns of the developed market economies;

(c) World demand for highly processed, special aluminium semi-manufactures is increasing, and, as a result, the borderline between aluminium semi-manufactures and finished goods becomes increasingly blurred. This phenomenon manifests itself in some developed countries with small populations where a sharp increase in the exported share of semi-manufactures may be greater than 50 per cent of the total production. Assembly plants and workshops for the use of these goods are mushrooming in the developing countries;

(d) It is unlikely that new products for civil use that would consume significant quantities of aluminium will emerge in the next 20 years, even in the developed countries. This statement seems to be well proven by the case of Italy [17], as presented in table 17;

(e) Some previous observations remain valid [6]. In the developed countries the need to save energy will call for an increase of aluminium consumption in transport vehicles, electrical industries, the production of heat exchangers and vessels, mass production of some machine components, and the production of vacation and sporting goods. However, the growth of aluminium consumption for building and packaging will stop. In this initial period of development for developing and semi-industrialized countries, the use of aluminium in electrical industries and in some cases the wide-spread use of packaging goods made for aluminium (e.g. for fish, milk processing and other canned products) and the establishment of industries to produce household goods has an important role. Other aluminium-consuming sectors will grow as well, depending on a country's economy. Agriculture requires up-to-date cold storage plants, irrigation installations, desalination plants and prefabricated building structures. Components for vehicles and machines first appear in assembly plants. Later on these are made in separate production facilities, such as high-quality mould-casting foundries;

TABLE 17. ALUMINIUM CONSUMPTION BY INDUSTRIAL SECTOR IN ITALY, 1977 AND 2000

(Percentage)

Sector	*1977*	*2000 (estimate)*
Transport vehicles	27	30
Mechanical engineering	8	5
Electrical engineering	5	10
Building and construction	18	25
Packaging	8	5
Household and other fabricated items	11	10
Miscellaneous	23	15
Total	100	100

Source [17].

(f) Parallel to the development of aluminium processing, recycling aluminium scrap should begin. Some 21-26 per cent scrap can be used in producing aluminium.

Table 18 summarizes aluminium consumption by end-uses for a few characteristic countries and for the developed market economy countries of Europe.

Aluminium consumption is always affected by competition from other materials. Figure VII shows past growth of aluminium production and gives four possible scenarios for the future.

Pricing

The world market prices of principal structural materials and their relation to aluminium over the 1935-1981 period are shown in tables 19 and 20. From the end of the Second World War a marked shift in favour of aluminium has taken place to the detriment of copper and steel. The 1973 rise in oil prices did not significantly affect the relative pricing of metals, and fluctuations in aluminium and copper prices were largely due to transient market speculation. Even the second great increase in petroleum prices and the ensuing recession could not affect most price ratios (some types of alloyed steel and plastic are an exception). Recently fundamental improvements in production technology have resulted in a significant shift in prices, to the detriment of aluminium [19]. As a result, sectors such as food industries and machinery for chemical industries showed a drop in aluminium demand, and there has been an increase in the use of stainless steel for the production of transport vehicles. The temporary fluctuation in 1981 can be seen in the great difference of the ALCAN mean price and the free quotation on the London Metal Exchange.

Published forecasts agree that the 1970 level of relative pricing of structural materials will persist, although a rise in prices for the period after 1983 is predicted. Price increases are considered to be necessary to ensure the economical operation of new capacities that are coming on stream to meet increasing demand. The magnitude of the increases will depend on the actual costs of

TABLE 18. ALUMINIUM USE BY SECTOR IN EUROPEAN MARKET ECONOMIES AND IN SELECTED OTHER COUNTRIES

	European market economies, 1979[a]		*Argentina, 1978*[b]		*Brazil, 1980*[c]		*Egypt, 1980*[d]		*Hungary, 1979*[e]		*India, 1979*[f]		*Japan, 1979*[g]		*South Africa, 1980*[g]		*United States, 1977*[a]	
Sector	*Thousands of tonnes*	*Percentage*	*Thousands of tonnes*	*Percentage*	*Thousands of tonnes*	*Percentage*	*Thousands of tonnes*	*Percentage*[h]	*Thousands of tonnes*	*Percentage*	*Thousands of tonnes*	*Percentage*	*Thousands of tonnes*	*Percentage*	*Thousands of tonnes*	*Percentage*	*Thousands of tonnes*	*Percentage*
Transport	1 137	20.0	9.0	13.0	67.7	19.2	1.2	4.0	14.7	7.9	31.0	10.0	505	21.2	3.9	7.0	1 368	22.6
General engineering	286	5.1	28	4.0	14.5	4.1	- -	- -	12.8	6.8	- -	- -	424	17.8	- -	- -	356	5.9
Electrical engineering	443	7.9	19.3	27.9	75.9	21.5	5.9	19.5	32.4	17.5	170.5	55.0	257	10.8	16.4	29.3	592	9.8
Building and construction	764	13.6	13.8	19.9	84.1	23.8	9.0	30.0	18.5	9.9	15.5	5.0	781	32.8	7.8	14.0	1 381	22.8
Chemical, food and agricultural appliances	68	1.2	9.7	14.0	28.6	8.1	- -	- -	4.4	2.4	- -	- -	125	5.2	10.0	17.9	81	1.3
Packaging	410	7.3	- -	- -	- -	- -	0.3	1.0	10.1	5.4	12.4	4.0	- -	- -	- -	- -	1 278	21.1
Domestic and office appliances	355	6.3	4.1	5.9	51.5	14.6	13.6	45.5	5.4	2.9	62.0	20.0	47	2.0	8.4	15.0	415	6 9
Powder-consuming industries	30	0.5	- -	- -	- -	- -	- -	- -	5.0	2.7	- -	- -	- -	- -	3.3	5.9	48	0.6
Iron and steel industries	203	3.6	- -	- -	- -	- -	- -	- -	- -	- -	- -	-	- -	- -	- -	- -	110	1.8
Metal industries not elsewhere specified	504	8.9	2.0	2.9	30.7	8.7	- -	- -	27.3	14.6	18.6	6.0	137	5.7	6.2	11.1	180	3.0
Miscellaneous	- -	- -	- -	- -	- -	- -	- -	- -	14.7	7.9	- -	- -	- -	- -	- -	- -	- -	- -
Export of semi-manufactures, foil, cable powder	1 433	3.9	8.5	12.3	- -	- -	- -	- -	41.7	22.3	- -	- -	108	4.5	- -	- -	238	3.9
Total	5 633	100.0	69.2	100.0	353.0	100.0	30.0	100.0	187.0	100.0	310.0	100.0	2 384	100.0	56.0	100.0	5 633	100.0

[a] European Aluminium Statistics, 1979.

[b] *Aluminium*, vol. 58, No. 1 (1982), p. 68.

[c] *Ibid.*, p. 71.

[d] *Ibid.*, p. 45.

[e] *Magyar Aluminium*, No. 18, 1981, p. 215.

[f] *Aluminium*, *op. cit.*, p. 50.

[g] Statistical data of NIMDOK, Budapest, 1981.

[h] Only semi-manufactures.

TABLE 19. MEAN WORLD PRICES OF SELECTED STRUCTURAL MATERIALS, 1935-1981

(Dollars per tonne)

Material	*1935*	*1950*	*1955*	*1960*	*1965*	*1970*	*1975*	*1976*	*1977*	*1978*	*1979*	*1980*	*1981*
Aluminium[a]	482	370	500	577	545	614	860	969	1 108	1 167	1 398	1 714	1 750
Copper[b]	172	472	500	712	780	1 393	1 205	1 381	1 293	1 358	1 945	2 167	1 584
Lead	69	300	332	265	260	304	446	446	617	--	1 202	937	639
Zinc	68	210	273	287	320	296	745	711	589	--	743	747	804
Tin	1 090	--	--	--	3 428	3 673	6 870	7 583	10 789	17 000	15 462	17 158	13 889
Tinned sheet-iron	--	--	--	--	--	--	487	480	571	605	665[c]	793[c]	764[c]
Steel rods	34	65	--	--	--	93	173	168	154	220	311[d]	324[d]	293[d]
Polyvinyl chloride[e]	--	--	--	350	351	359	642	566	619	650	825	680	550
Cement	--	6	--	7	8	120	20	--	25	29[f]	31[f]	34[f]	. .

[a] ALCAN mean price.

[b] Cathode copper.

[c] Estimate.

[d] *Metal Bulletin*, mean price.

[e] Mean price in the Federal Republic of Germany.

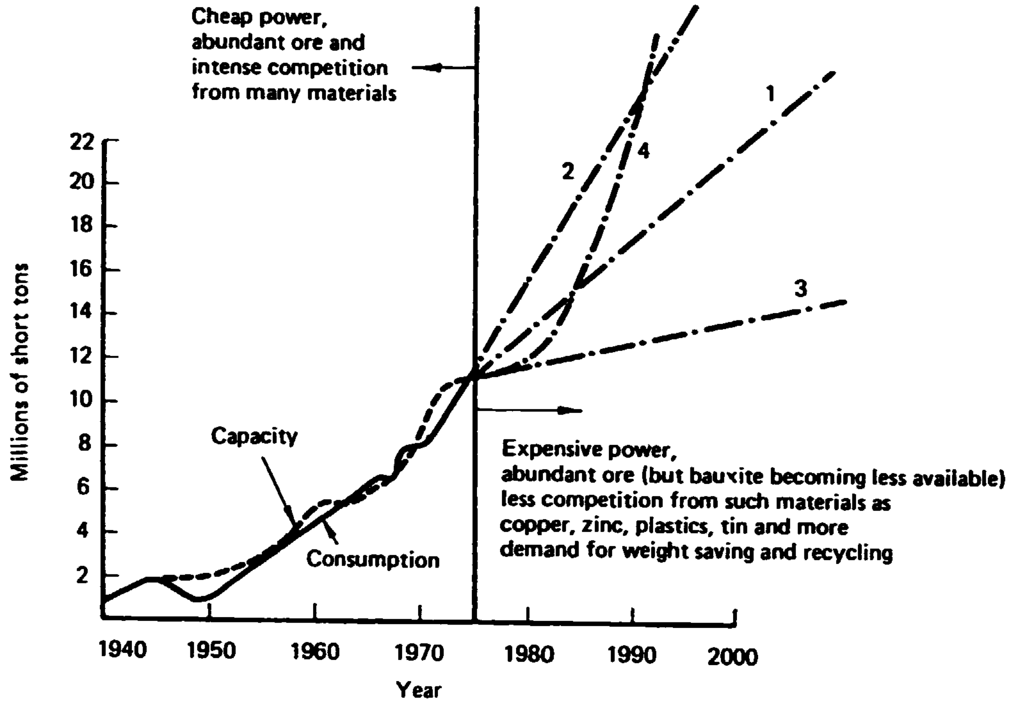
[f] Mean prices in France and Italy.

TABLE 20. RELATIVE WORLD PRICES OF SELECTED STRUCTURAL MATERIALS, 1935-1981

(Index relative to mean price of aluminium)

Material	*1935*	*1950*	*1955*	*1960*	*1965*	*1970*	*1975*	*1976*	*1977*	*1978*	*1979*	*1980*	*1981*
Aluminium	100		100	100	100	100	100	100	100	100	100	100	100
Copper	36		100	123	143	277	140	142	117	116	139	126	91
Lead	14	81	66	46	48	50	52	46	56	--	86	55	37
Zinc	14	57	55	50	59	48	87	73	53	--	53	44	46
Tin	226	--	--	--	529	598	799	782	974	1 456	1 106	1 001	754
Tinned sheet-iron	--	--	--	--	--	--	57	49	51	52	48	46	44
Steel rods	7	18	--	--	--	15	20	17	14	19	24	19	17
Plastics	--	--	--	61	64	58	75	58	56	56	59	40	31
Cement	--	2	--	1.2	1.5	1.6	2.3	--	2.2	2.5	2.2	2.0	. .

Figure VII. World[a] growth of the aluminium industry, 1940-1975, and estimated growth, 1975-2000 [18]



Key:

1 Growth rate is similar to that of 1940-1975.

2 Aluminium is used to replace copper, zinc and plastics.

3 Insufficient smelter capacities and rising energy prices have a marked effect in the building, transport vehicle and electrical engineering sectors.

4 More aluminium is used to replace other structural materials, but surplus demand has to be met by the available smelter capacities. New smelter capacities expected to go on stream in the mid-1980s to meet such extra demand are calculated to embody new technologies based on raw materials other than bauxite.

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[a] Excluding China and the USSR.

energy and capital. Advantages gained owing to savings as a result of low energy prices in some of the developing countries may be endangered by higher capital costs for the construction of smelters [14]. Forecasts predict an average annual increase of 3 to 5 per cent in aluminium prices. Higher average increases will be forestalled by the gradual emergence of new smelters, using cheap energy, in developing countries. Excessive prices of aluminium can easily lead to substitution by other materials. It appears probable that most of the new increments in aluminium consumption will be limited to a few sectors in which the application of aluminium yields economic advantage, such as electrical engineering, transport vehicles and packaging.

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II. Use of aluminium in new applications

In assessing the suitability of aluminium as a substitute for other structural materials, the benefits for a given country or area and the availability of raw materials and power must be considered. In addition the following have to be taken into account:

(a) The economic structure and distribution pattern of capital for the area involved;

(b) The experience of local labour;

(c) The domestic market and how far it may be influenced by intervention of government agencies.

To apply these considerations to aluminium, both favourable and detrimental conditions, as discussed below, must be considered.

Favourable considerations

Raw materials

Some 90 per cent of the world's aluminium output is produced from bauxite using the Bayer process. Assuming a 5 per cent annual average growth rate in consumption, the world's total bauxite ore reserves are sufficient for 150 years of aluminium production [1]. In addition to commercial-grade bauxite ores, there are also supplementary resources of poor-grade bauxites and other substances with low Al_2O_3 content, such as clay and ash. Efforts have been undertaken to economically process aluminium from these on an industrial scale. Considering this vast potential, the raw material to feed aluminium smelters seems likely to last almost indefinitely. Practically all high-grade bauxite reserves are located in the tropical areas of developing countries; Australia is the only developed country with substantial reserves. Thus, from a raw material point of view, the possibilities of expanding aluminium smelter operations appear to be practically unlimited.

Another important material used in operating an aluminium smelter is petrol coke, which is likely to be in short supply by the end of the century [1].

Energy

An indispensable prerequisite for running an aluminium industry economically is inexpensive electrical energy. The operation of an aluminium smelter of 100,000 t/a capacity calls for a steady power of 180 MW. In industrialized countries—where, up to 1970, most of the world's aluminium smelters were located—further large-scale expansion of power-intensive aluminium smelters does not appear to be feasible. The operation of new smelters in such areas could only be based on nuclear power. A case in point is the United Kingdom, where the aluminium smelters erected in the 1970s are connected to a grid where 60 per cent of all electrical energy transmitted is being generated in nuclear power plants. By contrast, there is still a vast unharnessed hydroelectric energy potential in the developing countries, as tabulated below [2]:

	Untapped hydroelectric power potential	
Continent	*(Percentage of total available)*	*(MW)*
Africa	98	429 000
South America	93	269 000
Asia (excluding the USSR)	93	637 000

In addition, the oil-producing countries have large amounts of natural gas that are burned away without being put to any particular use.

Fabricated products

With regard to fabricated products, the situation is somewhat different. For the manufacture of finished products, a stable aluminium ingot market, however desirable in itself, may not solve all problems. An equally essential consideration is to have sufficient and effective semi-manufacturing capacities that are capable of taking care of the full demand from the aluminium end-using sectors. The installation of semi-manufacturing facilities to produce a fair selection of basic semi-manufactured items for use by the finished product manufacturers may be feasible from a technological and economic point of view even if operations are kept at a more modest scale. Metal won in the smelter may be processed to semi-manufactures in the molten state forthwith by continuous casting equipment located at the smelter; such equipment could produce 10.000 to 20.000 tonnes of aluminium strip or rod wire annually. Extruded shapes, profiles and tubes, by contrast, should be manufactured elsewhere, using cast aluminium billets from the smelter. The installation of smaller semi-manufacturing capacities, while designed to produce many items (except wide strips), does not call for substantial capital investment and may also be expanded, if justified by demand.

Price levels

Until the end of the 1970s, some 70-75 per cent of total aluminium production by developed countries could be accounted for by six firms, the joint business policy of which determined the market price of aluminium. In order to expand aluminium consumption and penetrate new areas for aluminium use, the companies tended to keep aluminium prices as stable as possible. That is how the so-called "official" market price of aluminium came into being. The official aluminium price remains practically unchanged over long periods, sometimes for two to three years. From 1965 to 1973 it rose by only 10 per cent, corresponding to an average annual increase of 1.3 per cent [3]. In principle, 90 per cent of all aluminium market transactions are based on the official price.

Owing to the growing integration in the aluminium industry, a considerable part of aluminium produced by the major companies is sold to subsidiaries and affiliated companies, which receive special confidential discounts to protect them against market fluctuations. When there is a recession, such confidential discounts are frequently granted to independent producers as well. In addition to the official market price, the London Metal Exchange quotes (in an unofficial capacity) so-called "free market prices", at which, however, only marginal volumes of business are transacted. When demand and supply are balanced, there is no significant difference between the two prices. From October 1978, the London Metal Exchange quoted an official aluminium price as well. In 1981 there was a large difference (30-40 per cent) between the official price and the London Metal Exchange price.

This stable system of pricing undoubtedly contributed to the annual 9-11 per cent growth of aluminium consumption throughout the 1960s. The pricing policy has vigorously intensified aluminium usage in, for example, the building trade, packaging and transport equipment. However, certain drawbacks of the artificially stable aluminium prices became manifest after the 1973 oil price rise when profits from aluminium production began to decline sharply. By then, smelter capacities of the six major firms dropped to 44 per cent of world market capacity, after new and partly government-backed aluminium projects went on stream in developing countries [4]. To make up for losses, the major companies raised aluminium prices by 62 per cent over the period 1973-1976 [3]. Recently, aluminium production has become more economical, and there have been no significant changes in the price of aluminium in relation to most other structural materials (the 1977 to 1978 record low price of copper was only temporary). After the rise in oil prices, some of the structural materials displayed marked price fluctuations, however, aluminium prices did not display such behaviour. Figure VIII is a comparison of aluminium conductor and extrusion prices with those of rolled steel products in France [5].

Competitiveness

The recent widespread use of aluminium is only partly due to shifts in the price of other structural materials compared to relatively stable aluminium prices. The real reason for widespread use also lies in certain unique physico-technical properties of aluminium. In aviation and space research, lightness coupled with relatively high mechanical strength and good corrosion resistance make the metal highly competitive.

Aluminium may be used for economic or technical reasons. Shifts in pricing cause aluminium use to be economically attractive, and aluminium could be used to replace heavy non-ferrous metals. Modern aluminium structures may be more useful than those of traditional design and price is considerably lower. Typical examples are aluminium conductors instead of copper ones, aluminium collapsible tubes and foils instead of tin ones or screw-bottle closures (pilfer-proof caps) instead of corks. According to an inquiry made in the Federal Republic of Germany in 1970, the average cost of cork bottle closures was DM 0.045-0.100 per piece, and the price of aluminium screw-bottle closures was DM 0.02 per piece. Substitution of zinc rain-water hardware by aluminium or the use of aluminium coolers instead of heat-exchangers made from stainless steel or tin-coated copper are other examples.

However, even where costs are higher than those of traditional designs, the technical features of aluminium may make its use advantageous. Such aluminium applications may eventually return a profit, despite higher purchase price. Examples include various aluminium constructions used by the building trade, window and door frames or aluminium components used by other industries to enhance operational efficiency, for example pistons, machine accessories for textile mills and heat exchangers. These items require little or no maintenance expenditure.

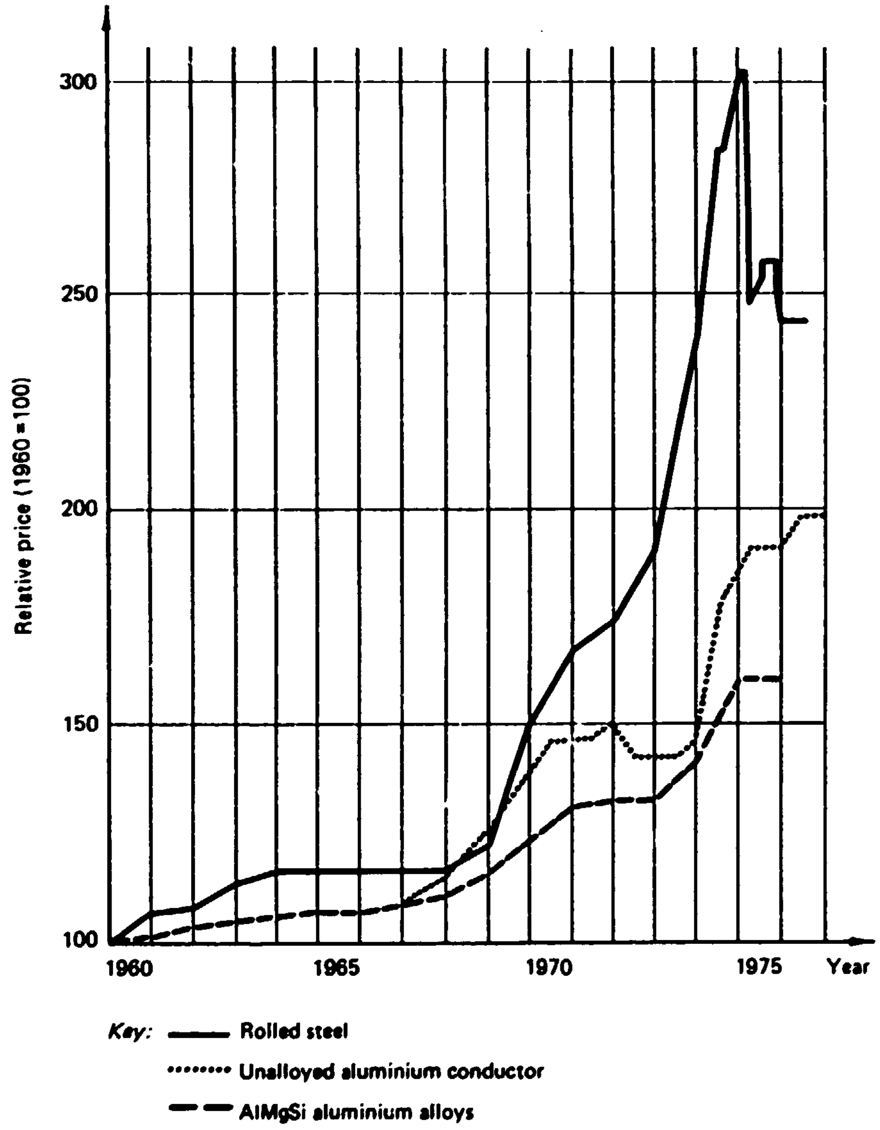
The following positive features of aluminium are of special interest:

Economies in energy
Environmental protection
Benefits from scrap recycling
Savings in labour
More comfort for the user

In feasibility studies it is not enough to examine whether or not aluminium is an equivalent alternative to the material to be replaced; it is very important that the consumer should benefit from its use. Thus, the relative pricing of raw materials involved in the production process has to be carefully examined, along with the amount, value and usefulness of scrap. In comparing, for example, aluminium and tin-plate bottle closure manufacture, allowance has to be made for 30 per cent scrap that results from cutting the discs to shape. While the recoverable aluminium scrap represents 9 per cent of the value of the aluminium sheet used, the corresponding figure for tin-plate is only 0.6 per cent [6].

The design of an aluminium structure should permit optimal utilization of the metal's favourable properties. The simple application of aluminium in designs originally prepared for other materials is uneconomical and doomed to failure from the

Figure VIII. Prices of aluminium semi-manufactures and rolled steel in France, 1960-1976 [5]



outset. A good example of how aluminium may be used economically is the latest metro carriage designed by Alusuisse, which features large aluminium extrusions for framings. Such carriages are 30 per cent cheaper than those of conventional design with steel framing [7].

For an accurate comparison, a detailed analysis has to be made of all operations involved in manufacture and assembly, with special regard to savings in time and labour. Several examples of this may be cited in the building trade and metalworking industry. The cost of materials for erecting conventional buildings for agriculture and livestock are 17 per cent lower than that of light aluminium panel construction, but the cost of labour and time to erect the latter is 30 per cent less. Thus, the cost is about the same. Moreover, light aluminium construction is well-suited for serial manufacture and for major agricultural facilities, such as cold-storage rooms or complex poultry farms, that are to be erected in remote areas of countries.

Special attention has to be devoted to the changing pattern of energy resources and rising energy costs. Throughout the world great strides are being made to save energy and there is now a universal demand for reducing the weight of transport vehicles. The price of structural materials used in the manufacture of such products, is a crucial factor in determining the viability of aluminium versus steel.

The good corrosion-resisting properties of aluminium allow considerable savings in maintenance costs. It is estimated that the maintenance cost for a steel structure over a period of 30 years will be 30-70 per cent of its initial cost, plus 0.6-1.0 hours of labour per square metre per year. For example, considering initial costs and interest costs, it appears that aluminium wire fencing may become more economical than that made from steel after six to eight years [8].

Aluminium presents great advantages for environmental protection. While the destruction of plastic scrap is difficult and the handling of steel scrap is cumbersome in view of its weight and volume, the collaboration of aluminium scrap and its recycling is relatively simple and inexpensive [9]. In the United States a recent campaign to collect and remelt discarded aluminium beer cans resulted in an increased turnover of aluminium-canned drinks.

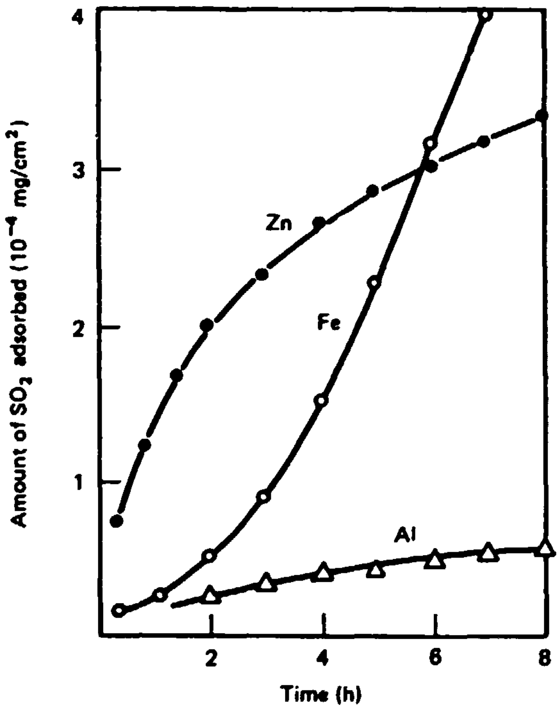
Technical features

The nature of end use determines whether low specific weight, good electrical conductivity, thermal conductivity or corrosion resistance are the principal properties sought in selecting aluminium as a structural material. Of course, it would be an ideal state of affairs if all these superior properties could be used for every application. This, however, is not the case, there being marked interactions between some of these properties. It is thus necessary to focus on properties that are most desirable in meeting some specific end. For example, the corrosion resistance and susceptibility to plastic deformation of high-strength alloys are inferior to those of medium-strength ones.

An important consideration in choosing aluminium to replace another structural material is its corrosion resistance, which is especially marked in an industrial environment polluted by SO_2. Table 21 is a comparison of SO_2 corrosion rates for steel, zinc and aluminium surfaces [9, 10] after 10 and 20 years at several locations in the United States. The rate of corrosion observed in aluminium, copper and zinc exposed over a long period to different types of corrosive environment has been the subject of a special study; the findings shown in figure IX demonstrate that the rate of corrosion has been smallest with aluminium [11].

Table 22 gives the prices of various structural materials in relation to their mechanical strength [12]. For tensile strength, the price of expanded concrete, high-tensile steel, cast iron and some

Figure IX. Sulphur dioxide adsorption on metal surfaces



Note: Period of time, 8 hours; relative humidity, 90 per cent; SO_2 content of atmosphere, 0.1 ppm.

Source: [10].

TABLE 21. RATE OF CORROSION OF ALUMINIUM, COPPER AND ZINC UNDER DIFFERENT CONDITIONS

(mm/a)

		Aluminium, 99.2 per cent		*Copper, 99.9 per cent*		*Zinc, 98.9 per cent*	
Location	*Climate or atmospheric condition*	*After 10 years*	*After 20 years*	*After 10 years*	*After 20 years*	*After 10 years*	*After 20 years*
Phoenix, Arizona	Desert climate	1×10^{-5}	7.6×10^{-5}	1.3×10^{-4}	1.3×10^{-4}	2.5×10^{-4}	1.8×10^{-4}
State College, Pasadena, California	Continental climate	2.5×10^{-5}	7.5×10^{-5}	5.8×10^{-4}	4.3×10^{-4}	1.1×10^{-3}	1.1×10^{-3}
La Jolla, California	Maritime climate	7.1×10^{-4}	6.3×10^{-4}	1.3×10^{-3}	1.3×10^{-3}	1.7×10^{-3}	1.7×10^{-3}
New York, New York	Industrial atmosphere	7.9×10^{-4}	7.4×10^{-4}	1.2×10^{-3}	1.4×10^{-3}	4.8×10^{-3}	5.6×10^{-3}

Source: [11].

TABLE 22. PRICES OF SELECTED MATERIALS COMPARED TO MECHANICAL STRENGTH

						Price per unit of strength (£/MN·m)		
Material	*Tensile strength (MN/m²)*	*Modulus of elasticity (GN/m²)*	*Fatigue (MN/m²)*	*Density (t/m³)*	*Price (£/t)*	*Tensile strength*	*Modulus of elasticity*	*Fatigue*
Cast iron	400	35.0	105.0	7.30	135	2.46	0.03	9.4
Cu-Zn alloys	400	37.3	140.0	8.36	515	10.75	0.12	30.7
Carbon steel	250	77.0	193.0	7.85	140	4.4	0.01	5.7
Alloyed steel	800	77.0	495.0	7.83	212	2.1	0.02	3.4
Titanium alloys	960	45.0	310.0	4.51	6 500	30.5	0.65	94.5
Aluminium alloys	300	26.0	90.0	2.70	800	7.2	0.08	24.0
Magnesium alloys	190	17.5	95.0	1.70	2 500	22.0	0.24	44.7
Oak	14	4.5	6.0	0.67	895	43.0	0.13	106.0
Polypropylene	30	0	7.5	0.90	325	9.7	0	39.0
Nylon 66	80	0	24.0	1.36	925	15.7	0	63.0
Polyvinyl chloride	50	0	12.0	1.40	240	6.7	0	27.0
Expanded concrete	38	10.0	23.0	2.50	23	1.5	0.01	2.4

Source: [12].

plastics is lower than that of aluminium. Aluminium compares favourably to the other materials listed, however, a fact that can be ascribed to its low specific weight.

How the favourable technical features of aluminium have affected the consumption pattern of some end-using sectors is discussed at length in chapter IV. That chapter also gives more details as to how aluminium may be used to replace other structural materials.

Recycling

In developed countries remelted aluminium scrap accounts for some 25 per cent of total aluminium consumption. Collected, sorted and cleaned, aluminium scrap is remelted by various metallurgical processes in the course of which it disposes of its non-metallic impurities. While earlier some 10-15 per cent of the scrap was irretrievably lost in the remelting process, this figure has now dropped to a few per cent upon the emergence of new remelting techniques. Also, thanks to fresh advances in such metallurgical processes, traces of oxidic and non-metallic impurities remaining in secondary metal won from scrap could be reduced by 100-200 per cent. The energy used in the remelting process, too, has declined sharply from 2,000 to 3,000 kWh/t to 800 kWh/t [13]. Secondary ingots remelted from carefully handled scrap, with an addition of a proper percentage of alloys, are in every respect equivalent to casting ingots won in the aluminium smelters.

A breakdown of scrap recovered in Hungary is given, for example, below:

	Percentage
New industrial scrap	40
Old scrap, discarded by the population	40
Turnings	20
Total	100

About two-thirds of the collected scrap is remelted to form casting ingots. One-third is added to slab and billet charges at the mills or used as a deoxidant in steel metallurgy.

A fairly elaborate organization is required to collect and sort scrap. Mixed scrap is difficult and costly to refine by metallurgical methods. It seems therefore expedient that upon the installation of any aluminium fabricating facility the effective collection, sorting, storage, handling and remelting of scrap be taken into account, together with arrangements for marketing the resultant secondary metal.

Other considerations

Power and capital requirements

Two basic considerations when installing an aluminium smelter are the abundance of cheap energy and the availability of large amounts of capital (much more than that required for setting up other raw material production facilities). Bauxite and alumina operations on site or in the area are not an absolute prerequisite, as aluminium is easily transported over large distances.

Until the 1960s, generally, only developed countries and centrally planned economies could afford to erect aluminium smelters. Thus, most such facilities are located in Europe, North America and the Union of Soviet Socialist Republics, where large amounts of hydroelectric and thermal power are available. The proximity of the consumer markets, too, had been an important consideration.

The location of new smelter projects is nowadays almost exclusively governed by the large energy requirements of smelting operations. It has become increasingly difficult for developed countries to supply abundant amounts of cheap energy. Hence, it is necessary to site new smelters in locations where a sufficiently large potential of cheap power exists. The tapping of new energy resources, however, invariably calls for further capital investment. Electrical energy is at present the largest and most significant cost consideration in the electrolytic extraction of aluminium.

The amount of energy involved in aluminium production is demonstrated in table 23, where a comparison of energy consumed at each successive step of production from the raw material to the semi-fabricating stage is compared to that for steel, copper and aluminium [14].

The huge energy requirements for aluminium production are striking. The requirement is high even after allowance is made for the lower specific weight of aluminium and the fact that by adding suitable alloys a composition may be obtained whose mechanical properties approximate those of mild steel. In calculating this, the energy demand of aluminium will be no longer 8 times, but only 2.7 to 3 times that of steel. By the same reasoning, energy involved in the manufacture of copper and aluminium conductors will be practically identical after allowance has been made for the difference in specific weights.

TABLE 23. ENERGY CONSUMPTION AT EACH STAGE OF STEEL, COPPER AND ALUMINIUM PRODUCTION

(GJ/t)

Stage	*Steel rounds, 30 mm diameter*	*Rolled copper wire*	*Aluminium sheet*
Mining, quarrying	..	51.9	4.2
Coking	20.1	—	—
Concentration	5.9	—	—
Crushing	—	20.9	5.9
Flotation	—	7.5	—
Alumina manufacture	—	—	41.9
Smelting	0.3	14.2	218.5
Steel manufacture	6.6	—	—
Electrolytic refining	—	12.6	—
Rolling	5.4	18.4	28.1
Total		125.0	298.7
Total (GJ/m³)		1 130.0	795.6

Source [14]

Surplus costs of energy incurred in manufacturing an aluminium product, however, may be recovered during subsequent use. An example is the energy saving derived from using transport vehicles with aluminium components.

Not only is aluminium production significantly more energy intensive compared to that of other metals (especially steel and copper), but the implementation of fully integrated aluminium projects calls for large capital expenditure. A model calculation is shown in table 24. Capital required for the installation of a 100,000 t/a aluminium complex is set out in detail. It should be noted that:

(a) The production pattern in stage IV (finished products) was chosen randomly;

(b) Estimated capital costs do not include infrastructure and social welfare facilities;

(c) Though the aluminium smelter itself is calculated to operate at 200 MW, the investment cost estimate does not include the installation of a power plant;

(d) Capital investment at each successive stage of integration may in actual practice greatly vary with the magnitude of capacities involved and the actual technologies used. Therefore, medium figures have been used;

(e) Capacities at each successive stage suggest realistic figures from an economic feasibility point of view; they are, moreover, co-ordinated to meet demand at the next stage;

(f) To facilitate matters, exports of raw materials and semi-manufactures have not been calculated.

According to table 24, the total investment costs of the hypothetical 100,000 t/a integrated aluminium complex are on the order of $670 million at 1977 dollar values.

The first stage of production includes raw material operations, including the mining or quarrying of bauxite, alumina manufacture and aluminium smelting and accounts for about 50 per cent of total cost.

The second stage is semi-manufacturing. Its share is 38 per cent of the total investment cost. Continuous casting of strip metal and rod wire

TABLE 24. INVESTMENT COSTS FOR A FULLY INTEGRATED 100,000 t/a ALUMINIUM PROJECT

(At 1977 dollars)

Production stage	*Operations and products*	*Investment costs (dollars per tonne)*	*Products or capacities (thousands of tonnes)*	*Breakup and total of investment costs (million dollars)*
I. Raw material	Bauxite operations	45-65	600	40.0
	Alumina manufacture	500	200	100.0
	Aluminium remelting[a]	2 000	100	200.0
Total, raw material				340.0
II. Semi-manufacturing	Continuous strip casting	2 180	55	120.0
	Continuous wire-rod casting	250	20	5.0
	Extrusion	2 700	20	54.0
	Foil manufacture and finish	4 000	5	20.0
	Casting (by machine)	4 440	7.5	33.0
	Casting (sand and gravity die, sited on an industrial scale)[b]	4 000	2.5	10.0
	Scrap remelting	200	20	4.0
Total, semi-manufacturing				246.0
III. Semi-manufacturing finish[c]	Anodization of sections	670	3	2.0
	Disc cutting	20	10	0.2
	Tube welding	230	3	0.7
	Corrugation of sheet	60	10	0.6
	Prepainting of sheet	700	10	7.0
Total, semi-manufacturing finish				10.5
IV. Finished products	Uninsulated conductors (drawing and stranding)	470	10	4.7
	Insulated conductors and cables	1 220	10	12.2
	Collapsible tubes and aerosol bottles	2 560	5	12.8
	Building structures	500	15	7.5
	Heat exchangers	1 000	5	5.0
	Holloware and thick-walled packaging items	800	5	4.0
	Equipment for foil packaging	300	3	0.9
	Components of mechanical engineering	800	7	5.6
	Sundry structural components	300	5	1.5
	Other metalworking items	500	20	10.0
	Household products	600	10	6.0
Total, finished products				70.2
Grand total				666.7

[a] The cost of installing a power plant is not included.

[b] Investment costs of a less complex gravity die-casting foundry would be about $2,000 to $2,500.

[c] Equipment, excluding premises. To avoid overlapping, tonnages are not summarized.

represents 50 per cent of the semi-manufacturing investment cost. The continuous-casting operation, however, is physically located near the smelter. If this is considered, the share of investment costs for raw material operations in the first stage will rise to 70 per cent and those of the remaining semi-manufacturing facilities (including extrusion, foil manufacture, casting and scrap remelting) will drop to 18 per cent.

The third stage encompasses finishing operations for semi-manufactures (for example, the surface treatment of cut sections used in prefabricated motor vehicle bodies). For technological and financial reasons, it is desirable to have such processes located at the mill. The share of investment is 2 per cent.

In the fourth stage, the finished aluminium is "manufactured". This accounts for 10 per cent of the total investment costs of the integrated project. The location of these facilities is governed by practical considerations. Manufacture may begin first on a small scale and be expanded later.

Raw materials must be supplied by domestic producers or by outside sources. If local circumstances, such as lack of power, insufficient capital or low domestic demand, do not permit the installation of domestic raw material manufacturing facilities, there are other ways of obtaining semi-manufactures or ingots under long-term agreements with foreign sources. If a 100,000 t/a aluminium finished-product industry such as that demonstrated in the model is based entirely on imported raw materials, the investment costs involved in the project—including operations in stage III—are estimated to be $80 million. If semi-manufacturing facilities are installed for making extrusions, foils or castings (which may use imported ingots) investment costs shown for stage IV may rise by another $100 million.

Engineering demands

The chemical, physical and mechanical properties of aluminium differ in many ways from those of other metals. In view of this, the handling and processing of aluminium calls for technologies that often may be regarded as a departure from conventional methods of metallurgy. Even the transport and storage of aluminium require particular care. Defective packaging, rough handling en route or poor storage may cause the vapour that repeatedly condenses and evaporates onto the surface to leave stains or promote corrosion. The surface of aluminium may be damaged by metal turnings, iron scale and coke or sand. This may be avoided by storing the aluminium under clean, well-aired conditions. Otherwise trouble may result in successive processing.

Almost aseptic cleanliness is needed in technological shops. In processing aluminium, it is wrong to use, without further treatment, any equipment, including machinery or dies, that has previously handled other materials. Before feeding aluminium into such equipment all components, dies and even the premises themselves have to be carefully cleaned.

The machining of aluminium in some ways resembles that of timber rather than steel. The similarity is enhanced by the use of high-speed cutting machines, although special tools suitable for aluminium have to be used. Although aluminium is a malleable metal, lending itself well to plastic deformation, dies of special design are required as aluminium is highly sensitive to the surface smoothness of the die. The deep-drawing of soft aluminium, for example, calls for dies of a harder surface than those used for less deformable and more robust steel. Technological instructions derived from inherent properties of the metal, for example, a more marked rounding off of edges, the conicity of the deep-drawing stub etc., must be strictly adhered to. Thus the process calls for technologies entirely different from those of steel. Another point in case is the manufacture of collapsible tubes and thin-walled hollow cylindrical items, where either the so-called injection-pressure die-extrusion technique or impact extrusion is used. Impact extrusion ensures highly accurate dimensions combined with suitable strength.

The welding and surface treatment of aluminium are fundamentally different from those of other metals. Upon exposure to air, a tenacious film of oxide deposits rapidly onto the aluminium surface. Because of this, traditional welding and surface treatment and painting methods used for steel are useless for aluminium. Because of the high thermal conductivity of aluminium and the oxide film, conventional welding technologies were replaced by the highly effective method of shielded-arc welding. Various modifications of electric spot-welding and seam-welding may be used also, although these call for greater power and use of automatic control. The cold-welding of aluminium requires a strong pressure to overcome the effect of the oxide film. Brazing or soldering of aluminium still calls for very elaborate techniques as modifications of conventional soft-soldering methods have produced rather unstable joints susceptible to corrosion. The use of adhesives in joining aluminium parts poses serious problems on an industrial scale, because of the stringent technological standards and the need for a high degree of cleanliness. A novel technique of joining components of aluminium structures, where the extruded sections to be assembled are slipped into one another to become firmly interlocked, is gaining ground. Although the extrusions have to be of highly accurate dimensions, the operation may be performed by unskilled labour.

An effective way of improving the surface of aluminium is the strengthening of its oxide film by means of anodic oxidation. The resultant anodized oxide film will be either corrosion-resistant or form a porous surface onto which a priming may be applied immediately. This must be done to prepare aluminium surfaces for painting. Another technique is to use a layer of plastic as a coating. Thus, whether corrosion resistance or surface preparation for priming is desired, an effective surface treatment is essential. A coating of paint is generally done as for other metals.

In the selection of semi-manufactures, some compromise may be possible. For example, use and selection may depend on whether the plant is furnished with facilities to anneal or age-harden workpieces within a small temperature range in the course of production.

In addition to the important task of selecting suitable materials and optimum technology, specialists engaged in siting and organizing a plant must be thoroughly familiar with facts and features essential in running an up-to-date aluminium industry.

Consumer resistance

Whenever a new aluminium outlet emerges, it has to prove its technological and economic feasibility in relation to traditional usages in a clear-cut manner. This is not easy, as the conservative attitude of the market is often governed by:

Habit

Previous experience in mass manufacture

Conventional assembly, maintenance and repair methods

Many years of deep-rooted operational practice

Regulatory legislation and practice (health, operational safety)

A first step is to convince a consumer that a prototype is useful. Extra, painstaking work, is required. A prototype or contract product is always costlier and as a rule not as perfectly made as a mass-manufactured one. Thus, technical assistance in assembly and maintenance is needed. The consumer has an ingrained wariness of accepting something new and this is hard to overcome. Finally, regulations have to be altered and new ones introduced. This process of changing attitudes is long, wearisome and costly.

The following chapter gives some concrete examples of how such initial difficulties may be surmounted with fair prospects of success.

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III. Promoting the use of aluminium

Advisory agencies

The processing of aluminium and possibilities of extending its use to various fields called for a certain reshaping of traditional technical thinking. In the late 1920s, the major aluminium producers of the world, at the time engaged only in smelting, began to undertake research in semi-manufacturing and manufacturing techniques and to report findings to their customers, so as to boost aluminium consumption.

In the meantime, aluminium has become the fastest growing metal, by consumption, of the century. This may be partly ascribed to the early pioneering in research and development, and, from the very outset, the results of research and development were passed on to the customer in the form of technical information, advice and assistance. This trend was sustained even when the smelting firms themselves entered the semi-manufacturing and manufacturing field; with growing integration, the advisory activities of the large aluminium producers became more differentiated.

In some cases, especially when a major aluminium concern had been the sole producer in an area, special information and advisory agencies were set up. They were to a certain extent independent and from an organizational point of view not tied to the research and technical development divisions of the aluminium companies. Their principal task was to commercially promote the findings of those divisions. Thus, they were called upon to keep in contact with designers, manufacturers and consumers and to take the initiative in various ventures designed to boost aluminium use.

Today, even if several large aluminium companies operate in the same area or country, it is advisable to set up such an advising agency in participation with the smelters, semi-manufacturing mills and representatives from the principal end-using sectors.

Whether the advisory agency is independent or company sponsored, the ultimate aims are identical, namely:

(a) To boost the economical use of aluminium in as wide a field as possible;

(b) To explore and promote new aluminium outlets;

(c) To help producers and consumers by providing technical advice and documentation and by organizing training schemes for technical management and skilled staff;

(d) To provide local authorities and international organizations with relevant statistical information on aluminium end-use and other developments.

The fundamental difference between the two types of advisory agencies is the business policy they pursue. The first type is established with a view to promoting the interests of the sponsoring concern or company. If the sponsor is a public corporation, whether operating only as a smelter or as a more integrated complex, it will be usually called upon to promote aluminium development programmes launched by central government agencies by co-ordinating the sponsor's interests with those of the prospective consumers. In doing this, the advisory agency is counting on the co-operation of the manufacturers and consumers. Its activities are largely governed by the research and development achievements of the sponsor, which the advisory body will have to then promote in an effective manner. Such agencies are to be found in countries where essentially only one major integrated aluminium concern is operating.

Among the second type of advising agencies, the Aluminium Zentrale (Aluminium Centre) of the Federal Republic of Germany, a corporate body financed by its member enterprises, is the best known. It also edits books and produces a journal. Of its 50 members, 18 are primary aluminium producers, 12 are semi-manufacturing mills and 20 are aluminium foundries and other manufacturers. The Aluminium Zentrale is a non-profit organization established to promote aluminium use and effective manufacturing techniques. Technical advice as well as the use of its documentation service and training schemes are free of charge. It co-ordinates aluminium information, represents the aluminium industry at fairs and shows and provides statistical information for various organizations. It runs training workshops and showrooms but has no research and development divisions.

In Hungary, a special advisory organization was established to emphasize the significance of the aluminium industry to the country's national economy. The Development Centre for Aluminium Applications of the Hungarian Aluminium Corporation, under the auspices of the special advisory organization, operated, until 1976, as a separate organization. Long-term aluminium activities of the Hungarian aluminium industry are governed by a central development programme approved by the Government. These plans set and coordinate medium and long-range targets for each stage of aluminium integration. The programme affects all industrial activities of the Hungarian Aluminium Corporation, such as bauxite and alumina operations, aluminium smelting, semimanufacture and the manufacture of some finished items, as well as activities of other aluminium fabricators in the country. All these enterprises are state-owned and operate under the auspices of various government departments. The Hungarian Aluminium Corporation runs a separate research and designing institute and acts as the general contractor for major aluminium development projects and provides the scientific background for development of the finished products.

In its activities the Development Centre relied on the experience of the research and design institute of the Hungarian Aluminium Corporation, as well as on suggestions and recommendations from different working committees and on co-operation with the major manufacturers.

The Centre had a staff of 50, of whom 20 were engineers and technicians and 10 skilled workmen who were employed at the training workshop of the Centre. The budget was jointly financed by the Hungarian Aluminium Corporation (60 per cent) and the National Technical Development Board (40 per cent). Most of the funds were used to develop prototypes, to subsidize a part of the extra costs incurred by the introduction of new products and to finance technical information, exhibitions, publications, training courses etc. Thus risks involved in innovations could be shared by the aluminium industry, the finished product manufacturer and the responsible government agencies.

There are several international organizations that provide advisory services. The International Centre of Aluminium Development (CIDA) consists of the eight largest European aluminium concerns. CIDA deals with various aluminium development and standardization issues, for example the dimensions of aluminium joints and new methods of corrosion abatement. Its findings are generally accessible to members only.

Some developing countries realized the necessity for setting up an aluminium development promotion agency and more may follow suit. Regardless of whether one, two or more producers are operating in a country or area, it seems desirable that such an organization be set up as an independent body in concert with all interested parties, including raw material producers, semifabricating mills, finished product manufacturers and consumers.

New solutions are no longer confined to a narrow field of engineering, thus the co-operation and goodwill of many specialists is required. The production of light-weight building components, for example, is complex, and in addition to aluminium specialists the designing architect, the building contractor and the customer must all have a say. In aluminium packaging for the food industry, the aluminium industry must co-operate with the food-processing industry, retail trade and consumers. In addition to technological advantages, active co-operation with all interested parties may greatly facilitate the medium- and long-range planning of production and consumption within a country.

Research and development

It has been shown above how advisory facilities may boost aluminium usage. Such efforts, however, may never be really effective unless supplemented by organized research and design. The many end-uses of aluminium and the many technologies involved in aluminium manufacture call for a carefully conceived development policy at all stages, from the raw materials to the finished product. Major aluminium concerns perform this arduous, costly and often hazardous task with a network of research, development and designing institutes. A typical example is ALCOA, which spends about 1.5-2 per cent of its receipts —about $60 million (1976 dollars)—for research and development. ALCOA Laboratories is the world's largest light-metal research complex. However, large amounts are spent on research by the world's other major aluminium producers, and the aluminium industries of smaller countries follow suit. In Hungary, a research, technical development and design institute operates under the auspices of the Hungarian Aluminium Corporation and is financed by funds amounting to 4-4.5 per cent of the total turnover of the Corporation. Other aluminium producers in Hungary devote about 1 per cent of their finished product turnover to research and technical development.

In countries just entering the aluminium manufacturing field, technical development work is indispensable. Research and technical designing must be capable of adapting aluminium applications used elsewhere. Development must deal with the exploration and testing of new outlets and products for the local market. In this case, the brunt of work and costs must be borne by the aluminium industry. Initially, such technical development should include:

(a) The manufacture or adaption of alloys best suited for local conditions;

(b) The introduction of modern scrap remelting technology, which is essential for the supply of a selection of ingots to foundries;

(c) The introduction of optimum joining techniques, including welding training courses, and the application of cold-joining techniques;

(d) The adaptation and, if necessary, modification of surface-treatment methods for on-site conditions;

(e) The study and practical application of plastic deformation technologies, including diemaking;

(f) The use and local manufacture of machine tools;

(g) The design and manufacture of prototypes and technical advice to prospective customers before serial manufacture.

It is desirable that, at this stage, local researchers and engineering specialists seek the assistance of qualified experts from various disciplines, so as to provide a sound scientific background for further technical development work ahead.

Product development

Testing the effectiveness of product innovation including research, designing, adaptation, licences and technical advice is a difficult and complex task. An indication of the effectiveness of product innovation is the rate of growth of consumption of semi-manufactures and increase in the profits of mills. Other indicators include:

(a) Replacement by aluminium of other metals so as to increase profitability and streamline operations. Examples are the replacement of copper in the manufacture of electric conductors, which reduces the installation costs of power-transmission systems, and the introduction of aluminium heat exchangers, and also of aluminium foil packaging, which facilitates the marketing of processed food;

(b) Use of aluminium components to provide significant consumer benefits. Examples are the considerable power economies in running transport vehicles and the use of aluminium accessories for fast alternating movements in textile mills and printing presses. These replacements improve technical standards and cost effectiveness;

(c) Savings in maintenance costs, especially in light building construction.

A method has recently been devised to evaluate the intensity of innovatory activities in the aluminium field by relating the average annual share of new products to the annual mean growth rate of aluminium consumption over periods of 5 to 10 years. This method was presented by R. Kumar at the 1978 International Symposium of Aluminium Transformation Technology and Applications in Argentina [1].

Table 25 shows the growth rate of the long-term share of new products and aluminium consumption.

TABLE 25. RELATION OF THE APPEARANCE OF NEW PRODUCTS TO INCREASING ALUMINIUM CONSUMPTION IN SELECTED COUNTRIES

Country	*Period*	*Average annual growth rate of aluminium consumption (percentage)*	*Average annual share of new products (percentage)*
Argentina	1965-1974	15.5	2.3
Germany, Federal Republic of	1958-1965	9.5	4.0
Hungary	1965-1970	9.8	6.3
Italy	1958-1965	9.8	5.8
Japan	1958-1965	14.4	6.5
Norway	1958-1964	12.0	6.1
United Kingdom	1958-1965	6.1	2.3
United States	1963-1966	12.4	6.9

Source: [1].

Figures for Argentina and the United Kingdom show the necessity of effective technical development work, in the absence of which growth of consumption in the successive periods may tend to decline sharply. Indeed, over the 1966-1976 period, the average annual growth rate of aluminium consumption in the United Kingdom dropped to 1.9 per cent [2].

The evaluation of product effectiveness is complicated by the fact that each product ought to be dealt with separately according to its merits. Moreover, the development, testing and final introduction of an aluminium application on an industrial scale may frequently take longer than the useful age of the product (e.g., the extruded aluminium sheathing of underground cables).

Hungary's 6.5 per cent share of new aluminium applications and annual average 9.2 per cent growth rate of domestic consumption for a six-year period compares favourably with the other statistics in table 25. The sustained overall growth of Hungary's aluminium consumption and the gradual decline or discontinuation of some forms of aluminium use, on the other hand, are always mandated by the need of the country in its changing industrial pattern.

Aluminium is being used less in Hungary in:

Water transport vehicles (small dinghies and medium-sized passenger river craft)

Aluminium-alloy overhead telephone conductors (use of buried cables increasing)

Aluminium doors, windows and roofing of railway cars (owing to the reorganization of domestic rolling stock)

Outer shells of thermos bottles (replaced by plastics)

Bottle caps (replaced by plastics)

New products introduced recently include:

Aluminium-sheathed underground power transmission cables with solid aluminium conductors

Aerosol bottles

Liquid-gas bottles

Pressure cookers

New types of composite aluminium foil for packaging ends and household use

New types of window frames and roofing

Radiators

The advisory agencies watch domestic and world market trends and must anticipate the long-term industrial development world-wide. This is a key question to exploring promising outlets and proceeding with prototype work.

According to the Hungarian experience, the funds of the advisory centre were distributed as follows: some 30-40 per cent was devoted to innovations that could be put to immediate use, some 20-25 per cent was spent on paving the way for new aluminium applications within the next 5 to 10 years and 40 per cent was spent on schemes that eventually turned out to be unfeasible. The relatively large share of negative experiences, however, had at least one advantage in that it pointed to certain areas where aluminium can definitely not be used to replace other structural materials.

The above examples will have amply illustrated that the work of advisory agencies may significantly contribute to effective product development. The advisory agencies also share the risks involved in every new aluminium application venture with all interested parties. Such risk sharing, of course, will vary with the economic system, the industrial pattern and the raw material availability for each country.

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IV. Aluminium applications

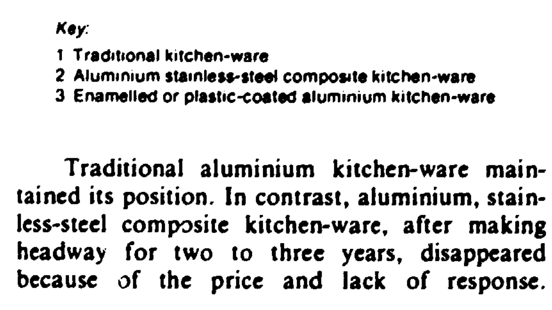
The great strides aluminium is making throughout the world and the efforts of its promoters to keep its positions intact are taking place in an atmosphere of keen competition with other structural materials. There are, however, certain areas where the position of aluminium seems to be firm and uncontested and not likely to change in the long term because of the world's raw material situation.

A case in point is the electrical engineering industry, where aluminium conductors for the transmission of high- and medium-voltage energy have irreversibly displaced copper. A similar process is now taking place in the manufacture and use of heat exchangers.

In transport vehicle manufacture, however, aluminium is faced with heavy competition from steel and more recently from plastics.

In other end-using sectors, competition is even more marked, with most items lending themselves equally well to manufacture from aluminium and other materials. An interesting comparison in this respect is made in figure X, showing utility curves plotted for aluminium kitchen-ware used in some developed countries of Europe [1].

Figure X. Demand for aluminium kitchen-ware in some developed countries of Europe



Key:
1 Traditional kitchen-ware
2 Aluminium stainless-steel composite kitchen-ware
3 Enamelled or plastic-coated aluminium kitchen-ware

Traditional aluminium kitchen-ware maintained its position. In contrast, aluminium, stainless-steel composite kitchen-ware, after making headway for two to three years, disappeared because of the price and lack of response. Development costs could have hardly been regained from sales within this short time. Later, plastic-coated and enameled aluminium kitchen-ware appeared on the market. After a three-year trial period, this kitchen-ware became popular and there has been a great increase in sales. How long this trend will continue will depend a great deal on future market demand. Yet, in spite of the heavy expenditure for development, this kitchen-ware seems to promise fast financial returns.

The following is a detailed analysis of a few typical aluminium end-uses. They have been expressly selected to demonstrate the importance of development, and the necessity of finding new market outlets and keeping the old ones. Several cases will be presented in which the merits of a concept were not assessed sufficiently or in which competition by other structural materials made it necessary to temporarily suspend or completely abandon the project.

The present chapter deals with technology. Chapter V contains information on sources of know-how and names and addresses of institutions and industrial firms that can provide information and other assistance.

Electrical engineering

In 1976 world aluminium consumption for electrical engineering was on the order of 2 million tonnes, accounting for 15 per cent of total world aluminium consumption [2]. The per capita amounts of aluminium used by the electrical engineering industry vary greatly with countries and areas, as shown in table 26.

TABLE 26. ALUMINIUM CONSUMPTION BY THE ELECTRICAL ENGINEERING INDUSTRY IN SELECTED COUNTRIES

(1973-1977 average)

Country	*Per capita consumption (kg)*
Developed countries of Western Europe	1.4[a]
Brazil	1.2
Hungary	3.5
India	0.15
South Africa	1.0
United States	3.7

[a] Weighted average. The range is 0.7 to 1.8.

The outlook for further expansion is bright both in industrially developed and developing countries.

The Post Office Administration of the United Kingdom indicated that 25 per cent of its telephone cable network is made from aluminium. Within 10 years, aluminium telephone cables will probably completely replace copper ones [2]. According to another forecast, the electrical engineering field in the United States—with its present high per capita consumption—should become the fastest growing aluminium outlet in that country [3]. By the turn of the century, electrical engineering is expected to account for 20 per cent of total world aluminium consumption [4].

Hungary has a large concentration of aluminium usage in electrical engineering. Historically, this may be attributed to the country's chronic dearth of and continued drive for savings in heavy non-ferrous metals throughout since before the Second World War coupled with the changing copper prices. Thus the use of aluminium gained ground rapidly in the manufacture of overhead power transmission cables, medium- and low-voltage conductors, as well as motor and transformer windings. In 1951 a Hungarian standard specification on the use of aluminium and aluminium alloys in electrical engineering was published; it dealt with the technologically and economically feasible application of aluminium for many end-uses in the field of electricity. It classifies each possibility as "desirable", "practicable" or "not practicable". The first standard specification has been subsequently revised in light of new technology.

Conductors

The share of aluminium conductors manufactured in Hungary is 76 per cent, against 24 per cent for copper. In most centrally planned economies, aluminium accounts for 50-60 per cent of total conductor manufacture, whereas in the Federal Republic of Germany 70 per cent of all conductors are still made from copper and only 30 per cent from aluminium.

Hungarian aluminium conductor and cable manufactures have acquired experience in turning out products with high technological standards. The remarkable advance of aluminium consumption in the conductor field was also precipitated by the early specialization of Hungarian engineering and working personnel in aluminium installation techniques and the application of aluminium in electrical equipment. In view of this, Hungarian engineering firms engaged in such operations today prefer using aluminium to copper.

Whether an aluminium or copper conductor should be used depends on the production costs of aluminium conductors, the economies of their use and their reliability. There is a marked downward trend in the price of aluminium conductors compared to copper.

The low specific weight, high specific conductivity (small energy losses) and corrosion resistance (savings in maintenance costs) of aluminium conductors present additional advantages. Reliability is ensured by the high mechanical strength and susceptibility to plastic deformation, casting, welding and soldering. Under the same load, the rate at which their ambient temperature rises is identical to that of copper.

An index of economic feasibility given by the formula $1/\rho p \gamma$ may be used to compare various metals, where ρ represents resistivity, p is price per unit volume and γ is density [5]. Calculated at 1974 prices and using one for aluminium as a basis for comparison, the corresponding indices for copper, magnesium and sodium are 2, 1.14 and 0.55, respectively. For the long term these seem to be the most promising conductors. From an economic feasibility point of view, magnesium and sodium are the two metals closest in values to aluminium. However, both are hard to come by in large quantities and are awkward to handle and difficult to process.

Overhead lines and cables

Hungary was a pioneer in installing complete aluminium power transmission and telecommunication grids. Experience has amply demonstrated that from an operational point of view aluminium is equivalent and, from an economic point of view, possibly superior, to previously used copper and cadmium-bronze conductors. Hence, throughout the world, most power grids use aluminium even at the highest voltages (for example, Hungary's 750 kV power transmission line).

High-voltage overhead lines

The resistance and price of cables used in high-voltage power systems is compared in table 27.

It can be seen that the resistance of an aluminium-based conductor is half that of a copper-based conductor of the same weight, and

TABLE 27. RESISTANCE AND PRICE OF THREE HIGH-VOLTAGE CABLES OF DIFFERENT MATERIAL ON AN EQUAL-WEIGHT BASIS

Material	*Relative resistance (Al = 100)*	*Relative world market price, 1976 (Al = 100)*
Steel-reinforced aluminium (ACSR 1:6)	108.7	70
Aluminium alloy (E AlMgSi)	100	100
Cadmium bronze	228	150

its price is one half to two thirds that of copper. The same applies to low-voltage networks, where owing to the frequent branching off of distribution mains and the proximity of towers holding them, the tensile strength of aluminium is not fully utilized.

Overhead power transmission grids and networks are usually made from the aluminium cable types shown in table 28.

TABLE 28. PROPERTIES OF CONDUCTORS COMMONLY USED IN OVERHEAD LINES

Material	*Specific resistivity (Ω·mm²/m)*	*Tensile strength (N/mm²)*	*Temperature specifications (°C)*	
			Normal temperature	*Permissible temperature in case of short-circuit*
Aluminium (hard)	0.0282	170-200	70	130
Aluminium alloy (E AlMgSi)	0.325	295	80	155
Steel-reinforced aluminium	0.240	1 530	..	..
	0.0282	163-197	..	..

High-voltage overhead lines have to be safe under all thermal and mechanical loads and resist corrosive effects of outdoor use. Moreover, they must allow for excess loads that may arise.

Because of their lower mechanical strength, unalloyed aluminium conductors are, as a rule, used in low-voltage networks, where mechanical loads are smaller. For medium- and high-voltage networks, steel-cored aluminium cables (ACSR) and, to a lesser extent, aluminium alloy cables are used [6]. ACSR are used also for specialized conductors. A zinc coating to protect the steel core against corrosion is usual. Lately, as an alternative, an "alumoweld" coating has also come into use [7]. ACSR are suitable for either phase or grounding conductors.

In electrical networks it is of paramount importance to determine the maximum power rating of a conductor correctly. This maximum will depend, in addition to environmental and climatic factors, on the composition, design and the stranding parameters of the conductor. In selecting a specification, particular attention must be devoted to aspects of operational safety throughout the projected life of the cable. Major damage must be avoided, and the cable's mechanical strength must not lose more than 5 per cent of its original value.

Performance and reliability of cables must be continually monitored. Efforts to develop new and more effective types of aluminium overhead conductors are widespread.

Table 29 shows maximum current ratings of high-voltage overhead conductors.

TABLE 29. MAXIMUM CURRENT RATINGS OF HIGH-VOLTAGE OVERHEAD CONDUCTORS

Material	*Cross-sectional area (mm²)*	*Maximum current rating*	
		Normal (A)	*In case of short-circuit (kA)*
Aluminium	300	680	27
	643	1 120	58
Aluminium alloy (E AlMgSi)	95	350	9
	240	625	24
	300	785	28
Aluminium conductor, steel-reinforced	110	430	12
	250	710	24
	500	1 120	60

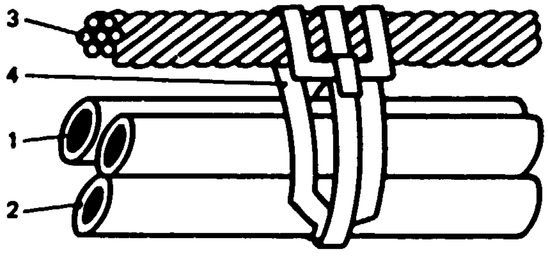
Note: Figures are for conductors made in Hungary. The values are valid for the worst environmental conditions (solar radiation, 30° C ambient temperature, 1 m/s wind velocity).

Cables

Aluminium aerial cables are used as phase and neutral conductors in low-voltage distribution systems, service mains, outdoor and provisional installations (see figure XI). They have won quick acceptance because of the increased ease with which 80 per cent of the faults occurring in low-voltage distribution systems caused by conventional outdoor service mains may be eliminated. Their salient features are easy installation and fewer faults.

Aerial cables are made from 99.5 per cent aluminium in cross-sections of 6 to 300 mm² with a tensile strength of 70 to 110 N/mm². The maximum rating of a 240 mm² cross-section cable under normal operation at a 25° C ambient temperature is 410 A; in case of a short the temperature must not rise beyond 150° C.

Figure XI. Aerial cables



Key:
1 Solid or stranded conductor
2 Plastic insulation
3 Stranded suspension cable
4 Suspension shackle

The dielectric strength of the plastic insulation is 40 kV/cm. The stranded suspension rope is made from aluminium or an aluminium alloy. If securely attached to the service mains, it will meet all technical and electrical requirements acting as the carrier of the insulated phase conductor on one hand, and as a neutral conductor on the other hand.

The installation of aerial cables has to be done in strict conformity with standing standards specifications. Quick assembly is greatly facilitated by prefabricated fittings.

Aluminium fittings

In electrical power transmission aluminium fittings are used as conductor, suspension and protecting fittings. Conductor fittings are designed to link two or more conductors of a transmission line; suspending fittings are used to hold overhead cables, aerial conductors and insulators in position or to connect them with one another; and protecting fittings are installed to enhance the operational safety of the transmission line. Pressure clamping is the usual method of fastening, providing reliable, economical and easy-to-handle conductor ends. These fittings embody the most recent advances in installation technology. They are used from 0.4-kV low-voltage networks up to the largest 750-kV high-voltage transmission system [8, 9, 10].

Power transmission

Throughout the world there is a growing shortage of skilled labour accompanied by a universal pressure for updating conductor installation techniques. Prompted by this demand, several aluminium structures have been recently developed that will save maintenance costs of power transmission lines.

Although erected 10 years ago in an industrial area of Hungary where chemicals are liberally used, annual checkups of an aluminium transmission-line tower prototype have so far revealed no trace of change or any damage. This and similar prototypes have aroused great international interest [11].

Telecommunications

In the past, aerial cables, used to carry trunk calls over more or less long distances, have been made of age-hardened E AlMgSi aluminium alloy wire. Statistical returns for the past 30 years have demonstrated that faults occurring during use were only one half or two thirds of the faults recorded using bronze conductors [12]. This was largely due to the effective fastening and jointing techniques applied, as well as the inherent properties of aluminium.

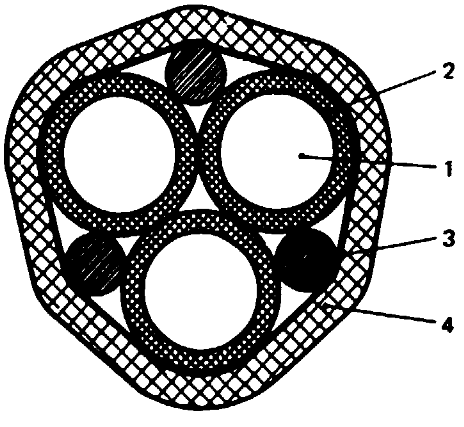
Underground cables

Aluminium conductors have been used in cable manufacture since the 1930s. However, it was not until after the Second World War that technologies for sheathing underground cables with aluminium were devised and introduced on an industrial scale. A major breakthrough in underground cable design occurred recently with the emergence of the solid aluminium conductor in low-voltage solid dielectric cables. The pioneer in this area was ALCAN, the first company to release in detail the technical features of its Solidal low-voltage solid aluminium conductor cables [13].

The production costs of solid dielectric 0.6- to 1-kV cables can only compete with those of impregnated paper insulated cables made from three-stranded aluminium phase conductors with an aluminium sheathing acting as neutral conductor, if all four conductors are made from aluminium. The standard specifications of some countries (e.g. VDE 0271/3.69 of the Federal Republic of Germany) explicitly forbid the use of aluminium as a neutral conductor placed concentrically around the three other conductors and insist that copper be used. Despite its technological merits, use of copper seriously jeopardizes the cost effectiveness of such a cable. However, with suitable protection against corrosion, the use of a concentrically placed fourth aluminium conductor is permissible in some countries. Examples are shown in figures XII and XIII [14, 15, 16].

The 95-, 150- and 240-mm^2 cross-section aluminium conductors extruded from 99.5 per cent aluminium have a tensile strength of 60-70 N/mm^2.

Figure XII. Cross-section of an aluminium cable with a three-conductor neutral



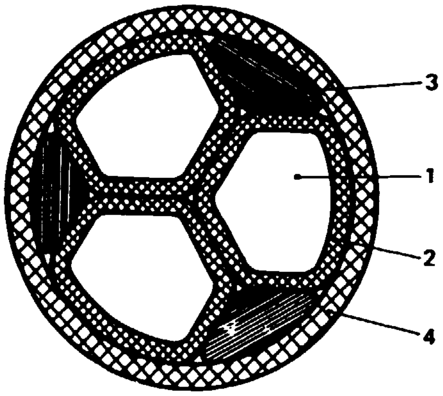
Key

1 Solid aluminium conductor
2 PVC insulation
3 Neutral: aluminium wire wound with aluminium tape
4 Black PVC sheathing

They are sufficiently soft and pliable to permit easy handling upon installation. Their use has confirmed that high-voltage underground cables no longer need to be composed of stranded conductors as up to a 240-mm^2 section solid conductors may be used.

Cable terminals may be joined by flattening and punching the solid conductor ends with a special tool. Cold-pressure technologies in fastening stranded conductors have been adapted to solid conductors as well. Moreover, traditional methods of welding may safely be applied to solid conductors for firm and reliable joints.

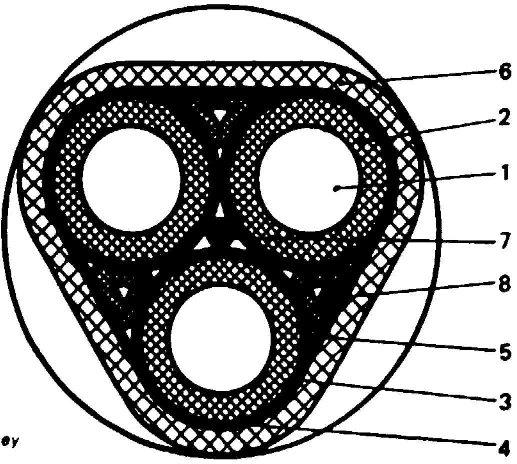
Figure XIII. Cross-section of an aluminium cable with a three-conductor neutral rated at 0.6 to 1 kV



Key

1 Solid aluminium conductor of arched five-angled section
2 PVC insulation
3 Neutral aluminium wire of arched triangular section wound with aluminium tape
4 Black PVC sheathing

Figure XIV. Cross-section of a high-voltage cable



Key

1 Solid aluminium conductor
2 Plastic insulation with graphite-coated outer surface
3 Partially conducting paper tape
4 Double-layer aluminium strip
5 Double-layer steel strip
6 Blue PVC sheathing
7 Aluminium guard wire
8 PVC filling

Thus, solid conductors have proven their usefulness and have been used for the last 10 years in 6- to 35-kV high-voltage underground cables as shown in figure XIV [16]. The cable is easily laid. Insulation is facilitated because a smooth-surfaced partially conducting plastic layer may be more easily added to a solid conductor than to a stranded one.

Although some international standard specifications do not permit the use of concentric neutral and guard conductors made from aluminium, in Hungary even the metal part of the insulation screening is made from an aluminium band [16]. Earlier, it was wound around the conductor, but the new 0.6- to 1-kV cable now has an aluminium band screening fixed longitudinally onto the conductor.

Favourable experiences have demonstrated that low- and high-voltage solid dielectric cables composed of aluminium phase conductors, screening and neutral or guard conductors may give savings in material and labour costs [16].

Telephone and telecommunication cables

When copper was in short supply during the Second World War, Hungary produced symmetrical carrier frequency long-distance and local telephone cables with aluminium and paper insulation and lead sheathing [13]. In the post-war period when copper prices began to rise steeply, there was a similar trend; however, only in Australia [3, 14] were these cables used to a great extent.

The emergence of fully filled cables has fundamentally changed the situation. These cables usually have cellular polyethylene insulation. The gaps between the wires are filled with a water-repellent petroleum jelly to protect the cable against corrosion. Sheathing is a polyethylene-coated aluminium band and polyethylene [15]. Some firms have developed a special AlMgFe alloy as a conductor, which approximates some of the mechanical properties of copper conductors and thus allows higher productivity in manufacture and easier techniques of joining upon installation [16]. Aluminium and aluminium alloy fully filled cables have won wide acceptance, especially in the United Kingdom [15, 16].

Service lines

Service mains are used to feed the interior electrical installations of buildings, households, industries and agricultural structures. The subjects discussed below include insulated conductors [17], busbar channels [18, 19] and joints and fittings [19, 20].

With new advances in manufacture and installation techniques, aluminium has become an equivalent conductor to copper for many uses. Aluminium is now universally accepted for general installation. Copper is used only where increased operational safety is a special consideration (e.g. warning signals, interior wiring of equipment etc.) [21].

Insulated conductors

The conductivity of aluminium depends on a great many conditions. Conductors in many countries have been standardized. The conductors are usually made from 99.5 per cent aluminium, either in solid form or in strands of several wires.

The 99.5 per cent aluminium is sometimes slightly alloyed with other metals, especially iron [22], to enhance flexibility. Some of these are known as Triple E and Super T conductor material. Their ratings are given by the relevant standard specifications, depending also on the conditions of installation (under plaster, extramurally armour-clad etc.).

In many countries predominantly or exclusively insulated conductors composed of several aluminium wires may be used for lighting or equipment operation in households, industries, schools and other institutions.

In the laying of joints, connections and fittings, some peculiarities of aluminium have to be allowed for in order to avoid the wires breaking or the strong creep causing excess temperatures and possible shorts.

Where strict safety regulations are imposed or where many joints and connections are to be made over a short distance (e.g. in hospitals, distribution boxes etc.), it is preferable to use copper conductors so as to avoid creep.

Conductor channels

Conventional building methods no longer keep pace with the latest technological advances. The emergence of light construction gave rise to various new designs of conductor bar channels. These, as well as the perforated assembly plates and the plastic-coated tubular uprising aluminium conductor bar systems, now greatly facilitate installation, improve productivity and give labour savings.

Aluminium is now considered preferable to plastics as a material for conductor bar channels. Aluminium has superior fire-resistant properties.

Joints and fittings

Aluminium conductors are susceptible to creep and sensitive to incisions. It is therefore of particular importance that effective technologies for fastening, joining, stretching and connecting conductors be applied and fittings of suitable design be selected [19, 20].

Joining may be done, for example, by soldering, welding or pressure clamping. In recent times a large variety of joints and fittings have been devised to ensure the reliable and cost-effective operation of service conductors. Handled by sufficiently trained and skilled personnel, they may greatly enhance efficiency and operational safety.

Transformers and capacitors

Transformers

For the past 40 years aluminium windings have been used for the manufacture and operation of transformers. Used primarily in distribution transformers, the windings are usually designed with ratings of up to 2.5 MVA and voltages ranging from 3.6 to 36 kV. Some of these are used for oil and others for dry transformers. Aluminium-wound transformers are also available for very small (several VA) and higher (in ranges from 25-63 MVA) ratings as well. In recent designs of high-power transformers several structural parts are made from aluminium, so as to reduce additional losses. These parts include clamps, containers, lids and electromagnetic screening surfaces.

The economics of the use of aluminium in transformer windings is governed by the price of aluminium windings compared to that of copper. If the copper windings of a transformer are replaced by aluminium windings of the same size, the ratio of the ratings of their windings at a temperature of 75° C may be expressed as

$$P_{Al} = P_{Cu} \times \frac{\rho_{Cu}}{\rho_{Al}} = 0.79\, P_{Cu}$$

where P_{Al} and P_{Cu} are the ratings of transformers with aluminium and copper windings, and ρ_{Al} and ρ_{Cu} the corresponding resistivities. If the price of a copper-wound transformer of P_{Cu} rating is p_{Cu} and for the sake of comparison its rating is reduced to that of the aluminium-wound one, its price will become p'_{Cu}. Since prices change with the ¾ th power of ratings, the following formula is obtained:

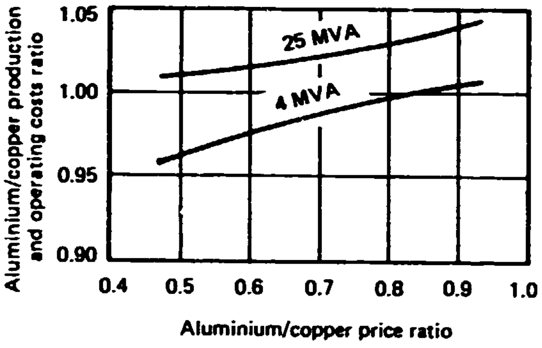
$$p'_{Cu} = (\rho_{Cu}/\rho_{Al})^{3/4} p_{Cu} = 0.84\, p_{Cu}$$

From the point of view of production costs, aluminium usage will be more economical if the reduced production costs brought about by the reduction of rating in a copper-wound transformer are still higher than those of a transformer with aluminium windings of the same rating.

A transformer is economical when its production and operating costs are minimized. For such a transformer, aluminium windings are under-utilized compared to copper windings under the same load. While with copper windings the most economical current densities are in the 2.5-3.5 A/mm^2 range, with aluminium the corresponding range is 1.5-2 A/mm^2.

In figure XV the ratio for total production and operating costs between aluminium-wound and copper-wound 25 MVA and 4 MVA transformers is plotted against the aluminium/copper price ratio, based on 1974 metal prices in Hungary. It will be observed that with a high-output transformer the use of aluminium windings is more cost effective, whereas with a smaller one, or whenever the aluminium/copper price ratio falls to or below 0.85, the use of copper-windings is more cost effective [3, 23].

Figure XV. Cost effectiveness of aluminium-wound and copper-wound transformers (based on 1974 metal prices in Hungary)



Metal and energy prices may vary with each country, but it may be accepted as a general rule that below a 2.5-MVA rating aluminium windings are more economical than copper windings. This is important because 90 per cent of the world's transformer production may be accounted for by ratings smaller than this. As for ratings above 25 MVA, for reasons of size, the use of aluminium windings is not practicable.

In dry transformers the windings take up most of the transformer space; therefore, the use of aluminium windings is economical and production costs are lower.

In view of the loads and sizes involved, the best aluminium winding material is half-hard wire with a conductivity of 35 S · m/mm^2, a tensile strength of 110 N/mm^2, an elongation at rupture of 12 per cent and a Brinell hardness of 200 N/mm^2. Recently, for ratings of up to 4 MVA, aluminium foil windings have been used both in dry and oil-insulated transformers [24, 25]. Their advantages are: better heat dissipation in the windings; increased resistance to short currents; and improved voltage distribution caused by impulse voltages. Such windings lend themselves well to automation.

The thickness of 99.5 per cent used without purity throughout aluminium foil used in oil- and plastic-insulated transformers ranges from 0.01 to 0.04 mm; above this thickness aluminium strips are used. Hungary now manufactures up-to-date plastic-insulated aluminium foil dry transformers under a special AEG licence.

Capacitors

The amount of electrical energy needed for capacitor sub-stations is rising. Up-to-date liquid-dielectric high-voltage and dry low-voltage capacitors are made almost exclusively with aluminium foil windings. The 99.9 per cent pure aluminium foil used is 0.005-0.120 mm thick and 60-400 mm wide. The foil surface has to be clean, even and free from oil. Fluctuations of more than 10 per cent in foil gauge lowers capacity and raises production costs.

Road vehicles

There is now a marked trend in designing road vehicles towards weight reduction and energy savings. Thus, research efforts are under way to substitute traditional copper conductors and coils in motor cars with aluminium. There is a good chance that aluminium will replace copper over the long run if suitable methods are devised for connecting and fixing aluminium conductors with the lowest possible voltage drop in a reliable and economical manner.

At present, the development of a flexible creep-resistant aluminium alloy and efficient low-voltage (12 V) contacts is under way. The application of these on a commercial scale is anticipated in the near future.

Lighting

The use of aluminium for lighting is determined by its low specific gravity, corrosion-resistance, attractiveness and good reflection. Aluminium is predominantly used for lamp casings and mirrors.

Low specific gravity is important if low weight is sought for supports for the lamp fittings. This is especially important where many lamps are installed in closed groups, such as in sports stadiums where often 60 to 80 spotlights are held by each pole.

Corrosion-resistance is important for lighting fixtures used outdoors, which must last 10 years or more. The surface of aluminium mirrors must be anodized. Although the reflection from such a surface is somewhat less, the increased hardness and resistance to wear allows for regular cleaning.

The attractive appearance of light fixtures is especially desirable for indoor use. The aluminium surface has to be provided with bright polish or dye-anodization.

Good reflection is a fundamental requirement for reflectors, street lamps and indoor illumination. To enhance reflection, 99.99 per cent high-purity aluminium is used with 0.5 to 1 per cent magnesium added. The brilliance of the aluminium surface may be achieved by chemical, electrolytic or mechanical polishing, or a combination of these.

The mass production of lighting calls for automation. A new technology uses steam pressure to apply aluminium on plastic surfaces. However, the heat resistance of such mirrors is still limited. In light sources where high temperatures are involved, such as mercury, halogen and sodium lamps, the use of aluminium mirrors is more feasible from a technological and economical point of view.

Electric motors

The windings of electric motors are usually made of copper owing to its high specific resistivity compared to aluminium. Aluminium windings are not yet widespread and are more or less limited to small motors. However, most small motors are of the commutator type and aluminium may not be readily used because of the oxide film formed on its surface.

By contrast, in the rotor coils of synchronous motors, aluminium, with its one-third specific gravity, considerably reduces centrifugal force. In turn, the coil grips are exposed to a smaller load and may be reduced in size, leaving more space for mounting the coils. Thus, aluminium may be used with advantage.

Some engineering firms that specialize in transformer winding material have also begun production of insulated aluminium wires for rotor coils. Such wires are round or flat, with enamel, glass-fibre or other insulation.

The relative prices of aluminium and copper will determine which of the two is more economical. Many motor manufacturers have begun using aluminium rotor coils, deriving considerable technological and financial benefits because aluminium wire and insulation is best suited for their particular technologies.

Installation equipment

The electrical engineering industry uses large quantities of aluminium for conductors, switches and other equipment, as described below.

Conductors

Aluminium conductor bars are now widely used for transmitting high-voltage electric power. In designing and installing them three parameters have to be taken into account: their specific gravity, electrical conductivity and mechanical strength.

Aluminium is obviously superior to any other conductor material from a specific gravity point of view. As far as conductivity is concerned, in theory it would be best to use aluminium of as high purity as possible. However, certain requirements as to mechanical strength have to be complied with. Therefore, in actual practice, aluminium alloys ($AlMgSiO_5$) that can best meet both of these requirements have to be given preference. Utmost attention must be given to the expert handling of contact surfaces in joining, connecting and fastening conductor bars.

Releasable joints may best be made by screwing the conductor ends together. In the case of extra-thin conductors, looping conductor ends is a possibility. The contact resistance of screwed joints will always depend on how they were made [26]. Contacts may never be really effective, unless the oxide film that forms on the aluminium surface—which is a poor conductor—has been removed from the conductor terminals that are to be fitted together or the conductor ends have been coated with a metal with good contact properties. Good contacts may be made by cleaning the terminal surfaces under a layer of vaseline (by applying zinc particles suspended in vaseline), by electroplating the contact surfaces with silver, copper or tin or by spraying them with a metal that is more conductive than aluminium (e.g. copper or silver) [27]. The Exconal bars developed by ASEA of Sweden combine the useful features of aluminium and copper by pressing a copper foil onto the aluminium conductor; the bars are 85 per cent aluminium and 15 per cent copper (coating). Such conductor bars may be joined in the same manner as pure copper ones.

Permanent joints are made by either welding or pressure [28]. Welded joints are better conductors than releasable ones and are not susceptible to a rise in transient resistance. The welding process is, however, unwieldy, calling for care in selecting a suitable technology [29, 30].

Permanent joints are made by pressure, as for stranded cables, or by cold extrusion, as for connecting foil conductors [28, 31, 32]. Cable wire ends are joined by either cold extrusion or pressure clamping.

Metal-clad bars

To increase operational safety for users, several armour-clad distribution systems have been developed. Such systems may be distributed throughout an industrial area and permit individual service lines to be linked up swiftly. Owing to certain difficulties in installation techniques, often preference is given to copper for this purpose. However, EKA of Hungary has developed an effective technology for connecting such branch lines to aluminium conductor bars either permanently or with the aid of suitable plugs.

Metal-clad bars are used in power plants and distribution systems to connect generators and transformers [33]. Each phase of the bars is metal clad separately, which practically excludes the possibility of busbar short circuits.

Metal-clad equipment

Calculations have demonstrated that the use of structural steel in equipment carrying currents of over 1,000 A gives rise to considerable secondary currents and losses. At around 3,000 A, steel can no longer be used in such equipment and has to be replaced by an aluminium alloy [34].

As a structural material, aluminium is also gaining ground for outdoor switch-gear, where corrosion and maintenance costs may thereby be reduced to a reasonable minimum [34]. Hungary has exported aluminium switch-gear to some 50 gas-turbine power plants [35].

Electrical equipment destined for indoor use may be mounted onto metal-clad aluminium switch-gear; substations to house the electrical equipment can be erected easily [34].

The use of aluminium in outdoor transformer substations has similar advantages [35].

An interesting application of aluminium is sulphur-hexafluoride gas-protected switch-gear, where both the conductor bars and equipment are mounted into an aluminium alloy body.

Outdoor switches

Substations within the 35- to 750-kV range are generally designed for outdoor use, as are most of the busbars used nowadays, which are made from an aluminium alloy in the form of a stranded conductor or tube.

In industrialized countries there is a trend to build outdoor substations with metal-clad switch-gear insulated by sulphur-hexafluoride gas, which saves considerable space. Under a licence from BBC of Switzerland, the Ganz Electrical Works of Hungary began production of 120-kV and 400-kV transformer stations of this type. Such gear (circuit breakers, measuring switches etc.) is also used effectively in traditional busbar substations.

Chemical engineering and food processing

Early in the history of aluminium the chemical engineering and food industries became major buyers of structural, packaging and storage equipment. The usefulness of aluminium for these purposes may be largely attributed to its corrosion resistance, its lack of toxicity, its workability, its low specific gravity and to the fact that in most cases it provides a good replacement for tin. The momentum of this growth, however, has recently abated owing to the emergence of stainless steel and plastics. These materials, and the subsequent price reductions of items made from them, have made inroads on the aluminium market in the last 10 years. To keep pace with such competition, serious efforts were made to find new aluminium outlets, to update old ones and to develop new technologies for producing large volumes with utmost cost effectiveness. Accordingly, the selection of aluminium items in chemical engineering and food industries is rapidly changing. The risks of introducing new innovations are great—a very thorough appraisal of the market is necessary.

Aluminium use in chemical engineering

The progress made recently by the inorganic and organic chemical engineering industries calls for more sophisticated designs for storage tanks and transport containers. In many instances tinned copper, tinplate or lead-coated steel can no longer meet new and increasingly stringent requirements. In view of this, aluminium, with its good corrosion-resisting properties and low density, has gained ground in such fields as oxygen, nitric acid and acetic acid manufacture. At first, the high price of stainless steel favourably affected this trend. However, stainless steel prices have fallen and operating experience in aluminium use has become more widespread. At present, these two underlying considerations determine a great deal where and how aluminium may be used with advantage in chemical engineering.

Some specific uses for large quantities of aluminium as a structural material in the chemical engineering industry are in making silos, tanks, transport containers and auxiliary equipment.

Storage silos have grown in importance since plastics manufacturing and processing capacities are expanding throughout the world. They are especially in demand in PVC and polypropylene factories. Their sizes range from 150 to 500 m^3; smaller units of 50 to 150 m^3 are used for intermediate storage at different stages of the manufacturing process.

Stationary and mobile containers are predominantly used in the manufacture of light chemicals, pharmaceuticals and paints. Mobile containers are also used in the transport of concentrated nitric acid, acetic acid and some products of the oil industry (petroleum, liquid gas). The manufacture of liquid-gas transport containers calls for great experience. In Hungary, 0.5- to 25-litre aluminium liquid-gas bottles and cylinders that are made by wall-reducing deep-drawing have been used with advantage for more than 20 years. A 25-litre cylinder weighs 3 kg less than its steel counterpart. Moreover, aluminium cylinders do not need to be painted every three years.

Air coolers in chemical engineering usually consist of ribbed aluminium tubes or aluminium ribbing around a steel, acid-proof steel or copper tube core. Tubes with pleated transversal ribbing are as a rule made at the semi-manufacturing mills using a special technology. The largest customers of aluminium-ribbed tubes are oil refineries and chemical engineering works, where such coolers form part of a complete heat-exchanging system.

Flexible aluminium tubes made by continuous edge rolling of aluminium strips is steadily gaining ground for air conduits in the chemical engineering industry. In square-section sheet-tube design, the zinc-coated steel variety is still widespread, but because of their flexibility aluminium tubes are also expected to make good headway for use inside factories or employed as flue stacks.

In chemical engineering most insulated tubes have to be provided with an extra protective coating. Aluminium strips usually are used, as they are corrosion-resistant and easy to handle, and zinc-coated steel strips have almost completely been replaced by aluminium ones.

Aluminium use in breweries and dairies

For several centuries tinned copper, wood and later tinplate equipment was used in beer brewing and milk processing. The use of aluminium began in the 1930s. Several decades of experience have amply demonstrated that aluminium manufacturing and storage equipment for breweries and dairies is more economical and has numerous technological advantages. These include:

(a) Aluminium does not react with food substances, except for a slight reaction with sour milk;

(b) In contrast to equipment and transport containers (e.g., milk cans) made from tinned copper or tinplate, aluminium ones require no maintenance whatsoever;

(c) With aluminium lending itself well to plastic deformation and welding, it is ideally suited for the cost-effective mass-production of containers and other items (beer casks, milk cans).

In using aluminium in breweries and dairies, the following considerations have to be taken into account:

(a) As a raw material only copper-free smelter aluminium (with a maximum copper content of 0.1 per cent according to the Deutsche Industrie Norm (DIN) and 0.2-0.3 per cent according to some standards in the United States) may be used either in unalloyed form or alloyed with a maximum of 3 per cent magnesium or a combination of a maximum of 1 per cent magnesium, 1.2 per cent silicon and 1 per cent manganese;

(b) Preference should be given to one-piece deep-drawn designs. Accessories—if possible made from the same material as the deep-drawn body—should be joined only by shielded-arc welding;

(c) Special attention must be devoted to the cleanliness and fresh-air supply of workshops and storerooms; after finishing pressure tests, the equipment must be dried to avoid the detrimental effects of condensed vapour. Also, when planning the layout, it should be remembered that aluminium equipment calls for increased space;

(d) Inner surfaces that are in direct contact with beer or milk have to be smoothed (for example, by mechanical polishing);

(e) Organic coatings may be applied only to primings approved by the health authorities. For example, a resin-coating for the inside of beer casks may be applied only to an electro-food anodic oxidation-based priming such as that developed by the Refrigerator Works of Hungary [36]. (See also chapter V.)

All equipment and transport containers have to be kept scrupulously clean. Dairy equipment may best be sterilized with the aid of a water-glass inhibited solution of formol; scale on the inner surface of beer tanks may be removed using silicon earth soaked in a dextrin solution, to which 10 per cent nitric acid had been added. This has to be flushed out with hot water after 24 hours [37]. Soda and inhibitors (solutions containing sodium metasilicate or trimetallic sodium orthophosphate) may be used with advantage. The cleaning of aluminium equipment that has steel components is described in patent number 2,948,392 filed in the United States [38].

However, despite its many useful properties, aluminium has in the last few decades faced serious and successful competition from stainless steel. The position of aluminium became precarious when the relative price of stainless steel decreased and when new detergents came into use [39]. The present situation and future outlook for the next 10 years may be summed up as follows:

(a) Aluminium will keep its position in the brewing and dairy industries in the case of mass-

produced transport vessels and containers (such as beer casks, new types of cold-storage milk transport containers and milk cans), large stationary or mobile containers, as well as storage tanks where good thermal conductivity is a special requirement;

(b) Stainless steel will win general acceptance for more sophisticated equipment where frequent cleaning is necessary (for example thickeners and milk separators).

Breweries

Most equipment used by modern breweries is made from aluminium, which has completely replaced wood and tinned copper. For storage, fermentation and transport, large unalloyed aluminium tanks of 5- to 10-mm thickness are used. Large underground fermenting and storage caves are cooled using aluminium heat exchangers and piping. Aluminium apparatus may also be used with advantage for the saturation of beer with carbon dioxide. In some cases boiling vessels have been made from aluminium, which replaced tinned copper. Recent shifts in the relative prices of aluminium and stainless steel, as well as the greater ease of cleaning stainless steel equipment, have caused a setback in aluminium usage. However, for the next 10 years or so, the position of aluminium as a structural material for small beer casks (25 to 100 litres) seems to be firm and uncontested. In weight, an aluminium cask is only one-third or one-fourth that of a wooden cask. As a further advantage, it needs no maintenance.

Aluminium beer casks are usually made from an age-hardened AlMgSi alloy by joining the two deep-drawn halves of the body into one by means of shielded-arc welding. For reasons of protection and hygiene, the inner surface of the cask is either plated with a 99.8 per cent pure aluminium layer or, after being given a proper priming, coated with a synthetic-resin film burned onto the inner cask wall. The second alternative improves chemical resistance and permits use of the cask also for other purposes. In Hungary at present, 100,000 such beer casks are manufactured annually. Recently, 30- and 50-litre keg-type beer casks that were designed in the United Kingdom and are easier to manufacture have come into use [39] (see figure XVI).

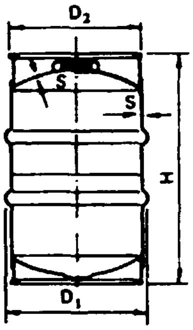
Dairies

In industrial dairies the situation with regard to equipment, for example, containers, coolers and pasteurizers, is similar to that of the breweries. For double-walled coolers and heaters a combination of two metals is gaining ground. The outer hull is made of aluminium and the inner body, which is in direct contact with the milk or milk products, is stainless steel. This combination permits easier cleaning. In coolers and heaters the use of integral tubes in aluminium sheets, the so-called "roll bond" sheets, is widespread. These are easy to manufacture; in actual practice they are of high thermal efficiency.

For milk collection and distribution, aluminium cans have completely replaced tinned steel cans. As tinning every three to four years is no longer necessary, deep-drawn aluminium cans manufactured in large series with high productivity have won universal acceptance. For reasons of mechanical strength and material economy, the use of $AlMn_1$ and age-hardened AlMgSi alloys in can production is increasing. A new deep-drawing technology that reduces the thickness of the can is highly effective in manufacturing large series of 100,000 cans annually.

The chain of operations from collecting to storing milk has recently undergone great changes. Milk has to be kept cool at the farm until called for by transport vehicles that are equipped with coolers; hence, both the storage tanks and transport containers have to be constructed with double walls. Their outer hull and the heat exchangers (pipe coil and others) can be made from aluminium. The inner material is generally stainless steel, which permits faster and more effective cleaning.

Figure XVI. A beer keg with three circular seams and a welded taphole



Volume (litres)	30	50
Outside diameter D_1 (mm)	381	381
Inside diameter D_2 (mm)	366	366
Height H (mm)	400	600
Thickness S (mm)	2.8	2.8
Approximate weight (kg)	6.5	8.0

Containers

Tinplate used to be a traditional material for cans, lids, bottle caps and other items for the food industry. Now, aluminium is replacing tinplate. One reason for this is the price of tin. World tinplate production, though growing at an average annual rate of 9-10 per cent, is not sufficient to meet actual world demand. In 1976 world tin production (excluding China, the Soviet Union and other centrally planned economies) totalled 178,000 tonnes for the following end-uses:

End use	*Percentage by weight*
Tinplate	40
Solder	25
Bearings	10
Chemical engineering	8
Surface coatings	5
Other	12

Some 75 per cent of aluminium packaging is used by the food industry (for canned food and beverages). Perhaps nowhere is competition between aluminium and other materials, especially tinplate, so keen as in the packaging fields. A reason for this is that the cost of modern packaging is often higher than that of the product itself (cosmetics and some foodstuffs). The selection of an economically and technologically feasible means of packaging may therefore considerably reduce overall production costs.*

Analyses conducted on an international scale have revealed a marked relationship between GDP and modern aluminium packaging. In countries with a GDP higher than $1,000 per capita, the use of beer and soft drink cans as well as aerosol bottles—predominantly made from aluminium—is rising at a dramatic rate. However, the realization that such a correlation does exist is in itself not enough to swing the pendulum of competition either way. To make a realistic assessment, local circumstances must be taken into account, notably the availability of machines and equipment, for producing cans.

The advantages of aluminium are:

(a) Flexibility and workability. The mechanical strength of aluminium in the unalloyed state, however, is less than that of tinplate. Unalloyed aluminium would be uneconomical. Even a 0.30- to 0.35-mm thickness may not ensure sufficient mechanical strength; therefore an alloy must be used;

(b) Higher corrosion-resistance. The annual amount of aluminium ions dissolving into food owing to corrosion is 6 to 70 mg per kg of food;

(c) Whether or not the inner surface is resin coated, no toxic metal ions are released. The inner surface of meat or processed meat never darkens; foodstuffs containing amino-acids with a sulphur content (e.g. fish, peas and cauliflower), do not have a sulphide reaction with the can upon heating;

(d) Low specific gravity, permitting great economies in weight, as shown in the following example for a 240-ml box:

Material	*Weight (g)*
Tinplate	77
Aluminium	27
Aluminium foil	15

(e) Up-to-date production lines permit the production of 800 to 1,000 pieces per minute.

The annual amount of metal cans manufactured throughout the world is in the order of 2 to 2.1 × 10^{11} pieces. Their manufacture requires some 8.5 × 10^9 m^2 of thin metal sheet per annum (with an annual growth rate of 2-5 per cent): of this about 10 per cent is aluminium [41].

In developed countries the share of aluminium cans in total can manufacture in 1975 was as follows:

Country	*Percentage*
United States	15.0
France	10.1
Italy	9.4
Germany, Federal Republic of	9.3
Norway	9.0
United Kingdom	7.0

From 1965 to 1971 the amount of aluminium used in the United States in box manufacture has grown 4-fold, compared to 1.3-fold for that of tinplate. Over the same period, the relative share of aluminium has risen from 1.9 per cent to 5.9 per cent [42].

An analysis of can production figures in the United States is shown in tables 30 and 31. Over the period 1968-1972, although the total turnover of fruit and fruit juice cans—5.8 to 6.0 × 10^9—

TABLE 30. USE OF TINPLATE AND ALUMINIUM IN CAN AND METAL BOX MANUFACTURE IN THE UNITED STATES, 1965-1971

(1965 = 100)

	Tinplate		*Aluminium*		*Aluminium related to tin*	
Year	*Thousands of tonnes*	*Index*	*Thousands of tonnes*	*Index*	*Percentage by weight*	*Index*
1965	4 407	100	85	100	1.9	100
1966	5 591	126	113	133	2.0	105
1967	4 671	106	158	186	3.4	179
1968	4 997	103	189	222	3.8	200
1969	5 149	117	246	289	4.8	253
1970[a]	5 407	123	295	347	5.5	289
1971[a]	5 715	130	345	406	6.0	316

Source: [41].

[a] Estimate.

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*A typical example of what benefits may be derived from selecting a suitable packaging material is an aluminium-plastic combination can developed for preserving meat and fruit. A batch of 1,000 weighs 6 kg; 1,000 tinplate cans of comparable size weigh 50 kg [40].

TABLE 31. ESTIMATED USE OF CANS IN THE UNITED STATES, 1968-1972

(10^9 pieces)

Type	*1968*	*1969*	*1970*	*1971*	*1972*
Tinplate					
Fruit and fruit juices	5.9	6.4	5.6	5.5	5.8
Vegetable and vegetable juices	10.2	9.7	10.0	9.6	9.1
Beer	13.8	14.5	15.5	14.6	14.4
Soft drinks	10.2	11.6	12.5	13.1	13.6
Miscellaneous	22.7	22.6	23.5	23.1	23.6
Subtotal	62.8	64.8	67.1	65.9	66.5
Aluminium					
Beer	3.4	4.2	4.7	5.9	7.4
Soft drinks	0.5	0.7	1.0	1.3	1.8
Subtotal	3.9	4.9	5.7	7.2	9.2
Total	66.7	69.7	72.8	73.1	75.7

remained practically constant and the number of vegetable and vegetable juice cans also remained relatively constant, the number of aluminium cans manufactured rose substantially. While the total number of beer cans rose from 1.72×10^{10} in 1968 to 2.18×10^{10} in 1972, the share of aluminium cans grew from 24.6 per cent to 33.9 per cent. Since then the growth of the share of the aluminium cans continues. In 1980 it reached nearly 70 per cent of all the manufactured beer and soft drink cans. As for soft drinks, while the total turnover grew from 1.07×10^{10} pieces in 1968 to 1.54×10^{10} pieces in 1972, the share of aluminium grew from 4.8 per cent to 11.7 per cent [40].

Aluminium cans are usually made from cold-rolled anodized aluminium strips or sheets that are coated with a synthetic resin or laminated with plastic. The synthetic resin film considerably improves the corrosion resistance of the aluminium surface. An epoxy-, phenol- or vinyl-base synthetic resin is used; it will dry in 30 to 40 seconds at 250° to 350° C.

In developed countries, 70 per cent of the aluminium cans are used for bottling of beer, fruit juices and other soft drinks.

For packaging in the food industry, as a rule, the following aluminium alloys are used:

Use	*Alloy*	*United States standard specification no.*
Food canning	$AlMg_{2.5}$	5052
Drink canning	$AlMg_1Mn_1$	3004
Easy-opening closures	AlMgMn	5182 and 5082

Although the production of strips from such alloys costs more than unalloyed strips, the difference in costs is offset by economies derived from the greater mechanical strength. The savings for 0.6-mm 99.5 per cent aluminium strip, are shown below [43]:

Alloy	*Index compared to "pure" Al = 1.10*	*Material savings due to higher mechanical strength (percentage)*
$AlMn_1$	1.04	28
$AlMg_1$	1.16	20
$AlMg_3$	1.38	32

Thin-walled packaging material is manufactured throughout the world from rolled semi-manufactures, i.e., sheets, strips and foil. Up-to-date packaging material has to be resin-coated inside and lacquered and printed outside. This is done using one of two techniques. The first is cold extrusion from slugs. The cans or collapsible tubes are lacquered and printed afterwards. The second is that lacquered and printed semi-manufactures are formed to desired shape [44].

Cans and boxes

In producing aluminium cans, the two principal operations are the manufacture of the body and the lid.

Cold extrusion [45] was the first manufacturing process by which thin aluminium boxes taller than their diameter could be produced from one piece. To achieve this, 2- to 4-mm thick slugs are given a strong impact and become malleable. The soft aluminium flows with great force through the gap between a stationary hollow die and the punch, thereby forming the body of the box. Cold-extrusion presses used in Europe are usually designed for 50 to 80 strokes per minute. Owing to the thickness of the box bottoms (1.1 mm) and sidewalls (0.3 to 0.35 mm), this technology is not economical as relatively large amounts of material are involved. The height of the boxes, too, is restricted.

The side walls of cans and boxes [42] produced by the deep-drawing technique are usually shorter than their bottom radius but may never be greater than 2.5 times the bottom radius. They are manufactured by 30- to 100-tonne eccentric presses.

Deep-drawn cans used by the food industry are as a rule made from an $AlMg_{2.5}$ alloy, which lends itself well to plastic deformation. Although the material hardens considerably when cold formed, it remains sufficiently pliable. In the process usually a 0.22- to 0.30-mm half-hard anodized and lacquered strip is used. The resultant can may be cylindrical, square, oval or elliptic. If the cans are manufactured in a plant at a distance from where they are to be filled, a conical shape may be preferable as it permits savings in space and transport costs. For a 6° conicity, such savings in space may amount to 70 per cent.

The side walls of the cans are sometimes reinforced by ribs to make them larger. The 0.25- to 0.30-mm alloyed strips are given a continuous lacquer coil-coating.

Cans are usually available in 100- to 350-ml sizes, with the inside surfaces lacquered and the outside lacquered or printed.

Recent demand for deep-drawn cans has been such that the Ministry of Fisheries in the Union of Soviet Socialist Republics set up a 12,000 tonne/year aluminium strip lacquer-coating facility at Dmitrovo in combination with a factory where round and oval deep-drawn low fish cans and tear-off lids are manufactured. The State Sea Fishery Enterprise of the German Democratic Republic operates a similar plant at Stralsund [41, 46]. Small-capacity aluminium cans of 100-200 ml are widely used in France, Norway and Switzerland for packing fish, pastes and milk.

World consumption of thin aluminium strip used in making food cans is 200,000 to 250,000 tonnes per annum, replacing some 400,000 tonnes of tinplate.

Despite the great difference in the specific weight of tinplate and aluminium, owing to the poor yield of the deep-drawing technology caused by large scrap production, 1 kg of aluminium may replace 2 kg of tinplate [47, 48]. The majority of the cans are manufactured by the canneries themselves, but many are produced by specialized aluminium box producers.

Automatic deep-drawing production lines operate with high efficiency. The basic operation in deep drawing aluminium is simpler than the processing of tinplate which includes cutting, forming the hull, soldering, flanging and capping. Therefore several heavy-duty presses may be installed and operated simultaneously with great savings in space. A modern 200-piece-per-minute production line fed by aluminium sheets cut to measure is shown in figure XVII.

The aluminium sheets are first placed on a feeder (1). To facilitate deep drawing and to prevent the sheets from ripping, sheet surfaces have to be oiled. The automatic press (2) punches the sheets and the resultant discs are deep drawn. The scrap material is removed from the edges and blown away. The cans are then passed through another feeder (3) to a receptacle (4) and are moved by a sledge (5) to another conveyor belt band (6), which moves them to a loading machine (7) that piles them on pallets in regular batches. Collected scrap is crushed and dispatched to be remelted.

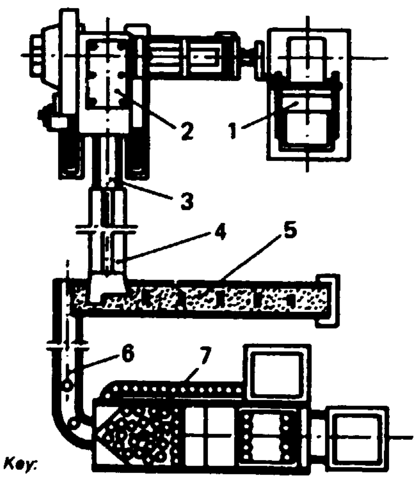
Cans and boxes with diameters smaller than 90 mm have to be deep drawn by special presses operating with 2-10 heads simultaneously and turning out cans and boxes at a rate of 200 to 1,000 pieces per minute.

Wall-reducing deep drawing (ironing) using this technology requires that cans for drinks that contain carbonic acid be made in heights that are 1.5-3 times the diameters. The orginal thickness of the $AlMg_{2.5}$ or AlMgMn plain unlacquered strip is 0.30 to 0.50 mm. The strip discs are first cut, and from them small cups are drawn. Then the cup is deep drawn to a cylindrical hull in a conventional manner. Next, wall-reducing deep drawing is done. The wall of the hull is drawn through three to five rings, the bottom is slightly raised and the lower and upper parts of the material become reinforced. In doing this, the diameter of the hull is slightly reduced by 2 to 3 per cent, and the height is stretched to more than three-fold. The production line operates at a minimum rate of 200 pieces per minute, although up-to-date heavy-duty lines can turn out as many as 600-650 pieces per minute.

The most commonly used sizes of cans may be produced by the modern wall-reducing technology. The bottom of a 12-ounce (0.35 l) beer can is 0.34 mm thick and its hull (except for its 0.30-mm lower and upper part) is 0.125 mm thick. It weighs 9 g. Its wall has a pressure resistance of 70 N/mm². The weight of a comparable cold-extruded box is 23-32 g.

The wall-reduced cans are then degreased. The outer hull is primed with enamel and passed through rubber rolls for printing. The inside of the can is coated with epoxide resin, and both the inside and outside lacquering is burned into the hull in a single operation. Finally, the hull is

Figure XVII. Automatic production line for manufacturing deep-drawn cans and boxes (Karges-Hammer system)



Key:

1 Feeder
2 Automatic press
3 Feeder
4 Receptacle
5 Conveyer
6 Conveyor
7 Loading machine

flanged so as to permit the lid to be firmly secured after packing. This process takes utmost advantage of the mechanical properties of aluminium. Cans of any size and height can be produced, and they are able to contain carbonic acid drinks in a completely sterilized environment [49].

Aluminium strips used in the process need not to be coil-coated, but technological standards are very stringent. The technology is gaining ground especially in developed countries, where the use of wall-reduced deep-drawn cans is growing at an annual average rate of 15-20 per cent. Table 32 shows the consumption in the United States in 1973 and 1974.

TABLE 32. USE OF WALL-REDUCED, DEEP-DRAWN CANS IN THE UNITED STATES, 1973 AND 1974

End use and material	*Consumption (million pieces)* 1973	*Consumption (million pieces)* 1974	*Change (percentage)*
Carbonated soft drinks			
Tinplate	15 862	15 482	−2.4
Aluminium	1 731	2 017	+16.5
Beer			
Tinplate	14 959	14 017	−6.3
Aluminium	8 905	11 862	+33.2
Total	41 457	43 378	+4.6

Source: [50].

A breakdown of drink packaging in the United States is estimated as below:

	Percentage
Aluminium cans	30
Tinplate cans	30
Glass bottles	40

According to information by a beer company in the United States, in 1968 investment costs for a 50 million piece-per-annum facility, amounted to 2 million dollars. The investment costs of a more modern line (1.3 × 10^9 pieces per annum) was 15 million in 1980.

Aluminium drink cans are manufactured with special easy-opening lids. In the United States at present, 770,000 t of aluminium are used to manufacture drink cans, accounting for 12 per cent of the country's total aluminium consumption. The fast rate at which aluminium drink cans gained ground may largely be attributed to the economies gained from reclamation. This is done by up-to-date continuous-cast wide-strip mills, such as the one at the largest brewery in the United States. It makes 4 × 10^9 cans and closures per annum, using about 100,000 t of aluminium. The continuous-cast wide-strip mill installed at the brewery is operated using a technology developed by Alusuisse and reprocesses about one-half (some 50,000 t) of the aluminium used by the brewery annually in the manufacture of cans.

In 1977 a company in the United Kingdom launched an experimental campaign for the collection of used aluminium cans from 5,000 households. The results were very satisfactory.

Lids

The design of aluminium can lids is similar to that of tinplate. Can lids must be easily opened or torn off. There are two kinds of tear-off lids: the lids of beer and soft drink cans are designed to be partially removed, whereas meat, fish and vegetable can lids may be fully opened and removed. In the middle of partially openable can tops there is a slightly depressed wedge-shaped notch, 0.09-mm thick, fitted with a small riveted ear. When the ear is raised the surface breaks and the can top opens when the ring is pulled.

In earlier designs of fully openable can lids there was a 1.5- to 2-turn spiral depression from the top centre towards the edge of the lid, with a tear-off ear riveted in the middle. This design has the following drawbacks:

(a) The pressure die necessary for making the lid was complicated and costly;

(b) The tear-off surface was too long;

(c) There was a danger of cutting fingers or hands;

(d) The spiral design impaired the rigidity of the lid.

In newer designs the lid is thinned only along the circumference of its rim. The can is not opened by a riveted ear but by a cutter, acting as a two-armed lever. Tear-off lids are made from an $AlMg_{4.5}Mn$ alloy (ASTM 5182 H19). They are of 0.3- to 0.35-mm thickness and are epoxy resin-coated on one side. They have a tensile strength of 300 to 370 N/mm^2 and a yield point ranging from 270 to 330 N/mm^2.

Jar tops

In preserving food in glass jars, technological problems arise when the glass jars are sealed with tin plate lids. When some foods are heated, the sulphur released may react with the iron in the tin plate, forming unpleasant black sulphide compounds that stain the surface of the lid. Aluminium lids overcome this difficulty. They are made in two types, cut from 0.15-0.25-mm aluminium strips, lacquered on one side and printed on the other.

The three principal types available are for food heated under a temperature of 100° C, for pickling and for food heated at higher temperatures than 100° C

In Europe, the aluminium alloy sheets from which the lids are made are usually lacquered using a dispenser from the United Kingdom, printed by a multi-colouring press made in the Federal Republic of Germany and burned in by a furnace also made in the Federal Republic of Germany. The lacquered and printed sheet is cut into strips using an Italian circular shear. The lids are subsequently formed and flanged. Finally, a sealing compound is applied and stoved using equipment and a furnace from the Federal Republic of Germany.

The lid is secured with the aid of a 1- to 10-head machine of 1,200 to 15,000-piece-per-hour capacity. (There are also all-purpose lids, manufactured in the Federal Republic of Germany, that are attached by three-, six- and nine-head machines with performances ranging from 800 to 12,000 pieces per hour.)

Bottle closures

Traditional tin plate crown closures for soft drink and beer bottles have not yet been economically replaced by aluminium. However, several other special aluminium bottle closures have been developed and introduced on a large scale.

Aluminium screw caps are used on bottles for alcoholic beverages. Caps are fitted with control rings that break when the bottle is first used. Caps are made from 0.15- to 0.25-mm thick 99.5 per cent aluminium strip, which is excellent for single- or multi-stage deep drawing. The inside is coated with epoxy resin and an adhesive sealing lacquer. The outside is lacquer-coated and printed. The cost is about one half or one third that of conventional corks.

Some aluminium caps are of a simpler tear-off design fitted with an ear. As a rule, they are used to close 5-10 centilitre glass bottles and are made from 0.18-mm plain aluminium narrow strip. They have also gained ground as the closure of 0.5- to 1.0-litre plastic bottles and for bottles in France [47].

Collapsible tubes

Much of the aluminium used in packaging is in the form of throw-away collapsible tubes. They are hygienic, inexpensive and considerably lighter than other traditional packaging. They give effective protection against the detrimental chemical and physical influences of the environment.

These tubes are manufactured by cold extrusion from aluminium slugs with a diameter of 3.5 mm cut from 99.5 to 99.7 per cent continuous-cast strip. Collapsible tubes are available in sizes of 50, 100 and 200 g. They are 0.11-mm thick, airtight, seamless, heat-resistant, unbreakable, flexible and sterilizable. The opening may be closed for foodstuffs and open for cosmetics and household cleansing agents. For the decoration of foods (with mayonnaise, sandwich paste, whipped cream), the opening may be star-shaped. The outside may be printed with multi-coloured designs, texts or publicity slogans. The inner surface is coated with two layers of burned-in epoxide-based synthetic resin film of 6 μm thickness.

The usual dimensions of collapsible tubes are 30 × 150 mm for 80 g and 40 × 180 mm for 150 g. Collapsible tubes can be used for such items as tomato paste, paprika- and tomato-based condiments, mustard, garlic paste, mayonnaise, meat paste, anchovy paste, concentrated milk, cheese, cream, cocoa, gravy, liver paste, jam, marmelade, ice-cream and juice. The food industry accounts for some 10 per cent of total collapsible tube usage [51]. In Hungary, in the long term, this figure may be expected to rise to 25 per cent.

In order to reduce transport costs, conical collapsible tubes are being developed. Some 30-40 per cent savings in transport space could result.

There is dramatic growth in the use of aluminium collapsible tubes throughout the world, both for foods and for cosmetics or household chemicals. In the Federal Republic of Germany, the total number of collapsible tubes manufactured in 1976 amounted to 1,230 million pieces, of which 1,100 million were aluminium. In the United States in 1970 some 1,120 million collapsible tubes were manufactured for pharmaceutical and cosmetic uses; 67 per cent of the tubes were aluminium.

Because even a double resin coating on the inside cannot completely protect foods against corrosion, a new type of collapsible aluminium tube has been developed, featuring plastics for enhanced protection [52]. It consists of three superimposed layers.

(a) A 0.050- to 0.100-mm inside polyethylene layer for increased corrosion resistance. This keeps the food quality longer and makes the collapsible tube suitable for welding;

(b) A 0.020- to 0.050-mm aluminium middle layer gives a gas and vapour barrier and protects it from light;

(c) A 0.050- to 0.100-mm polyethylene outer coating gives protection against the environment and allows welding and printing.

The resultant foil rolls are then formed into tubes and high-frequency welded hulls. A plastic inset, onto which a cap may be screwed, is welded onto the top part of the hull. After filling, the orifice of the collapsible tube is tightly sealed by welding. Multi-coloured texts and designs are printed on the white pigment-saturated outer plastics-foil layer and given a film of transparent varnish.

The capacity of such a production line is 600 to 1,000 pieces per minute. This process is relatively simple and has fewer operations than the manufacture of collapsible tubes from conventional slugs.

The properties of collapsible tubes made from aluminium, plastic and combined materials are shown in table 33.

TABLE 33. PROPERTIES OF COLLAPSIBLE TUBES

Property	Combined aluminium and plastic	Aluminium	Plastic
Light protection	+	+	−
Vapour tightness	+	+	−
Resistance to corrosive ingredients in:			
Toothpaste	+	+	−
Fluoride toothpaste	+	0	−
Mustard, tomato paste	+	+	−
Permanent deformation on emptying	+	+	−
Vulnerability of empty tube	0	−	+
Possibility of conical forming	+	+	−
Possibility of circular printing	−	+	+

Note: + = favourable
0 = average
− = unfavourable

Aluminium foil

Packaging

Aluminium foil has completely replaced tin foil for packaging.

The average annual growth rate of aluminium foil production is 10 to 12 per cent, but that of high-finish and laminated aluminium foils as well as of aluminium foil-plastic combinations is even higher. At present, the food industry accounts for 60 to 70 per cent of total world consumption.

In order to improve its properties, aluminium foil is often combined with other materials (paper, vellum paper, plastics) and given plain or printed protective coatings of coloured or colourless heat-proof lacquers and hot-melt films. A combination of these materials can produce a great variety of product types, and the food industry is the largest consumer. Aluminium foils and foil combinations and their end-uses in the food industry are shown in table 34.

Trays

Foil trays for commercial catering are used to hold prepared food, fruits, vegetables and bakery and confectionary products. They are formed from plain or slightly pleated hard 0.03- to 0.08-mm strips and are unlacquered or lacquered on one side only. Though sealed with flanging or otherwise, the tray is not airtight.

TABLE 34. USE OF FOILS BY THE FOOD INDUSTRY

Type of foil	End-use
Plain foil	Confectionary industry, household foil, prepared food trays
Patterned foil with coloured or transparent lacquer coating	Confectionary industry (chocolate, dessert, bonbons), wrapping of wine-bottle tops
Foil with coloured or transparent hot-melt lacquer coating	Dairy industry (cheese wrapping)
Hard foil with hot-melt lacquer coating, printed	Canning industry (lids of jam and marmelade jars)
Soft foil with hot-melt lacquer coating, printed	Dairy industry (milk and dairy product cup closures)
Aluminium foil-vellum paper combination, wet-laminated, printed	Tobacco industry (cigarette wrapping), coffee and spice bags
Aluminium foil-vellum paper combination, wax-laminated	Dairy industry (butter and cottage cheese wrapping), vegetable-oil industry (margarine wrapping)
Aluminium foil-paper combination, wet-laminated, with hot-melt coating, printed	Sweets industry (filled wafers, biscuits)
Aluminium foil-paper-polyethylene film combination, dry- and wet-laminated, printed	Dried soup bags, seasoning bags
Aluminium foil-single- or double-plastic film combination, dry-laminated, printed	Canning industry (fruit juices)

Source: [53].

The main advantage of the hard-foil tray—besides preserving both food quality and aroma—is that the prepared meal may be warmed or baked and then eaten from the tray itself. Because of its easy and hygienic handling, it has won universal acceptance in competing with plastics. In the United States in 1970, 4,500 million such foil trays were used for prepared food [54]. The storage and scale of prepared food in aluminium foil trays for commercial catering, however, calls for a well-organized chain of cold-storage facilities from the producer's end to the market.

Sterilizable cups and small containers

These containers, of maximum 30- to 35-mm depth, are manufactured by a single deep-drawing operation from 0.05- to 0.1-mm 99.3-98.7 per cent aluminium or AlMn alloy strip; they are coated inside with a 0.05-mm polythylene or poluproylene film. The containers are cylindrical, square, oval or elliptical. The main end-uses are summed up in table 35.

Polyethylene-laminated 0.07- to 0.18-mm aluminium foil cups and small containers are semi-

TABLE 35. STERILIZABLE CUPS AND SMALL CONTAINERS OF COMBINED FOIL

Shape	*Capacity (cm^3)*	*Wall thickness (mm)*	*Contents*
Cup	60-110	0.05-0.07	Ice-cream, cottage cheese
Box	30-130	0.10-0.15	Processed meat and fish, fruit cream, jam, marmelade, honey, cheese
Plate	150-1 300	0.07-0.09	Pasta, fruit-cake, buns, frozen food

Source [41].

rigid and, in the empty state, susceptible to damage. They are manufactured by one of two ways. In one, the forming and filling of the body, as well as the making and sealing of the lid are done by a single self-contained machine. The container is sealed at 240°-260° C and 6-8 atm pressure in two seconds. The output of the machine per minute is 80 to 120 containers with 20- to 50-ml capacity or 50 to 80 containers with 50- to 130-ml capacity.

Containers may be sterilized in autoclaves. Container bodies and lids do not have to be transported to the site, and, because the manufacturing process is at the same site, damage is reduced. The annual output of the machine is 20 million 100 cm^3 units, corresponding to 120 tonnes of laminated foil per annum.

Where conditions do not permit the forming and filling of the containers on the same premises, an apparatus that sends the container bodies and lids on separate pallets to the charging machine, where the bodies are automatically lifted and charged and the lids added and securely sealed, may be used.

Recently, several other foil combinations for the packaging of preserved food have been devised. Plastic trays with hot-melt aluminium lids are used in food canneries for packaging jam and marmelade. By vacuum forming PVC or polystyrene strip, small containers of 50-, 100- and 200-ml capacities are made, filled and secured with a printed hot-melt lacquer-coated aluminium lid. Another well-known packaging system has a 99.5 per cent hard aluminium foil of 0.03- to 0.05-mm thickness. The foil is coated outside with a 1 g/m^2 lacquer that resists temperatures to 180° C and inside with a 5- to 8-g/m^2 hot-melt lacquer film.

Heat exchangers

About ten years ago, the first aluminium ribbed tubes for thermo-engineering and refrigeration appeared on the market. A heat-transfer gas or liquid such as steam or water circulates within the tubes, while air flows in a direction vertical to the tubes. As air has poor heat-transfer properties, ribs are necessary on the air side.

In selecting a suitable ribbing material, the thermal conductivity, density and relative pricing have to be taken into account, as shown in table 36. It will be observed that aluminium has the lowest density. Copper has the highest thermal conductivity; however, it costs six times as much as steel. Aluminium is the next best conductor, and its price is only twice that of steel.

TABLE 36. FEATURES OF METALS USED FOR HEAT EXCHANGERS

Metal	*Density (g/cm^3)*	*Thermal conductivity ($kcal\ h^{-1}m^{-1}K^{-1}$)*	*Relative pricing (aluminium = 1)*
99.5% aluminium sheet	2.7	182	1.0
Aluminium alloy sheet	2.7	142	1.3
Copper sheet	8.3	320	3.0
Steel sheet	7.8	50	0.5
Alloyed steel sheet	8.0	13	0.8

From an economic point of view, therefore, aluminium is obviously the best material to be used as the ribbing of heat exchangers. Copper is a better thermal conductor, but, because of its greater density, what might be called its specific rate of heat transfer is 60 per cent less than that of aluminium (see table 37). The rate for steel is still lower—85 per cent less than that of aluminium. (The comparisons refer to the ribbing only and not the complete heat exchanger.)

TABLE 37. SPECIFIC RATE OF HEAT TRANSFER OF RIBBING MADE OF DIFFERENT MATERIALS

Material	*Specific rate of heat transfer ($kcal\ h^{-1}kg^{-1}$)*	*Relative rate (aluminium = 1.00)*
99.5% aluminium sheet	3 400	1.00
Aluminium alloy sheet	3 000	0.88
Copper sheet	1 250	0.367
Steel sheet	500	0.147
Steel alloy sheet	250	0.074

Small industrial and household heat exchangers

Aluminium can replace other non-ferrous metals used for heat exchangers, and it is superior to them. It lends itself excellently to plastic deformation and is thus an ideal material. In those heat exchangers where the heating medium circulates along flat surfaces, boundary spaces develop along these surfaces. These spaces strongly influence heat transfer: the thicker the boundary space, the less effective the heat transfer. The thickness of the boundary space increases with the distance from the entering edges of the sheets, thereby gradually impairing the local heat transfer coefficient.

For conventional cast-iron or steel-plate central heating radiators, air flows upwards along the flat surfaces of the radiators; hence, the heat transfer coefficient of the radiator surface tends to decrease with the growing height of the radiator.

The gradual impairment of the heat transfer coefficient along the long flat radiator surface may be offset by a series of small narrow strips cut as slits from the radiator sheets and slightly raised from the plane of the radiator body, creating a small-ribbed radiator with a far superior heat-transfer coefficient to that of conventional radiators. Though the small ribbing tends to increase the resistance of the structure on the air side, under identical conditions of ventilation the small-ribbed design will transfer more heat than its conventional counterpart.

In power engineering the heat exchangers and cooling components of the well-known Heller-Forgó air condensation system are based on the same concept. The design allows equipment for power plants to be located in arid areas (even in deserts). The condense water necessary for the operation of the steam turbines is circulated in a closed system and air-cooled with the aid of aluminium cooling elements.

Small-ribbed cooling elements, however, may not be used with advantage only in power plants. They may also be employed in a variety of other fields, for example for oil and natural-gas pipelines using oil, gas or water coolers at compressor stations located in arid areas and for air cooling in chemical engineering industries.

Engine radiators

In the transport industry there has been an increase in the use of aluminium in making pistons, engine-block castings and other components. The use of aluminium in water and oil cooling, however, is a relatively recent development, although the idea is not new. Towards the end of the Second World War and in the early post-war years, light metal heat exchangers and aluminium oil coolers were used by the aircraft industry. In ground transport, however, such innovations did not catch on, owing to heavy competition by the more durable copper coolers.

In the heat exchangers of transport vehicles, aluminium appeared for the first time as the lamellae of water coolers employed in diesel motor trains and diesel engines. For cooling transport vehicle engines, aluminium is the second best heat conductor after copper.

Recent developments in automobile cooler design have two purposes. On one hand, an attempt has been made to increase the amount of heat dispersed per cooler volume unit in order to increase the power output in automobile engines. On the other hand, great efforts have been made to reduce the overall weight of automobiles—be it only a few grams for a given component—so as to avoid the increase and, if possible, to permit the reduction of fuel consumption in spite of increased engine performance. This, obviously, calls for a weight reduction of the water cooler, and the development of new and more economical engine coolers is under way.

Air-conditioning and refrigeration

In air-conditioning and refrigeration aluminium is gradually displacing copper-ribbed heat exchangers and is now used exclusively in evaporators. Aluminium evaporation panels are made with integral tubes by a technology known as roll-bonding or Z-bonding. In roll-bonding, two aluminium sheets are joined into one by welding; but before this is done, the tracings of the future tube network are painted on the sheets. When the two sheets are rolled into one, the tracings do not fuse; they are slightly inflated by compressed air and the resultant tubing is provided with suitable fittings. Z-bonding is similar to roll-bonding, but the sheets are not joined by rolling but by brazing, with the ducts being eventually melted out.

Solar power

Recently the direct use of solar energy for heating has aroused much public interest. Heat from solar energy may be employed for heating, cooling or generating electric power.

The principal part of a solar power station is the collector, whose radiation-absorbing surface may be made from aluminium because of its high thermal conductivity. Owing to its good corrosion resistance, aluminium is also used in the framework and superstructure of the collector.

Miscellaneous applications

In some areas, the financial advantages of substituting aluminium for other metals are indirect and less obvious. A few examples are given below.

Castings

During the period 1974-1977 an annual average of 20 to 25 per cent of world aluminium consumption was devoted to the manufacture of castings. Of the 2.5 million tonnes of castings produced annually some 60 to 70 per cent were used as components for transport vehicles, especially automobile engines. According to one estimate, in the 1970s some 30 million passenger cars and motorcycles were produced annually, worldwide, and used about 1.2 million tonnes of aluminium castings. Predictions indicate that the type of structural materials to be used in passenger-car manufacture will change considerably [55]. There will be a trend toward further energy savings; and one way of accomplishing this will be to reduce the weight of components. Thus, in the medium term, a further advance in the use of aluminium castings may be anticipated, first of all to replace iron and steel and to a lesser degree copper and zinc (see table 38).

TABLE 38. ESTIMATED AMOUNT OF STRUCTURAL MATERIALS USED TO MAKE A PASSENGER CAR, 1975, 1980 AND 1990

Material	*1975*		*1980*		*1990*	
	(kg)	*(percentage)*	*(kg)*	*(percentage)*	*(kg)*	*(percentage)*
Steel and iron castings	1 210	77	830	67	614	56
Aluminium alloys	45	3	107	8.6	390	35
Plastics	55	4	95	7.6	127	11.5
Copper alloys	15	1	11	0.9	7	0.6
Zinc alloys	13	1	5	0.4	3.6	0.3

Source: [55]

The present and future consumption, technical features and manufacturing methods of aluminium castings were discussed at the International Aluminium and Automobile Conference organized by the Aluminium Zentrale of the Federal Republic of Germany, 22 and 23 March 1976 [56].

There are a number of reasons to expect an increase in the use of aluminium castings. Aluminium may be cast to high tolerances; castings are easy to interchange and require no additional machining after casting. They may be produced by various modern technologies in large series with relatively little labour.

The most effective mechanized casting technologies are high-pressure, low-pressure and counter-pressure die-casting and die forging. However, conventional sand or gravity die-casting techniques may be easily mechanized. A rough idea of capital expenditure involved in setting up a light-metal foundry was given in table 24. Investment costs for light-metal foundries are considerably lower than those of modern steel foundries. As a rule of the thumb, for up to 1,000 pieces sand-casting is most economical. For 1,000 to 10,000 pieces gravity die-casting is most economical. For larger series there are pressure die-casting technologies that are economical. In extreme cases, for example for stringent air-tightness demands or in cases where special techniques of a machining or surface treatment are called for, mechanized pressure die-casting may be more economical, even for a smaller series. A breakdown of the principal casting technologies for different areas of the world is given in table 39. Technical features of castings made by these methods are shown in table 40.

TABLE 39. BREAKDOWN OF PRINCIPAL CASTING TECHNOLOGIES, 1970-1974

(Percentage)

Country or grouping	*Sand-casting*	*Manual gravity die-casting*	*Mechanized casting*
United States	14	22	64
Developed Western European countries	20	40	40
Moderately industrialized countries[a]	35	45	20
Developing countries[a]	45	50	5

[a] Estimated.

Aluminium casting has the distinct advantage that any change-over from one technology to another is a relatively simple procedure. For example, in Hungary 110-kg diesel engine blocks were originally sand-cast; when this was no longer economical, mechanized gravity die-casting was introduced in its stead [58], and at present 10,000 motor blocks are cast annually using this manner. Comparatively small capital expenditure was involved in the change-over, and the purchase of costly high-pressure casting machinery was unnecessary. The castings may be protected against wear with the aid of a special surface treatment (extra-hard anodization) permitting the use of light-weight castings for components that are exposed to wear. Accessories for equipment used by textile mills and other industries to raise output (such as textile spindles, mobile frames of printing machines, castings and pistons of pneumatic control valves) are a case in point.

As discussed above, aluminium has a number of advantages in the casting process: mechanization is easy, large series can be produced and, in automobiles for example, fuel can be saved (roughly 1 litre per kilogram of weight saved per 100,000 km). In addition, the relative pricing of aluminium and cast iron is an important point in the design of transport vehicles. Although in order to manufacture 1 tonne of a steel product, 38 GJ of energy are involved compared to 300 GJ for aluminium, in case of diesel motor lorries this additional energy cost will be repaid within two years in the form of fuel savings [59].

TABLE 40. PROPERTIES OF DIFFERENT CASTING METHODS

Technology	Minimum wall thickness (mm)	Tolerance of wall thickness (percentage)	Productivity per worker (piece/h)	Die endurance (pieces)	Economical minimum of workpieces	Relative cost of workpiece[a]	Mechanical strength[b]	Surface smoothness[b]	Anodizability[b]
Sand-casting	3.0	±10	2	100-300[c]	under 1 000	1	C	C	B
Gravity die-casting	2.0	±5	30	10 000-20 000	over 1 000	0.65	B	B	A
Pressure die-casting	0.8	±2	75-150	10 000-50 000	10 000	0.50	A	A	B

Source [57]

[a] Sand casting = 1.

[b] A = best, B = average, C = least satisfactory.

[c] Using a wooden die, an aluminium die would improve endurance by one order of magnitude.

Similar advantages may be derived using aluminium in other industries as well. The possibility of setting up aluminium foundries at small cost for the manufacture of castings in relatively small series has many promising implications, especially for developing countries. This and favourable pricing trends are the principal reasons why light metal castings have become a viable competitor of copper, bronze and zinc castings in many areas. Therefore, when planning new industrial projects, the considerations outlined above may help.

Transport

Window frames

Aluminium use has been increasing in many areas of the transportation industry. An example is window frames in railway carriages, which were at first made from wood and then from bronze. The first aluminium window-frame design appeared some 50 years ago. Since then, for reasons of weight and economy, window frames made from anodized aluminium have completely displaced other structural materials.

Next, aluminium was introduced for certain fittings in railway carriages, mostly for castings, because it was less labour-intensive in manufacture and maintenance. The bronze, brass or zinc-alloy luggage racks, door knobs and handles had to be electroplated with nickel or chromium for corrosion resistance. In contrast, the surfaces of aluminium are simply polished or (in most cases) anodized for protection against corrosion and discolouration. Recently there has been heavy competition from plastics. But plastics have often failed to come up to expectations because of the heavy loads involved in rail transport.

The use of aluminium-alloy for automobile fenders is increasing owing to its high strength and ease of automation for surface treatment. In the United States, fenders made from an AlZnMgCu (7016-T6) alloy were first used in 1976. Compared to steel, the advantages of aluminium-alloy fenders are [60]:

(a) Favourable shock absorption in case of collision; the stringent standards of the United States are easier to comply with;

(b) Manufacture and surface treatment lend themselves better to automation and involve fewer operations; hence, an aluminium-alloy fender is cheaper than a chromium-plated steel one;

(c) The use of chromium (or nickel) in coating the steel fender may be completely dispensed with.

Bodywork

With cold and spot welding as well as adhesion techniques becoming more widespread, aluminium components for bodywork are gaining acceptance in public transport and commercial vehicle manufacture.

In some cases aluminium not only replaces other non-ferrous metals, but, when used to prevent corrosion, aluminium can replace steel as well. An additional advantage is the light weight of certain labour-saving mobile structures in modern rolling-stock design, such as room dividers, large sliding doors, tipping or sliding roofs and openable external panelling, as well as window frames, covers and gratings of freight cars.

An interesting development is the replacement of steel and wood bodywork on motor lorries for aluminium superstructures. Using aluminium, considerable savings may be arrived at in maintenance and repair costs [61, 62, 63]. Aluminium bodywork consisting of extruded aluminium sections that can be pushed into one another and secured with a catch costs about the same as the steel and wood combination owing to the labour savings; an extra benefit is that skilled workers are not necessary [64].

The potential for aluminium in transport vehicle manufacture is certainly promising. This is also true for automobile manufacture, where more aluminium is expected to be used in the years ahead. Table 41 is a projection by a producer in the United States.

TABLE 41. AMOUNT OF ALUMINIUM USED IN MAKING AN AUTOMOBILE, 1965-1985[a]

(Kilograms)

Year	*Castings*	*Rolled and extruded parts*	*Total*
1965	24	8	32
1970	26	9	35
1975	27	11	38
1977	29	15	44
1980	41-45	27-45	68-90
1985	57-79	34-102	91-181

Source: [64].

[a] Forecast.

Heavy-duty components

Die-forging is an important technological process in the plastic deformation of aluminium, ensuring added mechanical strength and longer life. The resultant product is suitable for high-duty performance and can cope with heavy loads frequently encountered in using transport vehicles. The technology is also significant in that it permits the manufacture of sturdy passenger car wheels from one piece; such wheels can be used over the most difficult terrain with utmost safety.

When all load-bearing parts of a vehicle—the chassis, body framing and the cladding of the superstructure—are made from an aluminium alloy, apart from weight and fuel economies considerable savings can also be made in manufacturing and maintenance costs. With the aid of the relatively simple technology of extrusion, consoles and supports for the superstructure can be produced that, in contrast to rolled or folded welded steel parts, permit wall thickness at different points to be distributed to ensure optimum mechanical strength.

Because aluminium does not corrode, parts remain intact for the vehicle's lifetime and periodic dismounting, surface treatment and re-assembly are unnecessary. The weight reduction may cause minor wear in rolling stock running-gear and underframe.

No doubt, the aggregate amount of specific energy used in producing a finished product of aluminium is higher than that of other structural materials. This, however, is highly deceptive; during the life of a transport vehicle, usually nine times as much energy may be saved than the surplus energy involved in the manufacture of aluminium parts and components. In case of aluminium underground railway carriages the situation is even better: 1.5 to 2 years suffice to make up for the difference [65]. This, coupled with advances in modern extrusion techniques, have led to the recent purchase by the Paris Metro of 1,000 aluminium underground motor carriages that were cheaper than their steel counterparts [65]. Encouraged by such developments, the Atlanta subway has now ordered similar underground carriages from Europe [66].

Agriculture

Because of the usual rough handling of outdoor equipment in farming and local geological and climatic conditions, the quality of aluminium items used by this sector must be high and exacting. Corrosion resistance is an important consideration in view of the large amount of chemicals used.

In agriculture, aluminium is faced with heavy competition from two other materials: zinc-coated steel and plastics. Eventual patterns of use will always depend on the relative pricing and technical specifications of these materials. To illustrate the relative advantages of aluminium in the field of agriculture, two concrete examples are cited below. These are based partly on experience in Hungary and partly on professional literature.

Irrigation

Irrigation systems greatly vary with the site where they are to be installed; those used on arable land differ from those used in gardening. Their design too depends on whether rainers, sprinklers or subsoil irrigation is required.

Aluminium irrigation systems on arable land use three types of pipelines: portable, self-propelling, or trailable over longer distances. Their common feature is mobility. Hence, next to corrosion resistance, two other prerequisites are lightness and sufficient mechanical strength. In weight, aluminium compares most favourably with zinc-coated steel; as for mechanical strength, it is far superior to plastics.

Portable systems are designed with one main pipeline and three or six secondary pipelines. The length of each component pipe is 6 m. Their two ends are fitted with fast locking joints. Portable systems differ from the other two because of the fast-locking joints of the Perrot or Wright-Rain type; the former are firmly fitting mechanical shackles, the latter used the pressure of irrigation water to tighten the packing rings. Both types allow for a ±15° deflection from the pipe axis. In Hungary mechanical locking is more widespread.

The size and weight of the main and secondary pipes are:

	Main pipe	*Secondary pipe*
Inside diameter (mm)	130	87
Length (m)	6	6
Thickness (mm)	1.2	1.2
Weight (kg)	1.5	7.8

Main and secondary pipes are welded from an aluminium-alloy band. The test pressure is 160 N/mm².

Moving self-propelled rain applicator systems save labour, the work being done by the system's own motor. A standardized rain-applicator system is made of welded aluminium-alloy pipes of 130-mm diameter.

A trailable pipeline system acts as the main pipeline of the self-propelled rain applicators. The hard work involved in moving the main pipeline is saved. The welded aluminium pipes are of 159-mm diameter and 2-mm thickness. There are 46 pairs of wheels; the sideline piping rests on 19 rollers.

Portable irrigation systems may be used for any kind of outdoor cultivation in arable lands, fields, large orchards or vegetable gardens, even on uneven or sloping ground. Trailable equipment is suitable for operation on flat ground only, but for any sort of cultivation, whereas self-propelled rain applicators will irrigate only low plants (not higher than one metre) cultivated on flat ground. They are thus unsuitable for irrigating orchards.

Gardening

The size of irrigation pipes used for gardening in greenhouses and foil tents is considerably smaller than that of pipes normally used in the fields. Stable aluminium irrigation pipes were used earlier, but these have been completely replaced by plastic pipes, especially of polyethylene. Plastic is also used for outdoor sprinklers to irrigate vineyards and smaller orchards.

Subsoil irrigation is predominantly used in vegetable cultivation, where underground pipes water the roots of plants. As a rule, plastic piping is used. Aluminium is used only in cases where the soil, upon changing culture, is disinfected using a high temperature rather than chemicals. Generally speaking, aluminium does not compete with plastics for subsoil irrigation. It may, however, be used with advantage as the framework of foil tents or as poles and supports in viniculture.

Foil tents are usually available in two sizes; they are either 4.5-m wide structures dug into the ground, fitted with a framework of aluminium tubing made pipes that are 300 mm in diameter and 1.5 mm thick or are 7.5 m wide with a framework of 40 mm in diameter, tubing 2 mm thick. In temperate climates such as that of Hungary, plastic tents have found wide acceptance for growing vegetables, seedlings and firstlings, the cost of erecting tents being only 10 per cent that of conventional greenhouses.

The use of aluminium structures as poles and supports for grape-vines is increasing. One of the principal reasons for this is that in contrast to timber and concrete, they lend themselves well to mechanized handling. Poles are 3 m tall, made from 2.5 × 40 × 60-mm folded aluminium channel sections driven into the ground 8 m apart using a hydraulic device mounted on a tractor. Grape harvesters no longer use timber and concrete. In facing competition from other metals, the corrosion resistance and easy maintenance of aluminium present great advantages.

Building and construction

In the building and construction industry, storage facilities, agricultural premises and office blocks as well as communal buildings and multistorey apartment blocks create demands that traditional building methods are no longer able to cope with. More sophisticated building techniques, prefabrication and light-weight construction components are therefore emerging. Where building capacities are inadequate or no building industry is operating at all, these new techniques may afford the following advantages:

(a) Facilities for prefabrication may be located conveniently in areas where a more or less advanced stage of industrialization already exists and where the necessary infrastructure is available;

(b) Multi-purpose industrial facilities (metalworking, mechanical engineering etc.) can also manufacture prefabricated building components, and part of the heavy expenditure usually involved in erecting separate building-materials plants can be saved;

(c) In comparison to conventional building methods, light-weight components tend to reduce the volume of material to one fifth or one-tenth, permitting great economies in transport costs;

(d) Assembly and installation require less skilled labour;

(e) The completion of projects can be accomplished faster and go on stream earlier.

Roofing

In light construction it is of paramount importance that prefabricated roofing and wall components be available in sufficient quantities ready for assembly on site. Various rolled aluminium products such as corrugated sheets, sandwich panels and other combinations of rolled aluminium may be used with advantage. This replaces large quantities of zinc-coated steel and is an important consideration especially in climates where zinc-coated steel soon begins to rust.

In the building and construction industry, the fields where aluminium may be applied with advantage include:

(a) Industrial premises and storerooms;

(b) Bays of framed design, featuring large roofing spans. Such premises are usually steel-framed. For cladding, corrugated aluminium sheets, sandwich panels coated with aluminium sheet, or other combined prefabricated components may be used;

(c) Agricultural premises where livestock is kept, usually designed for a small-span roof. In view of the large number of buildings and the rapidly changing animal husbandry technologies involved, building costs have to be kept down. For this reason, aluminium-clad timber framing is employed frequently;

(d) Facilities for the cold storage and deep-freezing of fruit and meat. Nowadays aluminium sandwich panels are used exclusively;

(e) Cladding the frames of public edifices and apartment buildings. Aluminium sandwich panel walls and partitions may be used. In tropical climates various types of shade-reflecting surfaces and ventilation shells may be made from aluminium;

(f) Aluminium-clad sun convectors to generate part of the heat energy required in buildings (e.g., hot-water supply). At present, this use is in the experimental stage.

For raising walls or putting up roofing, corrugated aluminium sheets are used as a rule. They are made from 1,000- to 1,200-mm or 1,260- to 1,600-mm wide strips that are corrugated longitudinally for rigidity. The usual material is an AlMn_1 or $\mathrm{AlMg}_{1.5}$ alloy. Being corrugated lengthwise, they are available in any desired length subject to transport possibilities. The thickness of the sheet will depend on the end use, the load and the depth of the corrugations. The usual thickness of corrugated aluminium sheets varies from 0.45 to 1.2 mm. The weight per surface unit is usually within the 1.2 to 5.4 kg/m^2, with 3 kg/m^2 a fair economical average. In using corrugated sheets on a commerical scale, various aluminium fasteners and other items of aluminium hardware (rain gutters, parapets and corner joints for connecting window frames or components made from aluminium or other structural materials) cold-formed by folding or by passing them through a set of rollers, are necessary. Sheet corrugating and hardware manufacturing facilities should be installed simultaneously.

A suitable design for fasteners, joints and aluminium hardware will save a great deal of labour and scaffolding costs, counterbalance the effects of the slight expansion and contraction of aluminium structures owing to changing climatic conditions and protect structures from rainwater leakage, thereby prolonging their use.

Various types of aluminium cladding systems have been developed, differing from one another only in slight detail. A single-layer, uninsulated, corrugated aluminium-sheet cladding may have thermal insulation suspended or placed behind it. A well-insulated wall or roof may be made by placing insulation between two corrugated aluminium-sheet claddings. The inside cladding may also be made from wood or some other building material. In such an event, of course, a further set of components have to be added such as distance pieces, adjustable trusses and secondary ribbing. Major aluminium producers have all developed suitable designs of insulated wall and roofing systems.

One drawback of light construction is the danger of over-heating in warm sunshine. In tropical regions it is difficult to regulate room temperature to a level required for delicate equipment (for example computers) or even for comfort even using traditional construction techniques. To reduce over-heating, special aluminium screening systems have been devised to be located independently of the roofing. These systems permit effective ventilation between screening and roofing. Surplus costs involved in installing such shading screens are amply repaid by economies in or the complete elimination of air-conditioning.

A widely accepted prefabricated building component is the sandwich panel, featuring a rigid plastic foam core firmly fixed between two hardwood, plastic, steel or aluminium layers. The plastic core is usually polyurethane, but research is under way to develop a more fireproof type of plastics foam. The ready-made panels are usually 8,000 to 12,000 mm long and 600 to 1,500 mm wide. The aluminium layer is made as a rule from a 0.6- to 1.0-mm strip of medium width passed through a set of rollers for corrugation. Cladding edges are so shaped as to permit rapid on-site assembly. While most sandwich panels are used for walls, some are also used as part of the roofing. In installation, great attention has to be devoted to effective sealing.

The overall thickness of panels used in industrial and agricultural premises as well as in public building is 35 to 55 mm. Such panels contain 5.5 kg of aluminium and 2 kg of plastics per square metre. In the construction of cold-storage rooms thicker panels have to be used: 80 to 100 mm for fruit and 200 to 300 mm for the deep-freezing of other food. Panels have to be joined with the utmost care and accuracy.

Compared to other designs, aluminium-clad sandwich panels have the distinct advantage that, owing to their corrosion-resistance, no extra surface treatment is necessary on installation and there is no maintenance work to be done later. The surplus expenditure involved in using such panels is amply repaid in the form of cost savings within five to eight years. Thus, the use of aluminium in cold-storage room construction is not only technologically useful, but also financially a sound proposition.

A special type of prefabricated roof has been developed in Hungary. It has an arched shell design, where two corrugated aluminium sheet layers are connected by rigid metal ribs; insulation is placed in and between the sheets. The roofing is available in 12- to 30-m long spans which are held in position without extra trusses or supports. Being fully prefabricated, installation is time-saving and highly economical. Over longer distances, however, the roofing is difficult to transport owing to the poor utilization of shipping space.

By using aluminium in building and construction, traditional silicate-based building materials may be replaced. Aluminium also has great potential as a substitute for zinc- or plastic-coated steel. Each tonne of aluminium sheet replaces 2.4-2.6 t of steel plate and 0.2-0.25 t of zinc coating. Moreover, the useful life of aluminium sheet is several times longer than that of steel-plated sheet. There is no extra maintenance, whereas zinc-coated steel has to be surface-treated every two to four years.

Gutters

An effective rain-water disposal system is essential in any aluminium light construction design. Its lack, poor design or damage may cause indirect financial loss and depreciate the value of the building.

The traditional material for rain gutters is zinc, although copper was sometimes used in the past. Since the 1910s zinc-coated steel has come into general use. Nonetheless, the thin and often not continuous zinc coating is not a good substitute for zinc plate, which normally remains serviceable for 30 to 40 years. As a rule, after 2-3 years of use, specks of rust become visible on the surface of zinc coating and after 5-6 years the rain gutters become defective at several points and have to be replaced. Attempts were made to prolong the age of the gutters by adding a coat of paint. However, the extra labour and paint costs were uneconomical; and thus, painting is only used for small private houses. Prepainting the zinc coated steel plate with an effective primer and a high-quality paint was more useful. This costly operation prolonged the serviceability of the rain gutter by 10 to 15 years, which is, however, only a fraction of the time a genuine zinc plate can last. Experiments were also conducted with plastic rain gutters (PVC or shatter-proof polysteryne), which have, however, poor cost-effectiveness.

In Hungary in 1970, only 2-3 per cent of the rain gutters were made from aluminium; in 1976, this figure rose to 30 per cent. Facilities for the manufacture of aluminium fasteners, fittings and other auxiliary components are now available, too.

According to experience so far, rain gutters for general use should be manufactured from 0.8-mm aluminium sheet. Outdoor corrosion trials with 99.5 per cent half-hard aluminium sheets have yielded the following results:

(a) After exposure for six months, a few small white corrosion spots, easily removed, appeared on the surface of the test pieces;

(b) After six months, the intensity of corrosion tended to slow down; even after several years corrosion did not grow substantially, and the exposed test pieces have not become defective at any point;

(c) The rate at which white spots develop, as well as their density, varied with the intensity of ambient air pollution;

(d) Corrosive inroads were found to be more frequent under the impurities on the surface of suspended rain gutters;

(e) On opening sealed joints, the insulation placed between two metals to avoid direct contact was found to be defective at various points; in spite of this, either no or only a slight degree of contact corrosion could be observed;

(f) The rear and the edges of the claddings are in direct contact with substances prone to alkaline reaction (for example mortar, cement and concrete). If such aluminium parts are not properly mounted, humidity entering into the resultant gaps may cause corrosive changes;

(g) Apart from the white spots referred to above, no substantial corrosion could be discerned;

(h) Laboratory tests demonstrated that the depth of corrosion did not increase proportionately with time; that is, the rate and intensity of corrosion tended to slow down in the long run.

Suspended aluminium rain gutters have to be given a greater tilt upon mounting than that of zinc-coated steel ones to prevent corrosive damage. If hardware is used in a new aluminium-clad building, it must be aluminium. If aluminium hardware is used for renovation, all other parts should be exchanged for aluminium, as far as possible. The use of different metals side by side is harmful and should be avoided.

The principal dimensions of aluminium building hardware are practically identical with those of zinc or zinc-coated steel, with the following exceptions:

(a) Half-hard 99.5 per cent aluminium sheet of 0.8-mm thickness has to be used;

(b) At a maximum distance of 10 m from points where suspended structures are firmly fixed (e.g., pipe end joints) water-tight clearances for expansion have to be provided.

In view of the properties of aluminium, rain gutters have to be installed with a slope of 3 to 4 per cent. Moreover, rain-gutter brackets have to be mounted at regular distances of 1,000 mm with a tolerance of ±100 mm and placed so that they may ensure the desired slope.

No effective technology has been devised to solder aluminium building components on a commercial scale; therefore, aluminium members can be joined only by riveting or folded joints. Rivets have to be of aluminium or material compatible with aluminium.

Aluminium and other metals may not be directly joined. To avoid the detrimental effects of corrosion, contact surfaces have to be provided with effective insulation.

Doors and window frames

Another aluminium outlet that is finding wide acceptance by the building trade is aluminium window frames. Latest advances in technology permit the manufacture of window frame components of highest dimensional accuracy, permitting easy and quick assembly on site. Apart from the universal demand for more personal comfort, more industrial plants, scientific and medical institutions need effective control of temperature, humidity, sterility and dust. Modern aluminium window frames and doors of practical and aesthetically appealing design can meet these needs. Cost savings in using aluminium window frames accrue in operational overheads rather than in capital expenditure.

The design of aluminium window frames is determined by local climatic conditions. If the mean temperature is above 18° C, single windows will generally suffice. For reasons of economy, sliding horizontal or vertical frames made of aluminium sections are used. The component aluminium sections are anodized in batches. Welded frame corners have been replaced by mechanical corner joints. For this purpose, screw fastenings, cast or extruded section insets, and nuts and cold-formed fasteners have come into use. Depending on size, the weight per unit area of a modern single horizontal aluminium sliding window frame varies from 4 to 7 kg/m^2.

In temperate climates the use of insulated double window panes is justified. The technology is practically the same as that of single window frames. However, in order to ensure air-tight sealing, special care has to be taken. The weight per unit area of an insulated double aluminium window frame is about 7 to 9 kg/m^2.

In the wake of rising fuel prices, a new aluminium window frame design has emerged that features "thermal bridges". A plastics layer, which is a much poorer thermal conductor than aluminium, is added between the outer and inner aluminium surfaces. Heat loss and vapor condensation may be reduced considerably. Because the plastic inset tends to impair the mechanical strength of the window frame, the aluminium frame has to be more robust; its weight per unit area usually ranges form 6 to 13 kg/m^2.

In regions with higher mean temperatures and more hours of sunshine, it is more difficult to cool in summer than to prevent heat losses in winter. Hence, research is under way to develop new types of window frames that reduce surplus heat without a separate screening system. A first step has been the introduction of light-reflecting window panes. A more effective solution may be a double window with two frames placed 10 to 30 cm apart; the natural or artificially incited flow of air between the two may drive out the major part of the surplus heat.

In buildings of traditional design, 60 to 80 per cent of the heat losses occurring in the winter months is caused by heat transfer through the building construction itself and 20 to 40 per cent through the window frames. Securely insulated modern aluminium window frames can reduce the latter figure to 10 per cent. To a lesser degree summer heat may be effectively reduced with window frames of suitable design. All this has a telling effect on energy consumption, an area where savings are always welcome in the face of steadily rising power and fuel prices. Aluminium doors are used in cold-storage rooms; large mechanically operated aluminium doors are installed in hangars, factory bays and some public buildings; aluminium doors and gates are also to be found in agricultural buildings.

The production of aluminium window frames calls for aluminium extrusions in sufficient shapes and of suitable specifications. Therefore, hydraulic presses for the extrusion of aluminium sections are often installed in factories that manufacture aluminium window frames.

Investment costs for aluminium window frame factories vary with the extent of mechanization and automation and with the rate of productivity. The installation of an automated 5,000 t/a (80,000 m^2/a) facility with a maximum of 20 employees may require a capital investment of $40 million. A plant of the same capacity with a considerably more modest scale of mechanization would cost about $13 million, but about 80 workers will have to be employed.

Prefabricated buildings and mobile homes

In the period following the Second World War, many aircraft manufacturing facilities became idle, and the premises—small prefabricated aluminium buildings—appeared on the markets in the United Kingdom and United States. The buildings were not popular, however, owing to shortcomings in design and corrosion that resulted from the use of an unsuitable alloy.

At present, two systems of small prefabricated aluminium building construction are used on a commercial scale:

(a) "Mobile homes", which are transported to and erected on site as completely prefabricated and self-contained single units;

(b) The module system, which permits combinations of the framing, roofing, side panels, room dividers, window frames and doors to be assembled on site.

In price, prefabricated aluminium buildings are more expensive than comparable buildings of traditional materials. They are viable, nonetheless, in specific cases:

(a) Temporary premises where dismounting and re-erection costs are lower than those for building new premises (for example, sites for building development or industrial projects);

(b) In areas where access is difficult or where maneuverability is poor;

(c) Where quick construction is desired.

In regions with inadequate infrastructure, there are extra advantages:

(a) As transport over longer distances is costly and difficult, the light weight of aluminium building structures and components is an important consideration;

(b) Labour, especially skilled labour, is often hard to come by on site; work involved in the assembly or installation of prefabricated construction is minimal.

Aluminium-framed buildings can have a maximum of two storeys and must be designed with medium or small spans not exceeding 6 m. They may be used with advantage as bungalows or bunk houses, offices, workshops, laboratories, engine rooms, schools, dispensaries, consultation rooms and motels.

Mobile homes were first developed in the United States. The aluminium frames use a high-strength AlZnMg alloy that lends itself well to welding. The frames are usually sent to the site for installation. The aluminium frame system developed in Switzerland is similar; here the welded frames are sent to site and joined by screws.

Two systems developed in the Federal Republic of Germany have aluminium rods that are cut to measure, bored and fitted with fastening devices to be secured with screws on site.

A system now being developed in Hungary has maximum prefabrication coupled with a minimum of labour. The frame is a welded design and the inside partitions and outer panels are prefabricated, permitting adjustment of interior space. Each panel and partition is fastened to the frame by a simple catch.

All the systems take advantage of the design possibilities of the extrusions, and they use joints that are easy to manipulate in connecting joists, roofing and sidewalls with the framework.

The amount of aluminium used in these systems per unit area varies from 10 to 30 kg/m^2 for each storey.

Miscellaneous uses

Other applications for aluminium in the building trade include:

Aluminium tube scaffolding for construction or renovation

Curtain walls, exterior building claddings

Banisters, friezes, ladders

Building engineering installations, air ducts, radiators and coolers.

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V. Product development

Boosting aluminium consumption is always a major concern of the aluminium industry. New outlets generate greater demand and put pressure on the semi-manufacturing mills and other operators to develop advanced technologies to meet the more sophisticated requirements of consumer increases.

Aluminium has to face constant competition from other materials. Maintaining the position of and finding new markets for aluminium is a difficult task—assistance is often rendered by advisory agencies (see chapter III). In product development, advisory agencies may:

(a) Help elaborate the general outlines of standard specifications through recommendations and active participation;

(b) Co-operate in compiling and editing textbooks, documentation and reference tables and in organizing lectures or post-graduate courses for engineering staff in the consumer sectors;

(c) Actively participate, in co-operation with with local authorities, in the implementation of projects calling for economies in energy or a more rational use of materials in short supply.

Standardization

Standardization ensures that the size of a product is accurate, that the product is interchangeable and endurable and that considerations of operational safety, hygiene and environmental protection are met. Consensus on all points has to be reached by a body made up of the principal producers and consumers in order for standards to be enforced. Regulations and special standards governing the assembly and installation of products and guaranteeing the quality of the product are also necessary.

A separate set of ingot and semi-fabricated product standards must be negotiated between the manufacturers and smelters and mills. This is sometimes an arduous task because the interests of the parties often conflict. The aluminium industry is at times faced with the necessity of introducing new and costly technologies before standard specifications are passed. Representatives of the aluminium industry should take part in the deliberations of all standardization committees.

Despite the difference in standards from country to country, there are three principal types:

(a) Raw-material standards governing the composition, mechanical properties, sizes and, more recently, the technological properties of ingots and semi-manufactures (e.g. electrical conductivity, susceptibility to deep-drawing etc.). They are usually drafted by aluminium experts, but before they are passed the principal consumers have to be consulted;

(b) Finished-product standards are applicable to a particular sector; they enumerate the essential technical features of the material from which the finished product is processed and the principal properties of the finished product itself. Such standards have to be co-ordinated with raw-material standards. They are usually jointly drafted by specialists of a given aluminium end-using sector (electrical engineering, building and construction, packaging etc.) and representatives of the principal consumers, in consultation with the aluminium industry;

(c) Technological standards are for welding, surface treatment etc. If such standards are initiated by the aluminium industry, the principal manufacturers who apply such technologies have to be consulted.

In many developed countries the properties and application of a very wide range of products are governed by standard specifications, which are often supplemented by a set of detailed technical and installation instructions or regulations. It is necessary for each country to revise and adapt the standard specifications to local conditions, if necessary.

In the early 1950s a system of recommendations was introduced in Hungary. Though not full-fledged standards, these recommendations were aimed at boosting aluminium usage on the one hand and restricting the use of other nonferrous metals on the other. They outlined whether it was desirable, advisable, possible or impossible to use aluminium for a particular purpose. (Such recommendations, of course, have to be revised from time to time to keep pace with latest technical advances.)

Handbooks

It is of paramount importance for designers, researchers, process and works engineers, specialists such as economists and, most important, skilled workers and craftsmen to become proficient in the design, processing and usage of aluminium in different sectors of industry. Although these people may be well-versed in the fundamentals of their own field, they are likely to be unfamiliar with specific technologies, standards, economic feasibility and other aspects of aluminium consumption.

Researchers, design engineers and consultants attached to the aluminium industry will have to take the initiative in drafting handbooks, textbooks, pamphlets and tables for engineers, technicians and skilled workers engaged in the industry. The Aluminium Zentrale of the Federal Republic of Germany has its own publishing firm, Aluminium Verlag. All major transnational aluminium corporations and most large aluminium companies publish, even if only on a small scale.

The main types of documents used by the aluminium industry are described below.

Handbooks. Handbooks describe the mechanical and technical properties of aluminium, technical features and end-uses (e.g. the large variety of extruded sections) of semi-manufactures, subsequent methods of processing, technologies and operations (e.g. casting, welding, surface treatment, machining). Handbooks also give guidelines on the design, installation and use of aluminium products.

Tables. Tables help the designing engineer to achieve optimum designs by taking advantage of the essential features of aluminium. Because designs using traditional materials can very rarely be effectively and economically adapted to aluminium, new and effective designs are essential.

Booklets and pamphlets. Particular operations or techniques such as plastic deformation, casting, welding, machining or surface treatment of aluminium are subjects that might be covered. Booklets should be factual, with plenty of illustrative material, and written in a style that can be easily understood by engineers, technicians and skilled workers.

Special publications. Such publications describe where and under what circumstances aluminium may be used effectively. The language too should be descriptive and unambiguous; professional "jargon" may be used if it cannot be avoided.

Textbooks for training courses. Abstracts of lectures presented at training courses or experience gained in workshops may appear in textbooks.

Catalogues and leaflets. Detailed specifications of semi-manufactures or descriptive features of a particular generation of products might be described in this type of publication. Auxiliary products used in the processing of aluminium (e.g. special lubricants, welding fluxes, surface treatment baths) should also be covered. The aluminium industry should promote the publication and circulation of such leaflets, even if it is not a manufacturer of such products.

Journals. The publication of an aluminium journal is recommended only if a powerful aluminium industry exists in the region. An aluminium journal is a useful instrument in fostering contacts between smelters, mills, manufacturing industries and consumers and in promoting co-operation between design and research institutes on the one hand and industrial firms on the other. The aluminium industry should be the principal sponsor of such a journal.

It would be desirable for aluminium technology to be included in the curriculum of mechanical and chemical engineering schools. Staff-training courses could also be organized for engineering personnel or skilled workers or to provide post-graduate studies for specialists. Moral or financial backing for such courses by government agencies would be desirable.

Regulations

When traditional material is replaced by aluminium, it may take as many as 20 years for the new technology to mature. The development of a new product or technology is time-consuming and entails many steps: the first is an effective design; the second is the manufacture of a prototype, which has to be tried out in actual practice. If the prototype does not prove viable, it has to be re-designed; only then can the serial manufacture of an item begin. This process takes place in the face of serious competition from other materials and at great financial risk. Major aluminium concerns are in most cases ready to take such risks, in the hope of good financial returns and a further expansion of aluminium markets. In countries with small independent aluminium producers or where the aluminium industry is part of the public sector, the State often has to subsidize such ventures to help restructure the country's production pattern.

State intervention, however, will only be effective if it fits into a long-range economic strategy for a country or area. The real or potential aluminium industry may be a significant factor in shaping the economic destiny of a country. Laying the groundwork of an economically sound and viable aluminium industry calls for systematic thinking, foresight and patience.

If feasible, as many stages of production as possible should be the goal when establishing an aluminium industry. A long-term programme has to be elaborated; investment and development programmes must be co-ordinated at each stage of integration with special regard to market prospects. The possibilities for replacing other materials with aluminium have to be taken into account.

In Hungary, for example, the fully integrated aluminium industry had a considerable effect on the country's economy. The aluminium industry is governed by a long-term central development programme, launched and approved by the Government [1, 2] In addition to dealing with the country's bauxite resources and covering every successive stage of integration (alumina manufacture, smelting and semi-fabrication manufacture), it also sets long-range targets for developing the aluminium end-using industries. Special attention is devoted to the replacement of other structural materials with aluminium wherever technologically and economically feasible. Objectives of long-term research and additional technical development details form an integral part of the central development programme [3, 4]. Also included are plans for substituting aluminium for other structural materials and facilities to be installed for that purpose.

In setting priorities, the authorities give full moral and financial support to research, design, prototype development and pilot plant operations. The implementation of the objectives embodied in the central development programme are controlled by a working committee, where all concerned parties are represented. The committee also co-ordinates the work of research and designing institutes with that of industrial enterprises, prepares periodic evaluations of achievements and failures and submits recommendations to government authorities. Because the government agencies, scientific institutes and enterprises often have conflicting interests and financial obligations and risks to be shared upon launching new projects may be considerable, this organizational pattern seems to be the optimum solution.

How much government intervention is necessary to run an aluminium industry effectively? This is a difficult question to answer, the situation differing from country to country depending on the economic system and structure as well as on the potential of the local aluminium industry. Winning new markets for aluminium, and using it as a substitute for other structural materials, is not a spontaneous process. There is often built-in reluctance or hesitation by the consumers to accept something new; most consumers expect new ideas to be presented to them in an elaborate form. In the implementation of new projects, high capital expenditure and a great deal of human effort are usually involved. In developed countries the aluminium industry is run by major companies with the necessary resources to face risks and penetrate into new markets, selling their products to the highest bidder. If necessary, they buy out smaller producers, establish subsidiaries or enter into joint ventures. In the developed countries the role of government agencies and of the public sector in the aluminium industry is usually a subordinate one. The situation in the centrally planned economies is different: the definition of long-term targets and the introduction of organizational measures to implement them are tasks of government agencies. In addition to being responsible for the control and co-ordination of different branches of industry, government agencies also frequently share financial risks in the projects launched and set priorities for boosting technical development efforts and innovations.

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