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TECHNOLOGICAL ALTERNATIVES IN THE ALUMINIUM INDUSTRY

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CONTENTS

GLOSSARY

General and Economic

CCA = Current Cost Accounting (Bird, [8]).

CPE = Centrally Planned Economies

GDP = Gross Domestic Product

GNP = Gross National Product

HCA = Historic Cost Account (Bird, [8]).

LDC's= Least Developed Countries

MEC = Market Economy Countries

mils= 1/1000 USD

R+D = Research and Development

TNC's= Trans-National Companies

UN = United Nations

UNIDO = United Nations Industrial Development Organization

Unit of measures

all tons are metric tons (t)

all temperatures are Celsius grades (°C)

A.C. = alternating current

g/l = gramm/liter

kA = Kiloamper

kg/c = kg/capita

kWh = kilowatt hour

MN = Meganewton

tpy or t/y = tons per year

A. INTRODUCTION

One of the main recommendations of the First Expert Group Meeting on the Non-ferrous Metals Industries, held in Vienna, 18-21 March 1985 [1], was to conduct studies relating to the selection of technologies in the aluminium, copper, nickel, zinc, lead and tin industries that would be more suitable for developing countries, with the aim of promoting a more integrated and self-reliant development in these countries.

The first study should be based mainly on the studies that have been carried out up to now, giving special attention to the research that has been done on reducing the size of the plants.

On this basis the drafter was requested by the UNIDO Secreteriat to prepare a study "Technological Alternatives in the Aluminium Industry" with the following terms of reference:

a) To analyse the present situation of technology in the non-ferrous metals industries under study in the developed and developing countries;

b) To examine the main research programmes presently being conducted in the field of technology, giving their objectives, characteristics, results and possible date of implementations. In order to easily understand where the main technological changes and/or alternatives are currently being introduced, as well as to obtain a clear view on what kind of technological routes the author is talking about, layouts concerning mining extraction, refining and further processing must be developed.

c) On the basis of the analysis of the present situation and research being conducted, to determine the possibilities of developing new technological alternatives that are more adequate for developing countries. Also to determine the main technical and economic characteristics of the possible technological alternatives concentrating on their main advantages and disadvantages for developing countries;

d) To propose a possible programme of cooperation (both North-South and South-South) to develop adequate technologies for the non-ferrous metals industries in developing countries.

The structure of the present study corresponds to the terms of reference indicated by the UNIDO Secreriat. As suggested a careful analysis of the previous studies was undertaken with particular attention to those prepared through the activities of the Negotiation Branch [1] and of the Metallurgical Industries Section [2].

According to the terms of reference the main objective of the exercise is to determine the possibilities of developing new technological alternatives that are more adequate for developing countries, indicating the main advantages and disadvantages of the possible technological options. For this purpose a review of the relevant publications was undertaken in order to examine the research programmes actually being carried out in the field of Aluminium Industry technology and a tentative assessment was made about the possibility of application of their expected results in developing countries. Obviously the presented results should be considered with justified caution, which is immediate consequence of the nature of the task to be performed, but also due to the fact that the presented analysis of the technological possibilities and options is based solely on the relevant publications and the experience in Aluminium Industry of the drafter. Therefore it might be expected that during the process of preparation of the Consultation Meeting, through the contribution of collegues, experts in Aluminium Industry, the number of technological alternatives more adequate for developing countries might be considerably increased and the conclusions of the present study consequently amended.

B. FRAMEWORK OF THE STUDY

1. THE ALUMINIUM INDUSTRY

Most of the integrated aluminium companies, in addition to the mining, chemical and metallurgical operations transforming the ore into aluminium ingots and semis, are converting the metal into different products (beverage cans, radiators for home heating, cables, etc.). To increase their share in the downstream fabrication business seems to be a generally adopted policy of the majority of the primary producers. When considering the technological alternatives in Aluminium Industry, more adequate for developing countries, the problems related to the conversion of the metal have to be very carefully considered because, in most cases, the metal is reaching the end user through this process. Therefore indications will be given concerning the viable size of conversion processes and the quality and quantity of semis requested for these technologies. They will be related to different levels of percapita aluminium consumption which could be envisaged in developing countries at corresponding steps of economic development. Nevertheless, in order to maintain the present study within coherent substantive limits, under Aluminium Industry bauxite mining, alumina-, aluminium and semis production will be understood.

2. SELECTION OF TECHNOLOGIES

Most of the processes and devices being used for the extraction of aluminium from bauxite correspond to a medium level of technological sophistication. There are relatively few exceptions e.g. the automatic regulation of some technological processes, the production of composite-materials, the development and fabrication of high-duty alloys. [3]

The majority of the main pieces of equipment, used in this industry, can be produced in any country having a relatively developed mechanical industry; R and D activities concerning this equipment are being carried out in most of the developed countries. Regarding the practical industrial realisation of R and D results, concerning new technological processes and new types of equipment, the big companies have the best possibilities. They only have the necessary means to create and introduce major innovations on an industrial scale; operate paralelly, if appropriate, in several fields of important R and D activities. This is particularly true concerning the alumina and aluminium production, if one has in mind the size of the up-to-date industrial units. Therefore, without any doubt, the big six TNC's, ALCAN, ALCOA, KAISER, REYNOLDS, ALUSUISSE and PECHINEY have, for the time being, the technological leadership in the Aluminium Industry. It should be, nevertheless, noted that there are several other companies operating in various countries, e.g.: FRG, ITALY, JAPAN, USA, USSR, not directly connected with the above mentionned TNC's, having a technological knowledge close to that of these TNC's, either concerning the majority of the operations in the Aluminium Industry or regarding a part of them. These companies can be considered as possible sources of Aluminium Industry technology. It should also be noted that technology for this industry can be purchased via the major industrial consultants.

One can agree with the opinion expressed by the UN Centre on Transnational Corporations [4] that in the most cases there is no major difficulty in the purchase of Aluminium Industry technology. Exceptions might occur with regard to relatively recent technological innovations, possibly under testing or concerning new very specific products. Generally speaking one could say that the market of the standard aluminium technologies is rather a buyer's market.

Attention is also drawn to the fact that in the cost of the aluminium metal reaching the consumer there are three important inputs the price of which are mainly determined by the location of the industrial objects. These are the quality of the bauxite, the price of the electrical energy used in the smelter and finally the transportation costs involved in the whole process of transformation of the ore into metal. The individual or consolidated influence of these three items on the profit of the operations might be stronger than that of slight differences in the technological level of the plants. This might be one of the reasons of the relatively good results achieved by some smaller companies on the aluminium market.

Actually there is no universally adopted methodology which would allow for choosing among technological alternatives, which is the most suitable in any given set of circumstances.

It might not be the objective of the present study to try to define relevant criteria, nevertheless it seems to be of purpose to explain some considerations on the constantly recurring question of "appropriate technology". [5]

According to Mr.Biritz [5] a technology is adequate when it satisfies four conditions, which are:

- purely technological constraints and parameters,
- limitations posed by the ability and know-how of the personnel to practice the technology,
- conformity to the economic requirements under which it has to operate,
- conformity to the prevailing socio-political environment.

Mr.Biritz defines also subparameters to the above indicated parameters establishing correlation among process technology; product, its application; raw materials; economic benefits; manpower; socio-political constraints.

From his findings the following main issues are quoted:

1) The adequacy of technology can only be defined for a single industrial plant and operation and it is not directly applicable to an identical factory somewhere else. The adequacy of products can be valid for a country or even for a subregion if prevailing economic conditions are similar. E.g. semis produced by strip casting can be suitable for covering the demand in several developing countries starting with broader application of aluminium for different purposes.

2) The economic conditions under which the enterprise has to operate should be clearly defined:

I) the plant is expected to make a profit;
II) the plant is to be subsidized, at least for some period of time;
III) the plant is to make a social or other contribution to the country, with profits being of secondary importance.

3) Process industries technologies, e.g. chemical, petrochemical and metallurgical operations cannot practically allow changes, if basic economic conditions are to be met, the only variation to be considered is the size of the plant.

4) The definition of appropriate technology is a continuing and never ending process for industry and its very survival depends on it, be it in developed or in developing countries.

An attempt will be made in order to be more specific on these basic issues when dealing with the technological processes being used in the Aluminium Industry (Chapter D).

A description of the sequence of operations for defining industrial manufacturing technologies, established by Mr.Biritz is attached for easy reference. (Annex 1).

C. PRESENT SITUATION OF THE ALUMINIUM INDUSTRY

1. DEMAND - SUPPLY

World consumption of primary aluminium shows a rapid increase from about the fifty's. About 2 million tons of primary aluminium were produced in 1950, but 3 million tons 5 years later and 4.5 million tons in 1960. The level of production increased rapidly and reached the 10 million tons in 1970.

Recently this trend changed considerably. Annex 2. gives the relevant picture 1973 to 1983 [6]. Allthough the world total aluminium consumption (primary + secondary) surpassed the 20 million tons in 1983, a considerable part of it was secondary metal (over 25 %) and the increase was not more than 3800 thousand tons during this period. More than half of this amount represented, however, additional secondary consumption, so the total increase on primary metal amounted only to about 1700 thousand tons.

According to Zorn [7] the consumption growth rate between 1970 and 1983 was 3 % per annum in primary aluminium. Regarding a shorter period, however, the increasing represented only about 1.9 % per annum in the MEC-s during the period of 1973 to 1979 and even less, only 0.5 % per annum during the period of 1979 to 1985 (Bird [8]). The increase of CPE countries' consumption was somewhat higher, about 3 % per annum.

It can be stated hence that the previous dynamic growth in consumption of this metal stopped and the actual trend of it is rather a very modest one.

Actually the growth of aluminium consumption is usually smaller than the annual growth of rate of industrial production in most MEC-s. On contrary the growth of aluminium end-uses is greater than that of industrial production in most developing countries.

The production of the primary metal did not always follow the demand. Consumption of the primary aluminium was decreasing in the early eighties, but production cutbacks came late, so inventories increased rapidly and reached a level in the vicinity of 3 million tons. This caused a rapid decline in prices. High interests worked in the same direction.

Consumption of aluminium is very different in various areas of the world. The world-average is 3.5 kg /capita/ year. Three countries: USA, Japan, FRG consume over 20 kg /capita/ year. The relevant figure for most of the developed countries is 9-15 kg recently. Developing countries use much less. There are some with a consumption of about 1 to 3 kg /capita/ year (e.g. Brazil 2.9 kg/c; Mexico 1.7 kg/c) and even the 5 kg /capita/ year is reached e.g. in Hong Kong and Venezuela, but most developing countries consume below 1 kg /capita/ year, even below 0,5 kg /capita/ year (e.g. Egypt 0.9 kg/c; India 0,4 kg/c; Ghana 0.5 kg/c) and the use of aluminium of most LDC-s is even below this level.

2. CAPACITIES

Capacities of metallurgical grade alumina plants, smelters and semifabrication are shown in Annexes 3. 4. and 5. per continent based on 1984 and 1983 data respectively. (King [9] and [10]). These data indicate clearly that there is a considerable surplus capacity in all phases of aluminium production. The total smelter capacity was over 18 million tpy 1984, whilst the demand in primary aluminium was only about 15 million tons in the world at the same time. This demand would need less than 30 million tons of metallurgical grade alumina, but the capacities amounted to nearly 40 million tons in 1984. Semi-fabrication capacities were also in excess in 1983.

An increase of these capacities is foreseen within the next years. There are slight differences in various forecasts for smelters (e.g. between King [9] and Bird [8]), but it is expected that the smelter capacity of the MEC-s shall increase by about 2 million tpy till 1991. Differences between the estimations of increase of alumina capacities are larger; Bird [8] expects a small increase only, while King [9] could imagine even an increase of 3 million tpy. At the same time, however, the possible close downs have also to be considered in respect of both smelters an alumina plants. Considering these as well, the smelter capacities might increase by 1.5 million tpy only and the increase of alumina capacities could be very little. There are no large expectations in increasing semi-fabrication capacities in the near future (till 1987).

3. PRICES

The price of the primary metal grew stadily - apart from shorter recession periods - up till 1980. A strong recession resulted, however, in the steep drop in prices thereafter and they are "sick" since. There are smelters which can hardly cover even their marginal (variable) costs, not speaking about their total costs including capital charges. According to Bird [8] the marginal costs on average smelters amounted to 51.7 cent per pound (1137.4 USD/t) and the total costs to 63.4 cent per pound (1394.8 USD/t) in 1984. At the same time LME aluminium prices have been below the top 52.7 cent per pound level of July 1984 (they were, however, over this figure previously).

Bird [8] had set up an analytical supply curve for 1985 to indicate the amount of smelter capacity that can profitably stay in production at different levels of the aluminium price (Annex 6). This demonstrates clearly the situation. It is easy to understand that smelters working much above their costs are cutting back their production.

The situation is similar, if even not worse, regarding alumina plants.

4. ROLE OF ENERGY PRICES

Energy prices increased since 1973. Aluminium smelting consumes a considerable amount of power, about 14500 kWh A.C. per ton of metal. The cost of this power differs, however, considerably in various regions of the world. According to the indications of a staff review of the World Bank [11] 1980 kWh prices for existing aluminium smelters were between 3 to 26 mils, if low ones, and 20-25 mils were estimated for new smelters. These prices are higher today and they vary between about 8 mils to 50 mils or even higher per kWh. So smelters have to pay a power bill within the wide range of about 116 USD to 725 USD per ton of metal. This explains some close-downs as well as the relocation tendencies of this industry towards cheap energy sources (as observed by e.g. Zorn [7] too).

Alumina plants processing expensive bauxite deposits and operating with unsatisfactory technology concerning energy conservation were also closed.

5. RECYCLING

Annex 2. shows that share of secondary metal in the total aluminium consumption increased from 18 % in 1973 to 25 % in 1983.

In some developed countries the share of recycled metal was much higher than the indicated average value (Bird [8]):

Italy	41.1 %
FRG	30.3 %
Japan	26.4 %
USA	32.4 %
UK	26.1 %

Further increase of the share of secondary metal in the aluminium consumption might be expected.

6. COMPETITIVE MATERIALS

"Specific property" is a very usefull characteristic when comparing competitive materials. This can be expressed as follows:

$$\text{Specific property} = \frac{\text{wanted property in end use}}{\text{specific gravity X weight unit price}}$$

The "wanted property" could be one of the following: tensile strength, yield strength, fatigue strength, conductivity, elastic module, etc.

Using the above equation the most suitable material for a given end-use may be determined, but only if a dominant single property is in the focus. Aluminium is on the top if conductivity is taken for wanted property. This is the reason why aluminium is generally preferred in power transport.

Aluminium has, however, an excellent or at least very good combination of properties which meet very well numerous end-use requirements. This is the reason of its wide range application in various branches of industry, but also of the limits of its use.

As indicated, aluminium is first only in one "specific property", therefore there are several materials and metals competing with aluminium, such as copper, wood, steel, high strength low alloyed (HSLA) steel and last but not least plastics. Synthetic materials seem to be the largest competitors for the future.

To a certain extent secondary aluminium is also a "competition" for the primary metal.

Competitors from the point of view of the growth of consumption of primary aluminium are the aluminium high quality products themselves.

Weight reduction of the finished products can be achieved by application of high-duty aluminium alloys and/or high quality extrusions. Price of such items is allthough higher, but less material is needed for the fabrication of the same end-product (e.g. higher strength by 10 % results in 3-5 % materials saving, when considering mechanically loaded structures).

7. REASONABLE EXPECTATIONS FOR THE FUTURE

The short term will bring no considerable changes, this is the essence of what e.g. Bird [8] states. A very slight increase in the consumption may be expected till 1990, maybe 2 % per annum and the "sick" aluminium prices may "cure" to a certain extent. No new capacities are necessary within this period.

This situation might change, however, considerably after 1990. Bird [8] expects an annual growth rate in industrial production approching that of the pre-oil crisis in the period of 1990 to 1993. This should bring an increase in aluminium consumption, too. The relevant data are shown in Annex 7.

The difference, however, between the periods 1964-73 and 1990-93 is respect of aluminium is, that in the period before the oil-crisis the annual growth of rate in aluminium consumption was in average much higher than that in industrial production, whilst in the 1990-93 period the annual growth rate of aluminium consumption is expected to be in average slightly below the annual growth rate in industrial production. Newertheless, the estimated 4.2 % increase per annum in world average indicates a brighter future for this industry.

This annual growth would mean, however, that capacities would be fully utilized by 1993 and new capacities have to be built to follow the demand. This would, however, be only possible if both aluminium and alumina prices raise considerably. An excessive increase in metal price, would work against the expected growth of rate. This situation might foster further relocation of the aluminium industry towards good bauxite and cheep power possibilities and these circumstances might represent an opportunity for developing countries to further increase their share in different Aluminium Industry operations.

8. IS ALUMINIUM A MATURE METAL?

Comparing with other structural metals the aluminium is the youngest and it had the highest rate of growth in the last decades. Aluminium is the only metal of which intensity-of-use (i.e. consumption per GDP) is estimated to increase in all group of countries by 2000 [12]. In this sense aluminium isn't a mature metal. According to another expectation [8] average growth rate of world aluminium consumption will be lower than the general industrial growth rate. A growth rate of aluminium consumption surpassing the world average might be expected, however, in developing countries, hence aluminium can not be considered a mature metal in repect of these countries.

Technologies used for bauxite mining, alumina and aluminium production are well established. Their theoretical background is well-known. Important possibilities of economy of scale seem to be exhausted, smaller developments particularly concerning energy conservation might be continously expected. A radical change in these processes will very probably not happen during the present century. Computer process control may bring, however, important economic results.

Theoretical background of the mechanical technologies is yet less clarified, rather technologies based on empirical results prevail. The future might bring hence more important development in semi-fabrication processes. Computer process control might bring additional economic results.

Regarding the products and their application one could rather say that these are not mature yet. Aluminium is not too young but there are still avenues to be explored for using it in the most economic way. Recycling of aluminium reached already a considerable level, but "designing for scrapt-aptness" is still not yet implemented in many fields of applications.

New developments expected in the fabrication technology, the production of new alloys and composite-materials might strengthen the position of the aluminium in the competition with other materials for the different fields of applications.

9. CONCLUSION

The situation of the aluminium industry is not bright today, but it might change and even considering non-optimistic forecasts one migh expect a considerable additional consumption, mainly in developing countries. A further relocation of the aluminium industry towards high quality bauxites and cheapest energy resources might be expected after 1990. These phenomena justify a carefull review of possibilities for creating additional aluminium facilities in these countries. Probable technological alternatives suitable to correspond to possible needs of these countries merit special attention.

D. ANALYSIS OF ALUMINIUM INDUSTRY TECHNOLOGY

1. BAUXITE

1.1 Bauxite Geology

Aluminium is the most abundant metal in nature representating about 8.2 % of the earth's crust. It is a common constituent of many minerals, where it is normally present in combination with silicon and oxygen, with hydroxyde groups, with iron, titanium and calcium and to a lesser extent with various other elements. The most important aluminium ore is bauxite, which is a sedimentary rock, containing at least 50 % of Al-, Fe- and titanium-oxides and hydroxydes, with dominance of Al-minerals.

The Manual Principles and Methods of Bauxite Prospecting issued by UNIDO contains a review of geology, mineralogy, spectrography and origins of bauxites and methods of prospecting including indications on drilling technics, the organization of exploration compaignes, the preparation of exploration reports and the computerized reserve's calculation [13].

Bauxite, currently the main source of aluminium, accounts for only a small part of the aluminium found in the world. Other possible sources of this metal may be classified as follows [11]:

i) igneous rocks, the most important being anorthosite, nepheline syenite and phonolite. Of these nepheline syenite has the highest commercial importance.

ii) sedimentary rocks, such as clays and shales. The high alumina clays have important applications in the ceramics, refractories, chemical and paper industries.

iii) metamorphic and metasomatized rocks, of which alunite is the most promising.

Aluminium is technically obtainable from non bauxite sources, but at present, in the majority of cases, the Bayer bauxite technology has significantly lower costs than the alternative processes [11].

The identified world bauxite reserves increased from 9 billion tons [14] to about 50 billion tons [15] in 10 years, the yearly bauxite mining representing actually about 100 million tons. The impressive increase in the bauxite reserves is, without any doubt, related to the development on the utilisation of up to date geological methods. From these e.g. the application of airborne- [16] and satellite-borne [17] remote sensing systems and the use of geostatistics [18] in bauxite deposits evaluation could br mentionned.

Bauxite deposits may be divided in two classes: karstic and lateritic. Karstic bauxites are usually fine-grained, they are associated with limestones and tend to have a higher iron content. Lateritic bauxites are found with aluminiosilicate rocks and are coarser grained. The structure of the deposits and the impurities found are different for these two classes of deposits [11].

The chemical and mineralogical composition of bauxites can be characterised by the data listed in Table 1:

Table 1

USUAL CONSTITUENTS OF BAUXITES

Denomination	Chemical composition	Mineralogical composition
alumina	40-65 %	gibbsite Al_2O_3, $3H_2O$ boehmite Al_2O_3, H_2O diaspore Al_2O_3, H_2O
silica	0.5-10 %	quartz SiO_2 kaolinite Al_2O_3, $2SiO_2$, $2H_2O$
iron-oxide	3-30 %	hematite Fe_2O_3 goethite Fe_2O_3, H_2O
titanium oxide	0.5-8 %	anatase TiO_2 rutile TiO_2
water	10-34 %	in gibbsite, boehmite, diaspore, kaolinite, goethite
trace elements	Mn,P,V,Cr,Ni,Ga,Ca,Mg etc.	
organic substances		

With respect to the selection of technology the mineralogical composition of the ore is of paramount importance, and accordingly, because of practical considerations the bauxites can be listed into the following five types:

i) trihydrate type: with gibbsite as main mineral and monohydrate content less than 5 % of the alumina content of the ore.

ii) trihydrate type containing quartz: the same as the previous one but with an important part of the silica content in non-reactive form.

iii) trihydrate mixed type: with gibbsite as main mineral, but monohydrate content over 5 %.

iv) monohydrate boehmitic type: containing mainly monohydrate with less than 5 % of diaspore.

v) monohydrate mixed type: boehmitic bauxite with diaspore content exceeding 5 %.

Concerning quantitative distribution trihydrate types occur in the largest amount, the lateritic bauxites belonging basically to these groups representing about 85 % of the world's reserves [13]. Karstic bauxites are generally of monohydrate type, though they can have a considerable gibbsite content too. Trihydrate type bauxites are the cheapest to process because of lower temperature and pressure requirements. Among the monohydrates, diasphore is the most difficult to treat [11].

Apart from the bauxite types [11] there are other important factors to be considered when assessing the practical value of a given deposit. The alumina content of the ore is basically determining the amount of bauxite to be processed for the production of a given quantity of alumina. The most harmful impurity is reactive silica causing alumina losses. Non-reactive silica is not particularly important. Other main impurities such as iron and titanium oxides are practically insoluble during bauxite digestion. Nevertheless additional equipment is needed for their mechanical separation from the alumina liquor. Highly soluble impurities of the bauxite such as organic substances, carbonates, chlorides and sulfates are also influencing processing conditions.

When evaluating bauxite deposits, besides the type and quality of the ore mining costs including infrastructure requirements have to be taken in consideration [11]. Attention is drawn to the necessity of including technological evaluation in the process of laboratory testing of bauxite quality.

Annex 8. illustrates the world bauxite ressources with regard to their state of development [15]. Annex 9. contains the relevant classification system for bauxite ressources [19]. It may be noted that about 70 % of the reserves are concentrated in four countries namely Guinea, Australia, Brazil and Jamaica.

1.2 Bauxite Mining

The character of mining operations depends on whether the ore is located on surface or requires underground mining.

Open-pit mining: may be applied in dependence of thickness and physical properties of overburden and degree of mechanization available. As a general approach the open-pit method is suitable if the overburden is of favourable physical proprieties (e.g. dry, sandy), and the strip ratio is less than five.

Most of the bauxite produced in the world is mined by open-pit methods. The main phases of the operations are shown on Annex 10.

Extraction involves removal of overburden by bulldozers, draglines and large wheel excavators, with the use of explosives for hard terrains. The bauxite is extracted by similar methods and the overburden is replaced to restore the surface of the mines for re-use as forest or agricultural land [11].

Where beneficiation is necessary, it generally consists of wet processes to reduce silica and clay content [20].

Most bauxites require crushing for ease of processing. The next stage is drying, which may be done at the mine site or at the refinery. If the bauxite is to be shipped great distances, it is usually dried at mine in order to reduce transport costs. Drying is carried out in rotary-kilns at moderate temperatures to remove free moisture [11].

In case of large-scale fully mechanized operations 0.4-0.7 manhours are required per ton of bauxite extracted. Indications concerning the up to date processes and equipment being used e.g. in Australia can be found in the 1983 November issue of the Engineering and Mining Journal [21].

The investment costs vary within wide limits. The main factors are: scale of the operation, strip ratio, possible treatment of the ore at mine (drying, beneficiation, classification, etc.), specifics of location, infrastructure required. A methodology to estimate capital costs for bauxite mines in function of these factors is explained in [11]. Accordingly, to open, e.g., a mine of 4 million tpy in Brazil would cost about USD 70/tpy (expressed in USD value 1980). A mine in Guinea of the same capacity would cost only USD 51/tpy due to the difference in strip ratio.

Concerning operating costs the figures shown in Table 2 can be extracted for illustration from the ample documentation reflected in [11].

Table 2

OPERATIONAL COSTS AND CAPITAL CHARGES OF BAUXITE PRODUCTION

Year 2000. USD/tpy of dry bauxite

	Australia	Brazil	Guinea	Jamaica
Operating Costs	10.20	12.60	10.30	11.00
Capital Charges	4.20	5.80	4.20	4.20
Total	14.40	18.40	14.50	15.20

The "Total" indicated in Table 2 gives only an indication concerning the differences in various costs related mainly to the geological characteristics of the deposits. In order to make comparisons on the appropriateness of using a particular bauxite, information on the quality of the ore, costs related to internal transportation, levies and possible ocean transport should be also taken in consideration.

Underground Mining: In several countries, e.g., France, Greece, Hungary, bauxite is also extracted at underground mining. If large scale mechanization is applied, ore layers of the deposit less than 2 m thick are disregarded for mining. Man-power requirement might amount to 1.5-4 man-hours/ton according to the level of mechanization of the operations. Investment requirements are generally considerably higher than for open-pit mining. Geological conditions, particularly presence of water, coal and gas might provoke additional complications and costs.

A very rough estimate of the possible actual investment costs would lead to USD 80-150/tpy excluding the investment related to eventual water pumping.

2. ALUMINA PRODUCTION

2.1 General

About 35 million tonnes of alumina were produced in the world in 1980 and roughly 34.5 million tons in 1984. The non-metallurgical grade alumina production can be estimated to approx. 2.5 million tons in 1984, the relevant figure for metallurgical grade aluminas being 32 million tons.

As allready mentioned in Section C.) metallurgical grade alumina production capacities amounted to approx. 40 million tons in 1984 [9] including also those producing alumina from non-bauxite materials. Allthough capacities had been finally closed since, there is still abundant production capacity.

About 95 % of all alumina is being produced from bauxite. This situation might not change considerably till 2000 [22].

2.2 The Bayer process

Alumina production out of bauxite is almost exclusively carried out by the Bayer p ss [23]. The essence of the process is the digesting o gh-grade bauxites with caustic soda solution, separation of the resulting sodium aluminate solution from red mud residue, decomposition of the aluminate liquor, precipitation and separation of the resulting hydrate crystals and calcination of same. By returning the precipitated aluminate liquor, the spent liquor, to the digestion of bauxite, the cycle of process becomes closed.

A general flow sheet in form of main unit operations of this process is attached (Annex 11.)

Two main varieties of this process exist depending upon the type of bauxite to be processed:

- the American Bayer
- the European Bayer process.

Trihydrate bauxite can be digested in the easiest way and the applied temperature is maximum 140 to 145 °C. Processing of such bauxites is typical for alumina plants in America and Australia. At the same time such bauxites can be digested at caustic concentrations of about 120-140 g Na_2O_c/liter. Precipitation is effected at a concentration of 90 to 110 g/l Na_2O_c, the alumina hydrate is classified. The coarse grains are transformed to sandy alumina through calcination, having a relatively high gamma content [24].

The American Bayer is called modified if the bauxite to be processed is of the trihydrate mixed type (gibbsite with minor amounts of boehmite). In such cases the temperature of digestion is raised up to 240 °C with a minor increase (to about 150 g/l Na_2O_c) in the caustic concentration. [11, 24] Precipitation and calcination conditions are not modified, so the end product is sandy alumina.

The digestion of monohydrate bauxites needs higher temperatures (220-260 °C). European plants use frequently such bauxites. In addition high pressure is also needed and a more concentrated caustic solution is being used (180-220 g Na_2O_c/liter). Precipitation concentration is 130-160 g/l Na_2O_c, there is no classification, seeding is done with large seed quantities, hence the product is much finer. This hydrate is calcined at a higher temperature. The obtained alumina consists to a large extent of alfa-particles (floury alumina).

The characteristics of sandy and floury alumina are indicated in Annex 12.

However, the American and European Bayer technologies came closer recently. The European Bayer technology users decreased their applied digestion-, and at the same time, to a certain extent, their precipitation concentrations in order to produce sandy alumina. On the other hand the American Bayer plants raised the precipitation concentration to some extent thus saving some energy in digestion, obviously in such a way that the coarse grain size of the hydrate would be retained. Some further details of this trend shall be discussed, however, in Chapter E.)

Digestion temperatures of diasphoric bauxites are 240-260 °C and even higher temperatures would be advantageous. Autoclave digestors are, however, not practical at temperatures much over 260 °C due to the increasing wall thickness needed at increased pressures correlated to these temperatures, so maybe the use of tube digestors would be more economic and suitable for this purpose, allowing temperatures up to 300 °C (see Chapter E.). Lime has to be used when digesting diaphoric bauxite.

In part D la./ of the present report some ideas have been already explained concerning the influence of the bauxite composition particularly of that of the impurities on refinery conditions. Two additional observations:

i) The red mud deriving from goethite containing bauxites shows generally poor settling and thickening capability. The problems related to the presence of goethite can be solved, however, with certain additives in digestion [25].

ii) The accumulation of some soluble impurities of the bauxites is undesirable because it decreases the effectiveness of the technology (see Chapter E.).

The quality of materials and energy consumed in production of alumina depends primarily on the quality of bauxite used, the size of the plant, the type of alumina produced, the level of technology applied and finally on the equipment used. As an orientation the specific consumption as per

Table 3 be mentioned [23]:

Table 3

SPECIFIC CONSUMPTION OF ALUMINA PLANTS

bauxite (dry weight)	2.0-2.5 t/t alumina
caustic soda	0.07-0.17 t/t alumina
fuel oil (for steam production and calcination)	0.28-0.38 t/t alumina
electric power	300-350 kWh/t alumina

It has to be mentioned that 7-9 tons of water/t of alumina produced are also needed and in selected cases lime and flocculants should also be considered.

In selected cases, it might be possible to produce electricity through cogeneration. The electric energy thus obtained might cover the need of the plant (see also 2.32).

2.3 Alumina plants

2.31 Size, economy of scale

In the 50's up-to-date alumina plants were established with production lines of 120-150,000 tpy. Production lines in alumina plants recently constructed are between 300-500,000 tpy. The plant capacities reach 1 million tpy and even higher. So e.g. the Sao Luis plant of Consorcio Alumar in Brazil will have an initial capacity of 500,000 tpy to be extended to 1 million tpy later. Most of the Australian plants have capacities of 1 million tpy or even more. The Kwinana plant of Alcoa has a capacity of 1.4 million tpy, the Pinjarra plant of Alcoa 2.5 million tpy; the newly built plant of Queensland Alumina at Gladstone has a capacity of 2.440 thousand tpy with the aim of extension to 2.740 thousand tpy, etc. [9].

Annex 13. (reproduced from [11]) illustrates the influence of different factors on capital costs for alumina refinieries.

Increasing the size of production lines results not only in decreasing specific investment costs, but also operation costs can be reduced having larger units (e.g. specific heat and electric power consumption as well as manpower requirement) [23]. The location factor referred to in the~~s~~ Annex 13. varies from 1.00 in developed countries to 1.25 in developing ones. The reasons lay partially in the differences of the existing general infrastructure.

2.32 Space and infrastructure

Alumina production requires relatively large space, e.g. a 600,000 tpy capacity requires land of 80-100 hectars (territory within fence only) plus space for red mud ponds which could be even 2-4 times bigger according to the given conditions [23].

The main off-sites and infrastructure needed for an alumina plant are:

- a) port
- b) energy supply
- c) water supply
- d) red mud pond
- e) housing estates
- f) rail-road, road

Ad a) For the production of 1 ton of alumina 3.5-4 tonnes of materials are to be moved. This is one of the reasons why alumina plants are often located as close as possible to sea-ports. Costs of the port installation vary according to local conditions. For a 600,000 tpy plant the cost of port construction was estimated to 10-20 million USD in 1978. [23]

Ad b) Several possibilities for the heat and electric energy supply of alumina plants exist, depending on the applied technology and the conditions offered by the location of the plant:

(i) A reliable electric network exists at the site:

In such cases - based on economic considerations - choice should be made between two possibilities

- Purchased electric energy and own steam production: The total electric energy requirement of the plant is covered from the network. Boilers are erected for steam supply to operate at the pressure corresponding to the digestion technology. Low pressure steam is produced by pressure reduction;
- Cogeneration: A power plant is erected in the territory of the plant for energy production by back pressure turbine. This variant makes possible to use the heat content of the steam raised in the boiler partly for conversion to shaft power in the turbine and partly for low temperature process heat. The advantage of back pressure power generation depends entirely on the low temperature heat requirement of the plant.

In case of low temperature digestion technology the majority of the total electric energy requirement can be produced by cogeneration. For this purpose adequate boiler pressure has to be selected and an extraction/back-pressure turbine is installed. The network is being used in that case for the compensation of possible load fluctiations and for emergency cases.

(ii) A reliable electric network does not exist at the site:

In such cases an independent power plant has to be established with the technological options explained above. Obviously that part of the electricity demand of the alumina plant which can not be supplied by cogeneration and the necessary spare capacities require the erection of appropriate power generation facilities through condensation.

In connection with the investment costs of a power plant it has to be mentioned, that these costs vary to a large extent depending on the technical solution. In case of a cogeneration power plant with a 300,000 tpy plant with high pressure, high temperature digestion the costs amounted e.g. to 17 % of the total investment costs in the early 70's.

Ad c) The specific technological water consumption of an alumina plant is generally 7-9 m^3/t of alumina plus drink water for the plant and the housing estate.

Ad d) From the point of view of environmental protection the red-mud pond is one of the critical elements of an alumina plant. The quantity of red-mud produced equals to or is even larger than that of the alumina. There are some alumina plants where the red-mud is disposed into the sea, but nowadays this is more and more prohibited. Using ponds, care has to be taken that there should be no such leakages through which ingredients of the red-mud can get into the soil. The ponds should be at the same time not too far from the plant because this increases pumping costs of the mud. The possibility of inexpensive disposal of red-mud might also influence hence the selection of site.

Ad e) In order to ensure undisturbed operation, housing estates located close to the plant are required even if there are larger settlements in the vicinity of the plant [23]. Often complete new settlements have to be created comprising in addition to housing also a shopping network, schools, educational and entertaining facilities, sanitary and other services.

Ad f) Should the alumina plant not be located at the sea, a suitable rail-road connection might be necessary. In any case the alumina plant should be connected to the inland road system.

2.33 Site

Alumina plants were first part of an integrated complex from bauxite mining to aluminium smelters. The increasing demand in metal could, however, not be followed by the integrated mines, hence either bauxite had to be imported (mostly from developing countries) and/or the alumina was produced at the site of the mines and this was shipped to the smelters. The most recent trend is again to have a complex from mining till smelting (e.g. in Brazil, Venezuela and Australia).

Besides these important aspects, the most significant siting factors are [23]:

- Vicinity of sea ports, waterways, railways and roads. (The quantity of materials to be transported, not counting the red-mud, amounts to 3.5-4 times that of the production of the plant)
- Satisfactory solution (independent of seasons) of technological and drinking water supply
- Possibility for inexpensive disposal of red mud and other waste material
- Meteorological and soil conditions
- Possibility of establishing the infrastructure required
- Location of the market for the alumina produced. (This question will be discussed in detail in Chapter F).

2.4 Operation of alumina plants

2.41 Production costs

Considering the consumption figures mentioned in Table 3 the production costs of 1 ton of alumina were estimated to be 147 USD in 1978 [23]. This figure contained 57.6 USD for the cost of bauxite/t of alumina (or 24 USD/t of bauxite) with the remark, that in case the alumina plant has its own open-pit bauxite mine and only the net bauxite mining costs are charged, the production costs could be considerably reduced. Caustic soda was calculated with 150 USD/t and fuel oil with 65 USD/t.

Due to the fact that especially fuel oil prices are much higher now, production costs of alumina are considerably higher. Annex 14. shows the production costs of 10 older and 6 newer alumina plants including variable and capital costs in the 80's [26]. An analysis of these show that the smallest variable costs are reached in Australia (124-126 USD/t) and that there are plants where the variable costs alone surpass 200 USD/t.

Bird [8] refers to a study of alumina production costs and contract prices made available by James F. King. According to Bird, King allocates all smelters to one of five cost bands, as per Table 4.

Table 4

COST BANDS OF SMELTERS FOR ALUMINA PURCHASES

very low	under 175 USD per t delivered
low	175-199 USD per t delivered
medium	200-224 USD per t delivered
high	225-249 USD per t delivered
very high	over 250 USD per t delivered

In mid - 1984 - he says further - the weighted average cif cost of alumina to aluminium companies was USD 204 per ton. At the same time spot market prices for alumina were much lower, 150 USD, or even below this figure in 1985.

A more recent document [27] states clearly that there is no typical cost for alumina production. The cash cost components for alumina production differ from plant-to-plant, they could vary between USD 60 (as a minimum) to 313 (as the maximum) per ton of alumina. This gives a simple average of USD 186.50/t of alumina which is - by a coincidence - very near to the abovementioned weighted average of USD 204. The capital charges - varying between USD 70 to 190/t of alumina - come on top of this.

Estimates for production costs of alumina for the year 2000 are explained in [11]. Accordingly the total cost of production (including capital charges) expressed in 1980 USD on f.o.b. basis will be from 292 USD/t to 378 USD/t at selected sites, depending on the bauxites processed and the sites. The lowest figure is allocated to local processing of Brazilian bauxite and the highest to the processing of Greek diasporic ore. The transport costs of alumina - if it is not converted locally into aluminium - have to be added. These costs vary from 6 USD/t of alumina between Jamaica and USA East-cost to 43 USD/t of alumina for Australian alumina to Western Europe.

Allthough the local processing costs of Australian and Brazilian bauxites will be very close, if shipped to the USA East coast, the Brazilian one will be much cheeper (309 USD/t versus 335 USD/t).

2.42 Maintenance, spare parts

In most cases the maintenance works are done by the personnel of the plant, allthough there is always a possibility to engage a contractor company for this duty or for a part of it in developed countries. In developing countries, however, the plant has to care for the total maintenance in most cases. To be able to do this, appropriate workshops have to be set up in the plant and maintenance personnel has also to be considered.

Maintenance and materials costs amount to about 8-9 % of self supplied alumina costs according to an USA aluminium price/cost model for the year 1984 [28]. The actual amount of 19.1 USD is to be split equally between maintenance, material cost and misc. costs.

Considering plants in developing countries, a spare parts stock representing about 3 % of the global value of invested hardware seems to be of purpose.

2.5 Processing of low grade bauxites and non-bauxite materials

There are several methods for processing of low grade bauxites and non-bauxite materials [29]. Out of the possible processes the sintering technology, the combined processes, processing of nepheline and alunite have to be mentioned, because of their industrial realization. A brief description of these processes can be found in Annex 15. Further on some aspects of the chloride processes are discussed in Chapter E.).

2.6 Non-metallurgical grade alumina

The expression non-metallurgical grade or special alumina covers a range of various alumina products having special characteristics (purity, grain form, grain size, etc.) to be used in various fields of applications. Their price is higher than that of metallurgical grade alumina, the factor of increase being between two and hundred. With increasing product value the demand decreases.

Production capacities for special aluminas can be estimated to about 3 million tpy in the world, the overwhelming part of these facilities producing those special aluminas the price of which is not more than two- to three time that of the metallurgical alumina. They are used e.g. as abrasives, ceramics and refractories. Most of these can be produced on the basis of the Bayer process, with certain modifications [30]:

- elimination of impurities, first of all of sodium. By modifying the Bayer precipitation (using warm-precipitation) the Na_2O content of the alumina can be decreased to 0.2 %; should be a need for even lower figures, partial washing after semi-calcination is indicated.
- adjusting the alfa-gamma content and the specific surface of the grains through calcination;

- classification or micronization to obtain selected particle sizes.

Problems related to the application and production of high-value aluminas are out of the scope of the present paper.

2.7 By-products of alumina production

There are two main by products of alumina production, vanadium and gallium. Their separation is possible as follows [24, 30]:

A large proportion of the V_2O_5 content of bauxites is dissolved during digestion and accumulate in the process liquid circuit. The V_2O_5 rich salts are separated by crystallization from the spent liquor either before or after its evaporation.

In case of using lime technology in digestion the separation of the V content is only possible in reduced quantity. Allthough there is a possibility to separate the vanadium after concentrating the spent liquor to about 200 g/l, but it is expedient to separate first a soda salt with low V_2O_5 content, and to cool the soda-free liquor, to adjust its P, V and F content to the appropriate ratio and to separate crystals of rich V content out of this liquor.

The separated V-salts are generally processed into V_2O_5 containing products of various purity or into ferrovanadium. Most of the V_2O_5 production processes can be characterized by the following process stages:

- Beneficiation (generally a fractionized crystallization)
- Dissolution of the crystal, production of vanadate solution
- Purification of vanadate solution is various ways [24].

Polyvanadates can be transformed into lamellar V_2O_5 in a multi-step procedure.

Practically the only source for Ga production is the production of alumina. The economy of Ga production depends on the amount of Ga going into solution from the bauxite, i.e. the Ga level of the solution, on the liquor purity and on the technology used for separation. The extraction is effected from the concentrated spent liquor (strong liquor). Its purification is necessary to reach a good yield in the separation of this metal.

For separation of Ga the mercury- and the aluminium cementation technologies are used. The latter is preferred due to environmental protection. The developed mercury process works actually with losses below 1 kg Hg/ 1 kg Ga, though it could become competitive again.

2.8 Wastes (Red-mud)

The only significant waste of alumina production is the red mud. Its chemical and mineralogical composition is highly determined by the bauxite grade and the process technology. The main components are generally in the following range as per Table 5. [31]:

Table 5

THE MAIN COMPONENTS OF RED-MUD

	Weight % (on dry basis)
Fe_2O_3	30 to 60
Al_2O_3	5 to 20
SiO_2	1 to 20
Na_2O	1 to 10
CaO	2 to 8

The main components of the liquid phase accompanying the residue are caustic soda and soda ash (0.5 to 8 g/l total Na_2O concentration) and some 0.5 to 8 g/l Al_2O_3.

The importance of environmental-friendly disposal of same was stressed allready under 2.32 d.). For further details see [31].

Red-mud is still a waste, its utilization is not yet solved. There are certain promising possibilities [31], but none of these is applied in industrial scale. Recovery of the sodium and alumina content of the red-mud does only solve part of the problem. Recovery of its iron content is feasible but has lost importance due to economic reasons. It can be used as an additive in iron production and for the replacement of pyrite sinter in cement production, however, the quantities used are not significant. Its application for soil amelioration, road building, etc. are al. of minor importance. Its processing to heavy ceramics might be a promising method to involve large quantities of red mud and to meet at the same time increasing requirements of the building industry.

3. ALUMINIUM SMELTING

3.1 General

The primary aluminium production of the world was near to 16 million tons in 1984. In addition more than 5 million tons secondary aluminium were produced.

Production capacities for primary aluminium amounted to about 18.5 million tons in 1984, hence about 2.5 million tons of capacity was unutilized.

3.2 The Hall-Héroult process

The only process being used on industrial scale for the production of primary aluminium is the 100 years old Hall-Héroult process. The essence of this process is the electrolysis of Al_2O_3 (alumina) in a Na_3AlF_6 melt at 960 °C in 50-230 kA cells with consumable carbon anode, aluminium pool cathode.

The electrolysis pot is the basic unit of an aluminium smelter. Regarding the anode structure cells of two basic types have been evolved: the continous (Söderberg) and the prebaked anodes. There are horizontal- and vertical stud continous anodes.

Horizontal type Söderberg anode cells have a closed main operating area with efficient local cell exhaustion, but it is difficult to apply them for amperages over 100 KA. This old type is not reproduced any more, but some 1/6 of the world's aluminium production facilities still used such anodes in 1978 [23]. Their share is decreasing.

The vertical stud Söderberg anode type pots may only partly be closed and so the efficiency of local cell gas exhaustion is 60-80 % only [23]. Some 1/3 of the production facilities were equipped with such pots in 1978, but this proportion is also decreasing, notwithstanding the considerable development which has been achieved in the 70's on this type of pots (amperage up to 160 KA, significantly high productivity).

One of the advantages of Söderberg anodes is that no separate anode baking shops are required, hence the specific investment costs are less for smaller capacities.

Recent requirements and regulations on environmental protection and working place could be met with this type of cells, however, only through intensive ventillation of the furnace hall and with washing the total quantity of gases therefrom.

Actually in at lest half of the world's aluminium production facilities pots with pre-baked anodes are being used. These pots exist in sidebreak and a center break variants. The sidebreak ones had originally a fully open operating area, later they were covered with lids, but these had to be lifted when charging alumina. This lifting resulted, however, in an intensive hall pollution by cell gases, so additional gas washing had to be installed.

The center break type pots are considered to be the most up to date. These are working with a relatively well-closed operating area, which is opened only partially and rarely. The charging of alumina takes place automatically in closed position. Local cell gas exhaustion is effective so there is no need for roof gas washing [23].

The anodes are manufactured from petroleum coke and tar pitch. The manufacturing of Söderberg anode paste and that used for prebaked anodes is similar, but is case of prebaked anodes pressing and baking have to be added. The shematic flow-sheet of the production of both is indicated in Annex 16.

Environmental pollution is a serious problem with aluminium smelters. Pollution is caused by the flourine compounds. In case of Söderberg anodes there are also tar distillate compounds among the main polluting components of the cell gas and also of the roof exhaustion.

The quantity of fluorine emission is 15-18 kg/t of metal produced, i.e. a smelter with a capacity of 100,000 tpy would pollute about 1500 tpy of fluorine if no gas washing is applied. The permitted upper limit of fluorine emission into the environment is today 0.5-2 kg per t of aluminium in most countries. Therefore the cell construction and the operating technology should ensure proper gas collection and the washing of the collected gas before exhaustion.

The center break prebaked anode type cell seems to be the most appropriate for satisfactory gas collection. The washing of the gases was done earlier with wet scrubbers, but these are costly and the recuperation of the fluorine is expensive too. Recently dry gas scrubbing has started to prevail, based on the adsorption of fluorine by alumina having a large active surface (sandy alumina). After having been in contact with the gas in the scrubber and having adsorbed the fluorine compound, the sandy alumina is forwarded to the pots and fed through chargers into the process, recirculating thus the fluorine adsorbed.

The parameters of an aluminium smelter (expressed in main material and power requirement per t of metal) were as per Table 6 in 1978 [23]

Table 6

PARAMETERS OF AN ALUMINIUM SMELTER (1978)

alumina	1.93-1.96	t/t metal
petroleum coke	0.44-0.47	t/t metal
tar pitch	0.11-1.12	t/t metal
fluorides	0.025-0.03	t/t metal
electric power	15000-16000	kWh/t metal

Newly built smelters with prebaked anodes show, however, better characteristics (see Table 7) [8]:

Table 7

PARAMETERS OF PREBAKED ANODE SMELTERS NEWLY BUILT

alumina	1.925	t/t metal
petroleum coke	0.34	t/t metal
tar pitch	0.09	t/t metal
fluorides	no data	
electric power	13693	kWh/t metal

Extrapolated figures concerning the possible development of specific power consumption of smelters are indicated in Annex 17. [11].

3.3 Aluminium smelters

3.31 Size, economy of scale

Nowadays 160-230 KA pots are used. A pot of this amperage produces 300-550 tpy of aluminium. The pots are in series, the number of pots in series may vary between

120-240. One line produces hence in average 50-130,000 tpy of aluminium. In general a minimum of two pot lines are to be built nowadays in order to reach economic plant sizes [23]. This gives 100,000 tpy as a minimal capacity for an economic plant.

Shorter lines require somewhat larger investment for electric equipment for the same capacity, but working conditions are more safer with lower overall voltage of the potline.

More than two potlines of a capacity of 130,000 tpy each might cause on the other end environmental pollution problems despite collection and cleaning of gases simply by its considerable quantity over an overall 260-300,000 tpy smelter capacity [23 p.31-32]. Nevertheless specific local conditions, financial considerations, the availability of cheep energy, the available market justify finally the selection of the size of the smelter.

Smelters of smaller capacities than about 100,000 tpy are, however, not justified in case prebaked anodes are used. Such anodes should be produced at the smelter, otherwise they cost more, their transportation is difficult and the proper utilization of the butts - representing 20-30 % of weight - cannot be solved. Smallest economic capacities for such anode plants correspond to a smelter of the about 100,000 tpy capacity.

As for any industrial plant, unit capital costs for aluminium smelters diminish with increaing plant size [11]. However, savings due to economy of scale are rather limited, since large plants differ from small ones only in the number of potlines installed. Considering the location factors according to point 2.31 as well as other data [11] a smelter of 100,000 tpy located in a developed country would cost USD 3400/t capacity, while a 200,000 tpy unit would cost USD 2900/t capacity under the same conditions. The same values for a remote location in a developing country are the following: USD 4100/t capacity for a 100,000 tpy and USD 3600/t capacity for a plant twice that size.

3.32 Space and infrastructure [23]

A smelter with a capacity of 100,000 tpy requires a territory of 30-40 hectares plus space for possible expansion. It should be not located nearer than 500 m to any settlement even if suitable environmental protection is secured.

Regarding the infrastructure the main needs are as follows:

a) transport facilities

b) power

c) water

d) housing estates

Ad a) Quantities to be transported in and out request about four times the capacity of the smelter. Either railway and/or road system apt for heavy road transportation or a deep sea port is required.

Special unloading facilities are needed for alumina and carbonaceous materials.

Ad b) The important questions of power supply is discussed separately in para 3.4.

Ad c) For the operation of a smelter industrial water is required amounting to 3-4 thousand m^3 /100,000 t metal/ year, even in case of recirculation. Drinking and sanitary water is also to be ensured additionally.

Ad d) Securing of operating staff may also have infrastructural preconditions (housing, transportation, etc.).

3.33 Site

The ideal condition is when sources of cheap energy and good bauxite reserves are close one to the other and the aluminium produced has local market possibilities or it can be transported by sea at low cost to buyer's market [23].

These ideal conditions are not frequently prevailing.

In the past smelters were rather constructed in developed countries, close to the aluminium market and as far as possible on possibly cheap electric power sources. Bauxite or alumina were imported. The increasing demand for aluminium required the establishment of larger and larger power generating facilities for new smelters and relevant amount of cheap cost energy resources were frequently not available in the developed countries. Increasing transportation costs played also a role in the establishment of the actual scenario: concentration of the attention in location of new industrial objects at particularly advantageous sites, or researching for the smelters locations with favourable energy prices and low transport costs.

In case cheap energy is available, but alumina and/or bauxite have to be imported the requirement for a smelter is to have cheap transport facilities. This is the reason that such smelters are set up at seasides or water ways. Continental transport costs of raw materials can namely add up to such amounts that a large part of the advantages of cheap power are lost.

Siting problems become more complex if the cheap energy is relatively far from the seaside, or water routes. In such cases besides the transportation costs of raw materials and the produced metal also those of the power have to be considered to find the optimal solution. In most cases, however, the building of a transmission line is still the better way even if it increases infrastructural investment costs. It has to be considered namely that once power is at seashore it can also be used for other industrial objects.

3.4 Power for smelters

Since aluminium is highly intensive in electric energy, producers require low cost sources for power. Annex 18. shows a Table about cost of electric power for aluminium smelters (costed at generating sites) in 1980 USD per kilowatt hour [11]. The possible variations of the existing low cost energy sources are indicated, as well as the possible power costs to be expected from new projects. Hydroelectric power and flared gas offer the best possibilities for cheap power generation: 6 mils/kWh for specific projects to 20 mils/kWh for high head hydropower or flared gas and to 30 mils/kWh for low head hydropower. Coal and nuclear energy are considered at a higher cost, i.e. 50 mils/kWh, except for Australia.

There are still large undeveloped energy resources in the world, mostly hydropower and flared gas. Oceania got also coal resources to be transformed into power [11].

In Annex 19. the current and possible new low cost electricity supplies available for aluminium smelting are indicated [11]. From this Table some conclusions can be drawn about the further relocation of the aluminium industry in the future, a~~l~~lready mentioned in paras 4 and 7 of Chapter C.

3.5 Operation of aluminium smelters

3.51 Production costs

Alumina, electric power and capital costs are the most important cost elements in aluminium smelting [11, 23]. Comparing the data of 1978 [23] and those of 1983 [11] their weight is, however, somewhat different:

	1978 [23]	1983 [11]
- alumina	25-30 %	30 %
- electric power	20-25 %	16-30 %
- capital costs	25-30 %	16-35 %

Bird gives more accurate data [8] in connection with case studies on 3 new plants. One of his case study results (Australia) is reproduced in Annex 20. The other two cases relate to a Canadian and a Brazilian smelter, having the same parameters. There are slight differences in both variable and total costs as follows:

	Cost in USD/t aluminium		
	Canada	Australia	Brazil
Variable cost 1987	1456.1	1506.8	1373.9
Total cost 1987	1954.8	2041.5	2034.8

The differences in cost originate partially from differences in electricity and capital costs. Electricity costs are the lowest in Brazil (22.1 mils), but capital charges are the highest here (660.9 USD/t): Canada has a somewhat higher electricity cost (22.8 mils), but the lowest capital charge (498.7 USD/t), while the electricity costs are the highest in the Australian case (28.1 mils) with medium capital charges (534.7 USD/t) for 1987.

Annex 21. reflects a prognosis for production costs of new smelters at selected sites in 2000 [11]. It seems that Brazil and Australia will be able to produce the cheapest aluminium in a new plant in 2000.

3.52 Maintenance, spare parts

Annex 20. illustrates maintenance labour and materials costs. Considering also the maintenance costs of the Brazilian and Canadian case one could say that the maintenance costs amount to about 5 % of the variable costs.

3.6 Wastes

There are several wastes in a smelter. Anode butts form the largest quantity, about 20-30 % of anode material used. In an anode plant with the smelter these can be fully utilized (see Annex 16.).

The cathode lining is from carbonaceous material. During the use it takes up fluorides. The lining has to be changed every five years in average. The amount of lining represents with an up-to-date cell over 200 KA about 30-35 tonnes. So some 1500 t of waste have to be considered per year with 200 cells of that size. Either a fluorine extraction is made if the quantity is reasonable or the wastes have to be put into water-safe ponds.

Dry scrubbing of fluorine containing gases is not producing any waste.

D.4 SEMI-MANUFACTURING

D.4.1 ALUMINIUM CONSUMPTION

Aluminium consumption is intimately related to the general standard of industrial development and through it to the per capita Gross Domestic Product (GDP) of a country [12]. Although such correlations may also be governed by numerous other factors as well (e.g. natural resources, traditions, etc. in the region), they may serve as a useful point of departure for preparing analytical surveys and prognostication.

As referred to earlier, aluminium usage may be strongly influenced by the emergence of new structural materials and/or by the relative pricing of competing ones. It is due to competition from such sources that in terms of time there may be lags in having Gross National Product (GNP) or Gross Domestic Product (GDP) correlated with per capita aluminium consumption. Earlier analytic surveys were prepared at a time when the growth rate of aluminium consumption was steadily rising and only little heed was given to the fact that the established relationships were not fully valid in case of countries having extremely high or small per capita aluminium consumption [32-35].

Up to the smelting stage, the flow of materials is more or less easy to follow in view of the long-term agreements by which such movements are backed; from the semi-fabricating stage onward, however, statistical overlapping of certain figures (such e.g. in case of foil manufacture) or different methodologies of grouping materials from a statistical point of view, may easily present pitfalls to the analyst.

In preparing a realistic assessment of aluminium consumption, also the actual aluminium content of all exported and imported finished products too would have to be taken into account; unfortunately, however, this is an almost unsurmountable task.

As pointed out earlier, developing countries are, as a rule, minor aluminium consumers, their aluminium usage lagging far behind that of world average. Only when a certain level of GNP has been reached does aluminium consumption show a steadily rising upward trend until a "state of saturation" has been arrived at. The shape of the so-called S-curve valid for a given year may be approximated by theoretical considerations (Annex 22.)

Owing to diversity in orders of magnitude, GNP [36] in relation to per capita aluminium consumption [37-39] is demonstrated for 1981 in a logarithmic manner as shown in Annex 23.

Excessively high figures (Belgium, Norway, Hungary) may be traced back to the high aluminium content of finished aluminium products exported. Where figures are very low, there is a great probability that the aluminium content of imported aluminium items has been disregarded. Annex 23 represents a static statistical compilation; therefore extrapolation of the aluminium consumption for any given country can be established only after a thorough investigation of the characteristics of the expected development of the national economy. Notwithstanding deviations in the possible value of the above indicated correlation, it seems to substantiate the claim that by the end of this century a marked shift is to take place in aluminium consumption in favour of developing countries [12]. A similar conclusion is reached by another author as well, who, however, suggests considerably more correlations to be taken into account on prognos~~i~~ticating aluminium consumption [8].

4.2 SEMI-FABRICATING

In contrast with alumina manufacture and aluminium smelting, in the semi-fabricating field a great diversity of items has to be produced. Even within a given heading of semi-fabricated items (e.g. strips), actual technologies employed may be varied.

In 1983 world aluminium consumption (primary, secondary and direct use of scrap) was approximately 20.6 million tons [6]. This figure is almost identical with that of semi-fabricated products including castings.

Discounting areas of centrally planned economies, 74 countries had smaller or major facilities for producing semi-fabricated items in 1983; their number was more than 1,000, without calculating minor light metal foundries.

According to available data [8] and excluding casting, the aluminium semi-manufacturing capacities of the world may be estimated to be 21.1 million tons [40]. Casting and powder usage taken as 25 %, the actual utilization of such world capacity may be estimated to be in the order of 70-75 %. This figure seems to be confirmed by several concrete inquiries conducted in this respect.

According to experience, semi-manufacturing projects are in the first place implemented in areas where domestic demand for finished products is already high, and where such demand has usually to be provided for by imports. The installation of new capacities may in most cases also permit exports.

To decide as to where and when it is feasible to launch semi-fabricating projects, is a complex issue calling for a careful consideration of different circumstances, coupled with effective market research. Such market research has not only to keep domestic demand, but also prospects of exports to surrounding countries in mind, with probabilities of exporting - especially rolled items - to more distant regions and thus catering for the world markets as well. In considering such exports, of course, duties and transport costs prevailing at the would-be destinations would have to be taken into account.

The matter is further complicated by the fact that in most developed countries items of commercial quality are manufactured by means of high-performance production lines with an impact on pricing in general, and a small margin of phase price differences in particular. The relative approximate pricing of several products is listed in Annex 24, as compiled on the basis of available references [41], [42]. The magnitude of profits may a great deal be influenced - next to transport costs - by the import duties levied, which in case of semi-manufactures may be relatively high, depending on the country of destination. On the other hand, significant phase margin profits may be arrived at if high value-added items of stringent standards and, if desired, of high surface-finish are supplied (e.g. anodized profiles made from medium-strength alloys), or where in terms of tonnages demand by the customer is smaller than is usual with items of more conventional specifications.

The basic technologies governing the siting and embracing the range of products to be manufactured are summarized in Annex 25. Technological break down of semis production for three developed areas is reflected in Table 8. [43]

Table 8

TECHNOLOGICAL BREAKDOWN OF SEMI-MANUFACTURING OUTPUT.
PER CENT

	U.S.A.	Western Europe	Japan
Rolled product	65.8	54.7	34.1
Extruded and dr[illegible]roducts	23.4	33.0	57.4
Drop-forgings	1.3	0.6	0.1
Wire and cabl[illegible]	[illegible]	[illegible]	[illegible]

It will be observed that sheet and extruded profiles account for most of the production, with the output of forged pieces being relatively small. No major change in this pattern may be anticipated until the turn of the century.

Following the outlines of Annex 25, the principal technologies involved are briefly discussed below.

Among the operations of reprocessing and finishing (separated by a dotted line in the Annex 25) special mention has to be made of the two most important ones: foil manufacture and anodization. (The Annex contains also cross-references to sub-chapters.)

4.2.1 Continuous casting

The basic advantages of the process are manifest where metal in the liquid state is directly received from the smelter and no re-melting of the ingot is necessary. For this reason, such equipment is usually sited at the smelter proper or at least not too far from it. In case of a suitable road system, transport of liquid metal over a distance of 500-600 kilometres, too, may throughout be economical, but in view of the capacities of the continuous casting facilities this is by no means an easy task. A wide strip continuous casting mill is usually designed to produce strip of up to 2,300 mm width and thicknesses from 4 to 40 millimetres; its usual annual capacity is 8-12,000 tons, though some with a 40 ton/hour or higher capacity too are in operation. Of course, operating larger capacities is generally more economical. As for continuous-cast narrow strips, they are usually manufactured in widths ranging from 200 to 300 millimetres; their minimum economically feasible volume to be produced is 2,500 tons per annum.

Rod wire continuous-casting equipment is usually designed for capacities of 10-20,000 tons per annum, although some have annual capacities of up to 50,000 tons.

4.2.2 Billet and slab casting

Up-to-date casting machines served by modern furnaces are capable of extruding more than 50 billets of 150 mm dia. each simultaneously. Large-size slabs (e.g. 450 mm by 2,000 mm in size) may be cast in batches of 10 simultaneously. Lay-out of an about 10,000-ton annual capacity casting shop [42] and of a smaller one [44] are to be found in Annex 26 and 27, respectively. The design of auxiliary equipment to be fitted onto the casting machine is determined by the properties of the feed as well as by the desired purity and mechanical properties of the product to be manufactured from it.

4.2.3 Mould-casting

Aluminium mould-castings are widely used by the transport, vehicle, building, electrical and mechanical engineering industries as well as in the manufacture of numerous mass-produced items. In most cases they are finished products ready for use, rarely calling for additional finish. Although in comparison to other metals their raw material may be expensive, such castings may be competitive with a good many items made from other structural materials.

Mould-casting is a collective noun denoting a variety of different casting technologies. Of these, four are of especial importance and these are compared in Table 9 by pointing out their essential features, the economically feasible minimum number of pieces to be produced, their usual weight, the conventional mechanical strength arrived at by casting an AlSi12 alloy and the pressure-tightness of such castings.

Table 9

CHARACTERISTICS OF CASTING PROCESSES

Processes	Usual number of economic series pieces/year	Weight of Castings kg/piece	Tensile strength (alloy AlSi12) MPa	Pressure resistivity
Sand casting	1 - 5,000	5 - 300	160	middle
Die casting	100 - 100,000	0.1 - 50	180	good
Low pressure casting	500 - 100,000	1 - 50	185	excellent
High pressure casting	10,000 - 1,000,000	0.01 - 20	200	acceptable

It will be observed that a mould-casting shop may be run economically at smaller annual capacities than a semi-fabricating plant. In case of sand castings even very modest capacities may suffice, whereas in respect of the different die -casting processes at least an annual capacity of 1,000 tons is required to have it run economically, because of the time and costs involved in die-making. Of course - especially in car manufacture - even capacities ranging from 10,000 to 50,000 tons per annum are being installed.

To facilitate casting, aluminium used for such ends usually contains 5-15 % alloying constituents featuring a fairly wide range of tolerances. For this purpose secondary aluminium is particularly suitable. Recycling of the metal starts with the collection of scrap, followed by its classification, preliminary handling and final remelting by a metallurgical process to secondary aluminium. Remelting of scrap is an energy-saving procedure. The energy necessary for scrap processing represents about 5 % of the power requirement of the production of the primary metal [45]. Collecting and classifying scrap effectively call for certain organizatory skills. A remelting facilicity handling at least 1,000 tons of scrap annually may already be a paying proposition. According to experience, secondary aluminium usage is growing faster than aluminium consumption in general.

4.2.4 Rolling

Today some 200 hot-rolling mills are operating in the world. Many of them have a 100-500,000-ton annual capacity but in developed countries even such of considerably smaller capacities are being operated.

Cold-rolling mills, as a rule, are installed simultaneously with hot-rolling mills. However, in a good many cases the hot-rolled product - including continuous-cast strip - is transported over long distances to other destinations to be further processed by cold-rolling. This explains why there are about 50 % more cold-rolling mills in the world than hot-rolling ones. Where both are present, the usual cold-rolling capacity is about 60-100 % of its hot-rolling counterpart. If only cold-rolling facilities are installed, capacities vary within a large range.

Of course, where output is small, technical performance data (productivity per capita or unit of area) are inferior to those of the larger mills. (Annex 28 and [42].)

4.2.5 Extrusion

In contrast with the so-called direct process of extrusion exclusively practised earlier, nowadays indirect extrusion is more and more gaining round, although for a long time to come direct extrusion is to remain more widespread. A comparison of the two technologies is indicated in Annex 29. Advantages of indirect extrusion, permitting more favourable conditions of friction, are discussed, along with concrete examples, in [46]. There are roughly 700 extrusion plants in the world. Their installed annual capacity usually varies from 3,000 tons to 10,000 tons, but also larger (80,000-100,000 tpy) as well as smaller (500-1,000 tpy) ones exist. Most of the smaller units located in developed countries are designed to produce high-precision profiles.

Annex 30 presents a simplified diagram of an extrusion plant. The capacity of each extrusion press is in direct proportion with the compressive force applied by it. In producing items of average commercial standard it amounts to 200-300 t/MN/annum; with profiles of more complex design, the corresponding figure is 150-200 t/MN/annum. Hence, by siting a single extrusion press, an annual capacity of 1,000-3,000 tons may be installed. However, - apart from some exceptional cases - running a single press is unusual.

4.2.6 Forging

Since forged aluminium pieces are relatively expensive and to produce such of fully accurate sizes calls for the use of costly dies, forging is a paying technology only if large series are involved. The major customers of aluminium forgings are the aircraft and vehicle manufacturing industries.

D.4.3 REPROCESSING OF SEMI-FABRICATED PRODUCTS

A considerable part of semi-fabricated products discussed under heading D.4.2 are only sold to the customers after having undergone some further operations of processing. It is a common feature of such operations that they are usually carried out by various equipments of relatively high productivity. Due to reprocessing, what finished item manufacturers have to do is more and more limited to the mere machining, cutting-to-size, drilling etc. as well as to the joining (in the first place welding) of the semis purchased from the mills. Reprocessing technologies of semis include foil rolling, manufacture of corrugated profiles, roll-bonded sheets, ribbed tubes, welded tubes, pigments and various processes of surface finishing.

Of these reprocessing technologies, foil manufacture and surface-finishing techniques may deserve special attention.

4.3.1 Foil manufacture

Strips of 800-1,600 mm widths and 0.2-0.5 mm gauges as a rule lend themselves well for transport in coils of 4-10 tons each. Therefore foil mills need not necessarily be sited directly adjacent to a cold-rolling mill.

Foil-manufacture consists of two distinct types of operations: foil-rolling proper, and finishing of the product thus arrived at. The latter is of special importance, in that only a part of orders to be received calls for foil in natural silvery finish, whilst most customers require coloured, patterned or printed ones, or such laminated with other materials to be used for packaging. Today some 150 foil manufacturers are to be found in the world. Their typical annual capacities are ranging from 3,000 to 50,000 tons, though mills of smaller or larger capacities too are known to exist.

4.3.2 Surface finish

When corrosion resistance or a decorative effect is striven for, in case of rolled (flat) products usually a paint-, plastics- or lacquer-coating is added. In case of uneven or extruded surfaces often a process of anodization is applied.

In the first case by choosing a suitable colour, and in the second case by depositing an electrolytically coloured anodized surface film or one directly obtained in the process of anodization (integral colour anodization), the desired effect may be arrived at.

Owing to their continuous operation, wide strip painting lines have to be designed for large capacities. (Each unit to handle 10,000 tons or considerably more per annum.) The installation of such equipment is costly and economically only feasible if large volumes are involved.

Depositing an anodized oxide film is a time-consuming process. In view of this - apart from a few exceptions - the operation of such equipment is intermittent, permitting the economical installation of smaller capacities (1,000-3,000 tpy).

D.4.4 General aspects of installing semi-fabricating plants

Compared to alumina manufacture and smelting, the production of semi-fabricated items is in specific terms a more labour-intensive, but considerably less energy-intensive process. In the production costs of semi-fabricated items the share of raw material costs and amortization of invested capital are two dominant factors. Varying with the nature of the product, the former may account for as much as 80 %, but even in case of reprocessed products it may usually be well beyond 40 %, (Annex 24).

Data concerning optimum capacities according to the type of technology involved are subject to considerable variations (e.g. rolling or forging). But even within a given major type of technology, a great deal depends on the actual specifications to be manufactured (e.g. proportion of unalloyed aluminium, the thickness of strip, etc). Indications on capital investment costs without a careful specification of the envisaged products may only furnish a very tentative estimate of the possible expenditure which might be involved in the realization of the project.

Annex 31 reflects tentative estimates concerning investment costs of fabrication facilities compared to those referring to smelters [34],[47]. Because the economically feasible minimum capacity of a semi-fabricating plant, this might be relatively small, involvment in these operations might start with reasonably modest investment resources.

D.5 MANUFACTURE OF FINISHED ITEMS

Finished product manufacturers are in direct contact with the end-users and mostly determined by the markets. It is from such quarters where indications as to competition from other materials may be forthcoming, while effective marketing work may do a great deal in coping with such exigencies and in contributing to a further rise of aluminium consumption.

The number of finished aluminium items or such containing various amounts of aluminium may now be put at several ten-thousands. The situation is further complicated by the fact that in a good many cases an individual item may contain but a very modest amount of aluminium, which - though seemingly negligible to the end-user - may be of great significance from the aluminium industry's point of view. (A case in point is car manufacture.)

In improving existing and developing new products, useful guidance may be obtained by preparing separate functional and value analyses. Their comparison may reveal expectations by the consumer as to the technical parameters desired on one hand, and the economic feasibility of meeting such demands by the producer, on the other hand. Such exercises may also provide guidance in the choice of a suitable material (a competing one, or aluminium alloys).

The life-cycle of aluminium finished products is highly varied; however, an average of five years may be regarded as a fair estimate. Hence, from time to time, the necessity arises to have designs updated or to come forward with completely new ones. This permanent drive for technical and product development has to keep considerably larger teams of specialists busy than is the case in the other sectors of the aluminium industry. Such domestic innovations, may also from time to time be replaced, if necessary, by purchases of licences from abroad, especially when it comes to the introduction of a new product on the market.

Prices per unit of volume are subject to great variations, even where the bulk of a concrete item consists of aluminium structures. Same applies also to small-size objects (e.g. artifacts) whose manufacture - in spite of the small series involved - may be troughout economical. It should be pointed out that with plainer items, in whose manufacture relatively few and simple operations are involved (e.g. holloware), as a rule only large-scale production may be a paying proposition. In contradiction, however, where wages are low and investment resources are poor, the manufacture of deep-drawn kitchenware may even in smaller series be economical.

Approximate optimum capacities for the large-scale manufacture of some selected finished items are dealt with in Annex 32 [47].

Here, too, capital expenditure is related to that of erecting a smelter. From a comparison of the corresponding figures it will be observed that specific investment costs for one ton of finished product may greatly vary with the type of product under review, and may be as much as 5 to 6 times that of the ingot (e.g. in case of kitchenware) or just a fraction thereof (e.g. in case of furniture frames, ladders or scaffoldings). One point, however, is especially significant: reasonable size capacities for this type of products can be found in the 500-5000 tpy range.

E. MAIN DIRECTION OF RESEARCH PROGRAMMES

1. ALUMINA

The Scientific Committee of the ICSOBA Symposium at Tihany [48] stated that the bulk of the world aluminium production will still be provided by the Bayer process at the return of the millenary. Due to this in the forthcoming trends in the development of this process shall be mainly investigated.

1.1 The Bayer process

Allthough the Bayer process is used since long for the production of alumina, there are steady developments to this process. Various ICSOBA and AIME meetings discussed such developments and the Scientific Committee of the ICSOBA meeting at Tihany stated also the main trends of development as follows [48]:

- to develop energy saving technology
- to increase the role of high temperature digestion
- to introduce high capacity equipment
- to apply a fully automated process and a computerized control system.

One could add to these as an overall trend that due to the increasing costs of capital goods, the promoter of technical improvement will be more and more the better exploitation of capital goods, the increase of the efficiency of the plant [49].

The main tasks of the technical improvements of Bayer alumina plants are summarized in Annex 33. This shows the 5 main directions of R + D, their targets as well as the possible solutions (based on [49]:

As can be seen from this Annex the main lines of R + D activity lay in the precipitation and the digestion steps of the process.

In precipitation the main line of development consists of those efforts which assure besides the high liquor yields of the European Bayer process (70-80 g/dm^3) the properties of American Bayer product, i.e. a sandy alumina. For this aim purification of the solution is necessary by removal of carbonate salts and of organics (where present). The whole precipitation technology is under steady development to ensure optimal precipitation yields with sandy alumina.

In digestion two trends can be found: in case of monohydrate bauxites the increase of digestion temperatures is the trend. For this aim the newly developed tube digestors could also be used, especially with diasphoric bauxites. The efficacy of the digestion can calso be influenced by using additives if the bauxites used necessitates it.

The adjustment of digestion and precipitation, futher the quantity of water to be evaporated contributes to the optimization of the whole process by increasing productivity and minimizing costs. Cost reduction is also the reason why attempts are made to reduce caustic consumption, whilst the red-mud washing is not only done for this purpose, but also to achieve a less environmental polluting mud.

1.2 Non-Bayer processes

An optimization of non-Bayer processes are also in course, these are, however, only of local importance. A more important activity are the R + D works to produce aluminium chloride.

The production of aluminium chloride serves various purposes. This material can be used per se in the chemical industry (allthough relatively small amounts are needed), or to produce certain special aluminas, but it might also serve as an intermediate product in the production of aluminium.

Aluminium chloride can be produced from iron-poor clays

(Tóth process) [50] or bauxite or gamma-alumina (Alcoa process) [51].

If starting from iron-poor clays these are sintered first with coke, followed by a chlorination in the presence of sulphur. Various chlorides are produced, which are separated by distillation.

In case of reactive gamma-alumina fuel oil is cracked into it in a fluidised bed reactor and the alumina-coke particles are then chlorinated in a fluidised bed reactor at about 650 °C in the presence of $NaAlCl_4$ [51].

Bauxite is calcined first and then subjected to a fluidised bed chlorination using a $CO + Cl_2$ gas mixture [51].

Other chlorination technologies have also been developed, but all these processes are more or less only in the piloting stage. (About the production of aluminium from chloride see E.2.2.).

2. ALUMINIUM

Not only the production of alumina looks for more economic solutions within the Bayer process, but also the Hall-Héroult process is under a stady R + D activity. Besides this an intensive activity for the development of alternative processes is in course.

2.1 The Hall-Héroult process

Better economics and the meeting of strict environmental prescriptions is the aim of R + D activities in this field. The size of pots was increased first, but surpassing 200 KA (230-250 KA) the results are not very impressive.

As a cumulative result of various developments, such as larger anodes, improved electrolyte composition, lower operation temperatures, computer control of cell operation, cell design, cell life, emission control and control of magnetic effects resulted in a lower energy consumption, but reduction of the energy consumption much below 12,100 kWh/t of metal is not expected [52].

R + D activities for some major modifications are, however, in course [52]. These are in the field of

(i) developing new electrode materials and designs

(ii) changing the electrolyte composition.

In the first field Kaiser develops a TiB_2 cathode, while Alcoa looks for a permanent anode on which oxygen is discharged. The result of both would be reduction of power consumption. It is premature to judge viability of these efforts.

In the electrolyte composition field the use of lithium salts to reduce electrolyte resistivity is the actual trend. The results could be decreased power consumption, improved current efficiency, reduced fluoride emission and reduced operation costs. Results are, however, not yet clear-cut.

Bird expects that gradual process improvements in existing smelters will bring in average 0.5 % cost reduction per year [8].

2.2 Alternative processes

Several alternative processes were investigated. Out of these processes the following merit special attention:

- the chloride process
- direct carbothermic reduction

The Alcoa chloride process (Alcoa Smelting Process or ASP) consists of the electrolysis of $AlCl_3$ in LiCl.NaCl melt at 700 °C with multicell bipolar stack of graphite electrodes-anode not consumed. (About the production of $AlCl_3$ see E.1.2). Allthough the electric energy consumed is less with the ASP than with the Hall-Héroult process, the overall costs are only slightly decreased if considering the chlorine production too, but the risks of the process seem to be higher. An improvement in the chlorination process and a decrease in costs could make this process, however, more attractive [51]. Pilot plants were closed [51].

Direct carbothermic reduction of clays poor in iron into an Al-Si alloy is feasible and might be possible.

The Kuwahara process consists of the briquetting of aluminous ores (e.g. bauxite or clay with some Bayer alumina addition) with coke, reduction of same into an Al-Si-Fe-Ti alloy in a reactor combining combustion and electric arc heating at 2000 °C, separation of the aluminium by extraction using lead as the solvent followed by vacuum distillation of the aluminium-rich phase. It was estimated, that costs would be about USD 1000/t [52]. Mitsui Alumina Plant had built quite a large pilot unit, but experiments were stopped recently.

E.3 SEMI-MANUFACTURING

E.3.1 GENERAL CONSIDERATIONS

While basic technological operations of semi-manufacturing (semi-continuous casting, rolling, continuous-casting, extruding, drawing, forging, die-casting) have been developed over a good many decades past, they have in the meantime been substantially improved in productivity and technological standards. A more recent development is the relatively widespread production of powder-metallurgical items, although basic technologies in this field are the same as have been practised in processing other metals and alloys for several decades past.

Referring to relevant literature and following the general outlines of the previous chapter, trends in developing individual major technologies are summed up below.

3.1.1 Continuous casting

As in earlier years, the bulk of continuous-casting is done by equipment designed by Properzi of Italy, SCR (Southwire Continuous Rod) of the U.S.A., SECIM of France and types manufactured in the Soviet Union.

A special feature of recent developments is growing productivity (increase of coil diameters). In wide- and narrow-strip continuous casting special attention was devoted to improving quality and expanding the range of alloys to be handled by this technology.

3.1.2 Billet and slab casting

Effective technologies of billet and slab casting fundamentally determine the quality and standard of semi-fabricated products.

In preliminary operations the use of filtering has become widespread. A description of such equipment and its operation are to be found in Annex 34. The design and introduction of more up-to-date high-performance filters may be anticipated in a not too distant future. [53]

In semi-continuous casting, the use of moulds furnished with heat-insulated linings represent a relatively recent and now widespread novelty. Here controlled heat-dissipation is the principal aim, whereby high-standard billets and slabs may be won. Such processes and equipment are described in Annex 35.

Conventional semi-continuous billet and slab casting technologies are nowadays sometimes computer-controlled by various producers (e.g. ALCAN); owing to optimum parameters, the resultant large-size and homogeneous billets and slabs are of excellent quality.

Kaiser Aluminum Company has developed a process for casting certain alloys susceptible to cracking. It features an inflatable wipers in the mould, removing water from the billets and slabs at critical points wereby the rate of chilling is only up to 320 °C intensive [54].

Under a process developed by the British Aluminium Company, on casting slabs the position of the heat-insulating insets is variable inside the mould, facilitating thereby the automation of the process. (Hence its name: Variable Chill Depth Mould [VCDP] System.) [55]

In case of high-strength alloys difficult to cast, electro-magnetic moulds are used. By this method cutting the ends and milling the surfaces of slabs and billets may be dispensed with, and homogenization times, too, may be reduced [56].

Advanced casting technologies may result in roughly, 90 % yields, permitting savings of energy and the handling of difficult, high-strength alloys.

3.1.3 Mould-casting

In this field there is a marked trend towards reducing wall-thicknesses. This is especially true in respect of high-pressure casting. More and more high-pressure casting machines are fitted with vacuum systems, with inblow of oxygen steadily gaining ground. Trials of controlling the rate of metal shots have been conducted with good results. Also in more and more up-to-date foundries robots are used, improving both productivity and the quality of castings.

A novel process is extruding liquid metal and freezing it under high pressure (squeeze-casting, rheocasting) [57][58].

3.1.4 Rolling

Recent research is in the first place aimed at increasing yields, improving quality, and providing uniformity of the product. With this end in view, electronic control of the roll stands and ancillary equipment is steadily gaining ground, permitting a reduction of operating personnel. Also with regard to rolled semi-manufactures a marked shift towards more complex specifications (high-strength, narrow margin of tolerances, etc.) may be observed.

3.1.5 Extrusion

In extrusion technologies no dramatic breakthrough may be reported, though in some particular operations underlying the conventional pattern, considerable headway has been made especially in techniques of control. Demands for higher mechanical strength could be met, coupled with a reduction of average wall-thicknesses. Also an increasing percentage of output is nowadays furnished with surface-finish. Of the processes involved, direct extrusion is expected to keep its dominant position in the medium term, though superior properties of friction may bring indirect extrusion more into focus, despite the more complicated designs of such presses.

In the short term, the extrusion of small pieces by the Conform-process may have fair prospects [59][60]. It is an economical technology, with the advantage that by utilizing the benefits of the prevailing friction force the extrusion process may become continuous. In this manner - starting from relatively small cross-sections - various thin-walled profiles and shapes may be manufactured. A diagram of the process is to be found in Annex 36. The Conform-process is - in principle - also suitable for producing rods by the continuous extrusion of powders.

In addition to improving productivity and yield, electronic control of the extrusion process is of paramount importance in bringing about throughout homogeneously distributed properties in the product, inasmuch as under other operating conditions a "quasi-stationary" state may either not or only at a very late point of time be arrived at.

3.1.6 Forging

Owing to the relatively modest market demand in forged pieces, technical development in this field is not very spectacular.

Present technologies strive to approximate, as far as possible, final shapes and dimensions fit for ready use.

3.1.7 Other technologies

One of the most fundamental technologies of mass-manufacture - especially in case of more complex designs - is powder metallurgy. In the aluminium field it was introduced on an industrial scale over the last decade, expecially in countries producing large volumes of passenger cars.

Further future developments may in this connection be anticipated particularly when such properties are called for as cannot be ensured by conventional technologies (so-called "pseudo-alloys", composite materials).

3.1.8 Alloy development; developing of micro-structure of products

Technologies of semi-manufacture and the behaviour of the alloying elements determine in an inter-related manner the micro-structure of a product and through it its very properties.

New technological solutions in casting and filtering, a suitably engineered combination of forming and heat-treatment, as well as meeting the demand of customers and consumers, have considerably improved the properties of the end-product, by now more closely approximating general expectations. In the wake of these painstaking efforts and gratifying results, the concept of "tailor-made" semi-manufactures is nearing its realization. [61]

An effective combination of heat-treatment and forming (thermo-mechanical treatment) results not only in energy savings but also in the production of a micro-structure that has properties superior to those of the usual products.

A new trend is the Al-Li-X combination of alloys, wherein "X" is an additional alloying element. It is now rather widely employed by the aircraft industry and in space technology.

E.3.2 REPROCESSING OF ALUMINIUM SEMI-MANUFACTURES

3.2.1 Foils

There is now a marked trend for reducing foil gauges and introducing automatic methods of controlling and testing foil gauges. Special efforts are made to raise rolling speeds, a point calling for further technical development in the design of equipment and technology, coupled with modifications in the properties of the raw material.

3.2.2 Surface finish

Trends of demand call for more pleasant product surfaces and enhanced resistance of the surface-coatings and films. Also higher productivity is striven for, but only in accord with rules pertaining to environmental protection.

F. TECHNOLOGICAL ALTERNATIVES MORE SUITABLE FOR DEVELOPING COUNTRIES

1. TECHNICAL SUMMARY

Chapters D and E showed that the extraction of bauxite, its refining into alumina as well as the production of the metal by electrolysis are well established technologies. Allthough a steady improvement of these processes is taking place, fundamental changes are not expected by the end of this century. Bauxite resources known at present will not be a limiting factor to further growth of the aluminium industry [48]. The application of up to date methods of remote sensing might facilitate the identification of new ore deposits particularly in developing countries. Nevertheless the processing of low grade bauxites and non-bauxitic materials into aluminium might have local importance, because some countries may want to process their existing own raw material [48].

An energy-centric aspect is dominating both in aluminium production and consumption, determining the development trend [48]. This and the better exploitation of capital goods - due to their increasing cost - is the promoter of the development of the Bayer and Hall-Héroult processes. Apart from the climatic factor there is no technical limitation to use these processes anywhere in their present or developed form, provided the erected facilities can be run and maintained in a given country, because when designing the plant a reasonable choice of automation and mechanization was made and the personnel was exposed to an appropriate training.

Due to environmental protection coming more and more into the fore new aluminium smelters are of the pre-backed anode type using sandy alumina. This is the reason that new plants are based on the production of this type of alumina and some older ones - if not producing sandy - are transformed to produce this variety of alumina. Developing countries have mostly trihydrate type bauxite, the production of sandy alumina causes no problem with such raw material.

The development in semi-products' fabrication looks to be more dynamic. Allthough the basic production methods are well known since decades, but the efficiency of these processes as well as the production of products with increased quality parameters lay steadily in the fore of recent development. Aluminium's success in the competition with other materials depends upon the steady improvment of the properties of its semi-products in order to meet better numerous end-use requirements. This objective and more economic production are the main development tendencies in this field. Therefore when establishing fabrication facilities the proper design of the product mix is of paramount importance.

Size of units plays an important role in the economy of production. As mentioned in Chapter D.) the size of an alumina plant grew from the previous 120,000-150,000 tpy to a line capacity of 300,000-500,000 tpy. Plant capacities reach or surpass hence often 1 million tpy. On the other end smelters are nowadays built with capacities of about 100,000 to 300,000 tpy, the actual capacity depending on the line capacity.

The above mentioned sizes of alumina plants and smelters do, however, not always coincide. Due to the fact that about 1.95 t of alumina are required to produce 1 t of metal a 600,000 tpy alumina plant would need an approx. 300,000 tpy smelter to absorb its production. There is often no possibility - due to various reasons, e.g. lack of electric energy or financial means - to build such a complex at one site. In such cases an alumina plant has to have more than one smelter as consumer of its production, one nearby and the other(s) far away. In other cases, compromising solutions might be accepted and the rentability of the integrated plant would be the prevailing factor in the investment decision.

A further solution is to build e.g. only one line of the alumina plant with the aim of later expansion. It is, however, an important point to have the consumer of the alumina before deciding to build a plant, because metallurgical grade alumina can only be used to be transformed in a smelter into aluminium.

Bauxite reserves play also an important role in deciding the size of an alumina plant. A new capacity of 600,000 tpy should have a reserve of at least 50-60 million tons of bauxite thus allowing operation of the plant for at least 30 years.

Sizing of semi-production lines is an even more complex question. There are certain semi-products the transport of which is only economic within a very limited area. Fortunately such semi-products can be produced in relatively small-size plants. This is typical for extruded products, where 1-3000 tpy production facilities might be economic. Rolled products on the other end are transportable even to long distances, but the size of their economic production is much larger. Cast-rolling units could be of smaller size, even 10,000 tpy units might be viable. Such production lines have to operate, however, in conjunction with a smelter and the spectrum of the semis production with this type of equipment is narrower than with usual rolling mills and the fabrication of some high-alloyed aluminium products is not possible. The size of economic rolling mills - which are indenpendent from a smelter - is much larger, at least 40,000 tpy and the larger the capacity, the better its economy. Cold rolling mills could be of a smaller size than the hot ones. It is ideal, however, to have both at the same place, otherwise an intermediate products has to be shipped to the cold mill, but it is also a common practice to set up cold mills processing coils. For viable sizes of other semi-production facilities reference is made to Chapter D/4.

Majority of the rolling mills are located in the center of consumption, supplying with their products relatively large areas. Due to transportation reasons extrusion facilities are, however, located nearer to the customers.

The location of finished product manufacturing facilities depends on the type of product and the technology used. Special marketing an promotion can be carried out for finished products having a predominant aluminium content. Wire and cable manufacturing, facilities producing kitchenware and other utensils, containers and certain aluminium products for the building industry could be typical ones. The setting up of such facilities depends - in the majority of cases - only from the market, domestic prices of the product and the choosen technology, while the local production of other types of finished products depends to a larger extent from the general development level of the area under consideration.

2. SOME ECONOMIC CONSIDERATIONS

It was already mentioned in Chapter C.) that there are relocation tendencies in this industry and they will probably continue. The reasons of this relocation are, however, multiple. When the demand of aluminium could not be followed any more with the bauxite available in the developed countries, the utilization of the raw material resources in the developing countries started. First the bauxite was shipped to existing alumina plants, later alumina plants were built in the vicinity of the mines in developing countries. A further step is to set up an integrated plant at the bauxite location, provided that at the same place relatively cheap electric energy is also available. In that case the metal is shipped to the consumers.

From the analysis of the present worldwide situation of the aluminium industry one can draw the conclusion that the geographical relocation tendencies might be amplified in this industry during the next decade.

The following factors might justify this opinion:

- the important idle capacities in refineries, smelters and fabrication plants,
- the unfavourable evolution of the aluminium demand on the biggest markets notwithstanding the actual low prices,
- the decreasing share of metals, among others that of aluminium in the unit costs of industrial production due to structural changes,
- the strengthening competition of other materials, particularly that of plastics, which might be increased through the evolution of petroleum prices,
- recycling and application of high-duty alloys decreasing the demand in primary metal,
- due to the structural changes worldwide in industry a possibly new pattern of the evolution of the development of the economy of the developing countries requiring, maybe, less materials with a mix strongly deviating from the indications corresponding to the established correlations.

The above explained phenomena allow to state that the present difficulties of the aluminium industry are not of temporary character but very probably they will be observed also at least during the first half of the next decade. This situation leads also to the conclusion that refinery and smelter activities will be more and more concentrated in important industrial objects located at the most favourable sites, a considerable part of which are in developing countries.

Annex 37 shows the regional distribution of aluminium industry structure per continent in 1983-1984 and forecasts for the future. It can be clearly observed, that a considerable protion of bauxite originates from regions where its processing into alumina and aluminium is relatively small, but e.g. in Latin America the proportion of locally refined bauxite is increasing. Similar trend could not yet be observed for Africa.

Annex 37 demonstrates also clearly that the present relocation of the aluminium industry concerns only to the alumina and aluminium production. Its objective is to decrease energy and transportation costs. Fabrication of semis is actually not involved in this process, it is mainly located in developed countries close to the consumers. Furthermore notwithstanding the increase in aluminium production in Oceania, considerable projects for the development of the semi-production in this continent could not be identified.

Alumina and aluminium production are highly productive, capital-, energy-, ore and material intensive processes, for semis manufacture practically capital, manpower and metal are needed. The average price of the fabrication products might reach the double of that of the ingot, therefore the possibilities of broader involvment of developing countries in this process merit particular attention.

The aluminium consumption is a critical point concerning the possibilities of the development of the aluminium industry in developing countries. In Chapter D/4. it was already mentioned, that there is a correlation based on experience between aluminium consumption and the GNP. However, it is not the only determining factor and conclusions drawn from the correlation of the GNP and aluminium consumption should be handled with caution and certain flexibility within reasonable limits. Own aluminium sources e.g. combined with a sufficient promotional activity might result in a larger than expectable aluminium consumption, which is still economic, as the example of various countries (e.g. France, Hungary, Venezuela) show. Allthough a national aluminium industry might be acting in the positive way, there are also countries like Hong Kong and South Korea consuming considerable amounts of aluminium (3-5 kg/capita/y) without having any bauxite. In these countries considerable semi-fabrication capacities had been set up recently [10]. On the other hand the specific consumption of India or Indonesia with large bauxite reserves and in India with a well built-out aluminium production is very small, even below 0.5 kg.

As already discussed in Chapter C.) a growth of aluminium consumption is expected in the years 1990-1993 (see Annex 7). This expected annual growth of rate is in average 4.2 % regarding the market-economy countries. The presumed growth of rate is, however, below this average figure in the USA and in Europe, i.e. the large consuming parts of the world. The only country expecting a growth rate over the average is France in this region. The growth of rate is expected, however, to be over this world average in Japan (4.8 %) and in the rest of the world (5.4 %). This would mean that the consumption in developing countries, but most probably not in the LDC's, will increase considerably. This fact might influence the relocation tendencies. Gonzales-Vigil quotes in his study [12] Alcan Aluminium's Annual Report for 1982 saying: "Developing markets cannot be economically served by the high-volume production facilities used in mature markets. The multiple variety of small orders typical of a developing country must be served by a flexible capacity, capable of adjusting outputs to demands, and of growing by incremental stages." One might, accordingly, expect increased activity for the location of semi-fabrication facilities in developing countries, during the last decade of this century.

Semi-fabrication facilities are established in the vicinity of the markets, nevertheless there is an important international trade in these products (see Annex 38) [6]. This phenomenon is caused partially by technological, partially by economic reasons. The metal statistics shown in Annex 38 indicate that the overall export figures of 15 countries, including the largest users, in aluminium semi-fabricated products (partially including some finished products too), added up to 2,290,791 tons in 1983 and imports of the same countries reached 1,716,535 tons in the same year. The balance of 574,256 tons in favour of the export were shipments to other developed but mainly to developing countries.

The share of semi-products involved into international trade compared to the overall consumption is very different in the abovementioned countries. This share in big markets - with important production and consumption of large varieties of semi-products (e.g. the USA) - is relatively smaller than that in relatively smaller countries for which the participation in the international division of labour is more imperative.

Attention has to be drawn also to the fact, that the overwhelming part of this semi-fabrication trade consists of rolled products, which shows repeatedly that the large capacity units are dominant and transportation costs are acceptable for these products.

The position of the developing countries in semi-fabricated products international trade can also be illustrated with the following:

(i) Table 10 contains indications concerning the trade of semi-manufactured aluminium products with developing countries [62]

Table 10

TRADE OF SEMI-PRODUCTS WITH DEVELOPING COUNTRIES

	Imports of developing countries	Exports of developing countries	Net trade position
1963	101,000 t	2,000 t	- 99,000 t
1970	132,000 t	17,000 t	- 115,000 t
1977	301,000 t	25,000 t	- 276,000 t

The import figures could have surpassed the 400,000 t/y since.

(ii) Annex 39 shows the semi-production facilities' capacity in selected developing areas in 1983, the possible capacities in 1987 as well as the consumption of primary metal ingot in 1981, based on [10].

3. POSSIBILITIES IN THE NORTH-SOUTH COOPERATION

The tendencies for building new complexes in areas where bauxite and cheap energy are available, the expected increase in the overall aluminium consumption after 1990 and the larger than average share of the developing countries in it justifies to suppose that a considerable future development in the aluminium industry will take place in developing countries. The forecast of demand in aluminium in the developing countries adds a new element to the picture: not only refineries and smelters, but an increasing share in semi-fabrication facilities might be expected in developing countries. This overall trend can be explained in a more articulated form as follows:

Scarcity of bauxite in developed countries was one of the main reasons of relocation of alumina producing facilities to developing countries. Availability of raw material and of cheap power resources in Australia and in Brazil leads to the erection of important refineries and smelters in these countries representing the most important recent event in the worldwide development of the aluminium industry. There are also important possibilities in other regions, particularly Africa, which have been utilized up till now only to a very limited extent, so a further development might be envisaged in this areas in the late 90's.

The question of creating semi-fabrication facilities in developing countries is more complex. Increasing consumption demand in some developing countries resulted already in the setting up of considerable facilities e.g. in Brazil, Mexico, or in some countries in Asia. There is, however, also a further possibility for the utilization of fabrication facilities operating or to be erected in developing countries:

As mentioned above, statistics show that there is a considerable trade of aluminium semi-products among developed countries. This trade is partly consequence of a reasonable international division of labour. Participation of some developing countries in this trade could be envisaged in the future especially of those, producing the metal and having a considerable local consumption of aluminium. It might be concieved that in selected cases, semis produced in these countries could be sold not only for covering local or possible subregional demands, but also partly in developed countries or in other regions.

In this respect attention could be drawn to the possibility of the redeployment of existing semi-manufacturing plants into developing countries. Especially equipment producing up to date semis but having smaller capacities than those suitable for a large industrial country could be transplanted into a developing country where it could still well cover local needs and maybe even produce semis partly for exportation.

Acquisition of equity positions in plants operating in developed countries might in selected cases be possible for developing countries. Examples for this type of North-South cooperation are quoted in [63].

The question of how to set up semi-production facilities that these should suit the best the needs of developing countries including possible deliveries for domestic, regional and interregional markets will be reviewed under point F.5.

4. COOPERATION AMONG DEVELOPING COUNTRIES

Bauxite resources are only one of the prerequisites for setting up a partly or fully integrated aluminium industry in a given country. The justifying factors may be the availability of cheap electric energy, the population of the country and the expected demand in the future in aluminium. Countries with a possible local and external market of about 100,000 tpy aluminium might consider to develop an integrated aluminium industry if having both bauxite and cheap power resources. Others could first of all take part in the international division of labour searching appropriate partnership.

Subregional, regional and even interregional cooperation among developing countries might be envisaged among the possibilities of creating important aluminium industry objects in developing countries. This has been seldom the case up till now. Some attempts were made for such cooperations e.g. the JAVEMEX case between Jamaica, Venezuela and Mexico, which was converted later into a bilateral Jamaican-Mexican cooperation, in the frame of which Jamaica would have produced the alumina and Mexico was thought to be the producer of metal from the alumina; or an other case: Indian authorities also showed interest in the erection of a smelter in Mozambique using Indian alumina. Information is not available concerning the realization of these ideas. Some further examples for South-South relations can be found in [62], but is has to be noted, that these examples are rather covering cases of cooperation between plants belonging to TNC's and located in different developing countries.

Iniciatives regarding cooperation among developing countries in the production of various semi-products could have sound bases even in lack of metal production in the area under consideration. Increasing demand in a region is aluminium products might well lead to such cooperations in the future. The production of a broad variety of semi-products needs namely a market of considerable size which is seldom available in one country as illustrated by the example of several developed countries.

5. ESTABLISHMENT OF FABRICATING FACILITIES IN DEVELOPING COUNTRIES

In envisaging the installation of semi-manufacturing facilities in developing countries, the following options or combinations of them appear to be feasible [41][42]:

- Meeting the semi-manufacture demand of an already operating finished item producing industry by the partial or full use of domestic semi-manufactures, to the extent of which the latter may suitably replace so far imported ones. This objective being achieved through relatively modest investments, the erected facilities usually performing final operations of fabrication with raw material imported (e.g. hot-rolled coils, etc.);
- Installation of continous-casting facilities to produce strip and rod wire by receiving liquid metal from an already existing adjacent smelter or one to be erected in the immediate vicinity, and thereby benefiting of heat energy savings;
- Installation of a fully integrated complex semi-manufacturing plant, irrespective of where the smelter is located.

On comparison, each of the above approaches have merits and drawbacks. These are more amply dealt with in references [41][42].

6. AVAILABILITY OF TECHNOLOGIES

Most of the technologies described are available on the market. Exceptions might be recent development not yet fully prooved in large scale operations. There are hence practically no limiting factors in this respect to set up an aluminium industry in any developing country, provided the selected technology has been correctly adjusted to the available raw materials and local conditions.

About some further details of the possible transfer of technology in this field reference is made to an UNCTAD study [62]. It has,however, to be stressed as an addition, that the production of finished products needs relatively a considerable amount of know how to be absorbed and its price might represent a relatively important share of the investiment costs.

7. MARKETING

Marketing questions do not form part of the present study. Due to its importance, however, reference is made to [62], dealing with these questions in detail.

8. SOME GENERAL REMARKS

8.1 A certain correlation between GDP and aluminium consumption was identified. Due to the fact that the present technical revolution brings new elements in the whole structure of the industry, it is most probable that this correlation should be reviewed. It would be more appropriate to set up trends for aluminium consumption of the future on a more articulated basis, as e.g. Bird tried to do [8]. One should not only consider the overall pattern of development of the economy, but one should also carry out an analysis of the different fields of possible future application of the metal.

8.2 Aluminium semi- and finished production needs relatively little energy and practically no additional raw materials. It has also to be taken into consideration that in these activities the creation of emloyment considering investment cost is cheaper than in the case of setting up alumina plants or smelters.

8.3 Aluminium finished production facilities, the establishment of which was based on appropriate marketing, in most cases increase the aluminium consumption of the area. This might result in the backword integration of the aluminium industry first to local semis-fabrication and maybe later to the production of metal in the country or its import within a scheme of cooperation.

8.4 Access to professional information, acquisition of technical knowledge are important features in the promotion of the development of the aluminium industry in developing countries. Among the different possibilities the following are quoted:

- Dissemination of information in developing countries, technical and commercial, e.g. papers, periodics, pamphlets, catalogues, etc.
- Visits of experts from developing countries in Aluminium Institutes, enterprises, their participation at international meetings, UN, AIME, ICSOBA, etc.
- Experts group meetings with participants from developing countries.
- Participation in trainings or group trainings organized for specialists from developing countries.
- Creation of local R + D facilities in developing countries.
- Setting up aluminium advisory services in countries desiring to promote development of the use of aluminium in different fields of applications.

9. THE ROLE OF UNIDO [2]

Since its establishment UNIDO has always made particular efforts to contribute to the development of the aluminium industry in developing countries. UNIDO operates on requests from individual governments through the programme of technical assistance. The operational activities supported by the organization of sympozia, seminars, export group meetings, workshops and the preparation of studies, papers and other documentation.

Among the objectives of the project activities carried out by UNIDO in the field of aluminium two merit special attention:

- Promotion of Research and Development Capabilities (China, India, Jamaica, Yugoslavia)
- Assistance to the establishment and operation of industrial units (China, Iraq, Indonesia, Mozabique)

Regarding supporting activities the following important undertakings of UNIDO can be quoted:

- Workshop on Case Studies of Aluminium Smelter Construction in Developing Countries
- Organization of Group Training Programmes on Alumina Production
- Confection of Studies dealing Manufactures of Semis and use of Aluminium in Developing Countries

The convening of the First Consultation in the Non-Ferrous Metals Industries represents an important milestone in UNIDO's activities in the aluminium field and it has to be reflected in the relevant programme of the Organization in the future.

Regarding operational activities it seems that the possible contribution of UNIDO in the follwoing fields would be particularly appreciated:

- Technical evaluation, laboratory testing of raw materials and other products
- Provision of expertise for efficient operation and modernisation of existing production units
- Planing, establishment of R + D units and new production facilities
- Creation of Advisory Service for Customers.

In the opinion of the drafter of the present report the follow up of the Consultation Meeting will also require a considerable expansion of the supporting activities of UNIDO principally with the objective to reveal further possibilities of the development of the Aluminium Industry in developing countries via subregional, regional and interregional cooperation. It seems to be desirable, that particular attention should be payed to the development of aluminium semis and finished products manufacturing in developing countries. Action oriented studies as well as expert group meetings should also be initiated with a view to identify the possibilities of design and manufacturing of semi-fabrication equipment more suitable for the conditions prevailing in developing countries. Improvement of the knowledge about the correlation between aluminium consumption and general development level of a given country might also be a subject of importance for UNIDO's supporting activities.

G. RECOMMENDATIONS

1. DEVELOPING COUNTRIES may wish and companies operating in these countries are invited to consider:

1.1 because of the relocation tendencies of the aluminium industry to continue bauxite exploration using up-to-date methods, particularly for deposits which are suitably located and possibly close to cheap energy resources,

1.2 only under special conditions the local processing of non-bauxite materials or low grade bauxites,

1.3 if having particularly cheap power resources the erection of a smelter even if they do not posess bauxite resources,

1.4 to follow up of the developments of the Bayer and Hall-Héroult technologies because very probably they will be prevailing in the aluminium industry at least by the end of this century,

1.5 due to the special structure of the alumina as well as the aluminium markets and the size of competitive facilities, to explore - when appropriate - all possibilities of subregional, regional and interregional cooperation, which could reasonably be conceived under fair and equitable conditions for the creation of the objects under consideration. In all cases appropriate feasibility and marketing studies are required in the decision making process,

1.6 whenever appropriate, local subregional, regional and interregional market possibilities when examining the problems related to the establishment of semis fabrication facilities. This action might be profitable - in frequent cases - even based on imported metal. Similarly, installation of production of finished goods in a country without having any fabrication facilities might lead gradually to a demand in semis which can induce later on the erection of facilities for semis production, 1.7 technological possibilities of gradual development of semis-production particularly the viable size of capacities for the fabrication of extruded and rolled products through different suitable processes,

1.8 the setting up of semi-fabrication facilities with second-hand equipment of high quality. This solution has generally also the advantage that in most cases the agreement includes the transfer of technology,

1.9 the establishment of R + D institutes for the aluminium industry and advisory service for its customers.

2. DEVELOPED COUNTRIES may wish and companies operating in these countries are invited to consider:

2.1 when establishing new production facilities in the aluminium industry or replacing for different reasons existing ones to locate them possibly in developing countries following an objective analysis of the expected production costs and on the basis of mutually advantageous agreements including financing,

2.2 to review with particular attention in the framework of relevant cooperation agreements the possibilities of involving companies operating in developing countries into the supply of aluminium semis of the market of developed countries,

2.3 to provide for developing countries information in the activities of R + D institutions, advisory services and new technological achievements in the aluminium industry which might be useful for these countries in the selection among possible realistic options,

2.4 to receive trainees from developing countries in particular in courses dealing with different problems of aluminium application.

3. UNIDO MAY WISH TO CONSIDER:

3.1 to expand its operational activities as required from authorities of developing countries,

3.2 to strengthen its supporting activities via preparation of action oriented studies and the organizaton of expert group meetings concerning the follwing important issues:

- to review possibilities of subregional, regional and interregional cooperation in the establishment of new aluminium industry objects at locations particularly suitable for this purpose,
- to identify possibilities of cooperation among different countries in the supply with aluminium semis and finished products of different regions,
- to investigate the modalities of design and manufacturing of equipment for aluminium semis production more suitable for the conditions prevailing in developing countries,
- to initiate research in order to establish a more articulated correlation between the aluminium consumption and the overall development level of a given national economy.

The present study was based first of all on technical and to a certain extent economic considerations. The tentative suggestions (Chapter G) were drafted on this basis. When establishing the recommendations of the Consultation Meeting other important issues, e.g. the present international structure of industry, transport costs, financing problems, levies, duties and other commercial aspects (like those discussed in [62],and particularly the differences in the economy of developing countries, will have also to be considered.

***

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ANNEXES

1 to 39

CONCEPT OF A METHODOLOGY FOR DEFINING APPROPRIATE TECHNOLOGY

Extracted from Biritz [5]

In a simplified form, considerations for defining appropriate industrial manufacturing technologies should proceed in the following sequence:

(a) define the product in technical terms; if more than one product variation is possible, identify and describe each;

(b) determine the markets for each product variety assuming several, reasonable price levels, and establich an order of "preliminary preferences" between the various products. Other aspects of social acceptability must also be taken into account.

(c) identify and list all process technologies for manufacturing the products;

(d) identify which process alternatives look most advantageous as regards (i) raw material availability; (ii) capital investment; (iii) labor utilization; (iv) ease of operation and maintenance; etc;

(e) define the exact economic parameters for the plant (i.e. expected profitability, available subsidies, etc.);

(f) determine all envisaged mandatory socio-political constraints (i.e. plant location, labor hours, environmental issues, etc.) and estimate the resulting added costs;

(g) determine the availability of manpower to operate the plant and its level of qualifications;

(h) review various process possibilities in the light of raw materials availability, economic, socio-political and manpower constraints and select one or more processes showing greatest promise in most requirements;

(i) break-down selected processes into individual process steps and determine which of those can be modified to minimize investment and operating costs, including allowing maximum labor utilization, if this is desired;

(j) define optimum plant size to achieve desired production rates within the context of the required, detailed feasibility study;

(k) finally, the detailed feasibility study should identify clearly all key assumptions and critical input needs (e.g. training of personnel) for successfully operating the plant after it has been built.

Annex 2

ALUMINIUM CONSUMPTION

1973 - 83
thousand tons

1. Total world consumption (primary + secondary)

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
World less CPE	13787	13901	11065	13958	14463	15334	16141	15572	15117	14861	16355
CPE countries	3020	3550	3500	3750	3900	4100	4175	4135	4115	4180	4245
Total	16809	17451	14565	17708	18363	19434	20316	19707	19232	19041	20600

2. Consumption of primary aluminium

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
World less CPE	11189	11269	8619	11095	11366	12027	12618	11969	11318	10948	12124
CPE countries	2578	2763	2840	3024	3175	3316	3374	3321	3301	3336	3342
Total	13767	14059	11459	14119	14541	15343	15992	15290	14619	14284	15466

3. Consumption of secondary aluminium

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
World less CPE	2598	2705	2446	2863	3097	3307	3523	3603	3799	3913	4231
CPE countries	444	687	660	726	725	784	801	814	814	844	903
Total	3042	3392	3106	3589	3822	4091	4324	4417	4613	4757	5134

Note: Primary consumption of World less CPE countries in 1984: approx. 12450 th.tons

Reference: [6]

Annex 3

CAPACITIES OF METALLURGICAL GRADE ALUMINA PLANTS PER CONTINENT IN 1984

in Thousand tons

Europe (including Yugoslavia and Turkey but excluding CPE countries)	6445
Europe (CPE conuntries)	6755
North America	7105
Latin America	6070
Oceania	9110
Far-East (excluding CPE countries)	2772
CPE countries of Asia	920
Near-East	-
Africa	700
Total	39877

Reference: [9]
(partially revised)

Annex 4

ALUMINIUM SMELTER CAPACITIES PER CONTINENT IN 1984

in Thousand tons

Europe (including Yugoslavia and Turkey but excluding CPE countries)	4008
Europe (CPE countries)	3735
North America	5933
Latin America	1059
Oceania	847
Far-East (excluding CPE countries)	1292
CPE countries of Asia	569
Near-East	377
Africa	622
Total	18432

Reference: [9]
(partially revised)

ALUMINIUM SEMI-FABRICATION CAPACITIES PER CONTINENT IN 1983

in Thousand tons

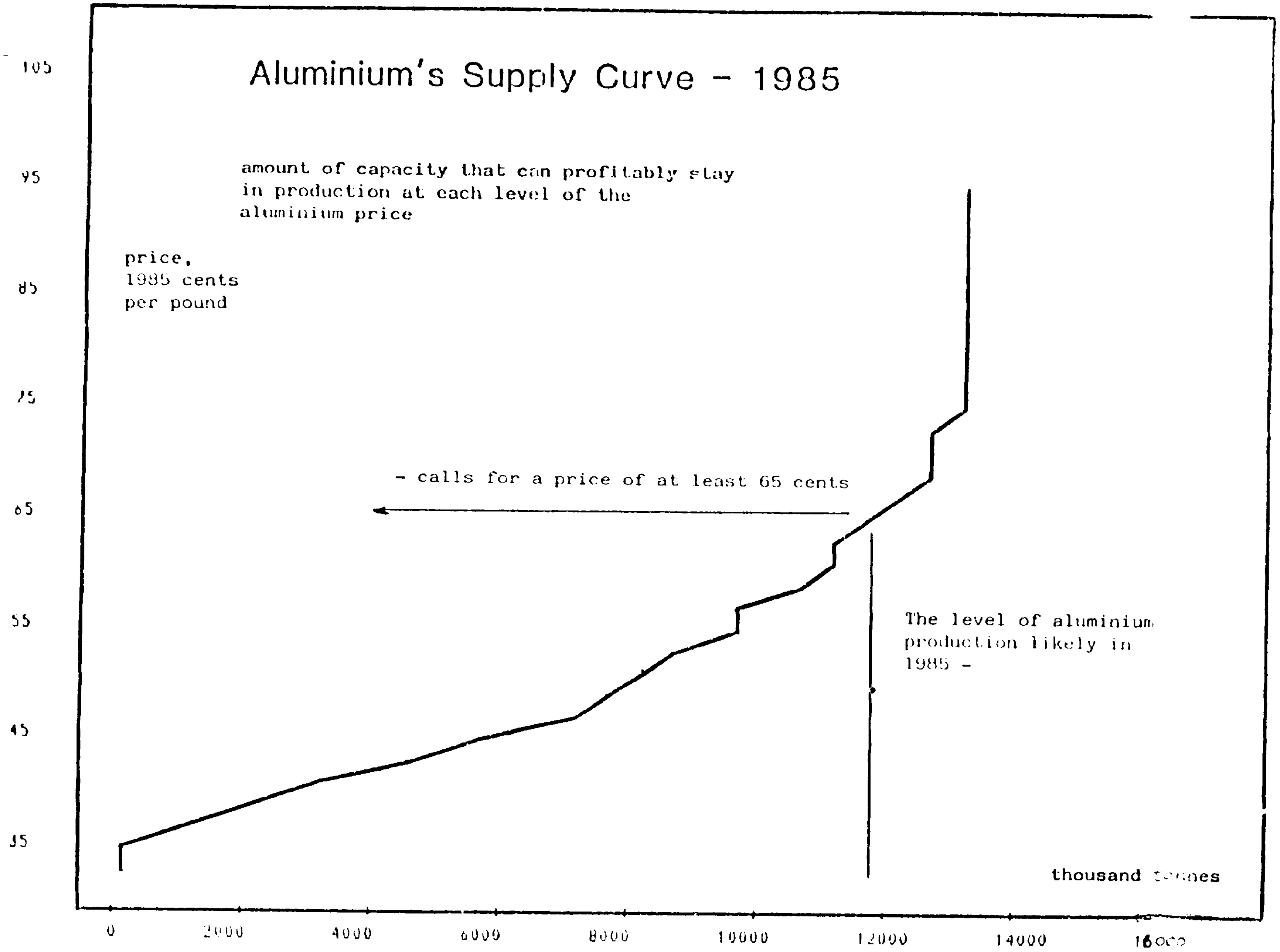
Europe (including Yugoslavia and Turkey but excluding CPE countries)		5103.5
Europe (CPE countries)	appr.	3500.-*
North America		7910.5
Latin America		653.5
Oceania		322.5
Far-East (excluding CPE countries)		2667.6
CPE countries of Asia	appr.	570.-*
Near-East		160.6
Africa		239.9
Total		21127.9

Notes: * estimated

- only primary semi-fabrication taken into consideration, i.e. only hot-rolling, but not cold-rolling and no foil capacities; extrusion and rod-manufacturing capacities included, but not wire manufacturing. Does not include casting capacities!

Reference: [10] (partially revised), [40]

Annex 6



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Annex 7

EXPECTED ANNUAL GROWTH OF RATES
1990-95

	in industrial production	in aluminium consumption
USA	4.6 %	4.0 %
Japan	5.8 %	4.8 %
France	4.8 %	4.8 %
Germany	3.8 %	3.1 %
Italy	4.8 %	3.8 %
UK	3.4 %	-0.2 %
Other Europe*	4.1 %	3.8 %
Europe total*	4.1 %	3.4 %
Rest of world*	no data given	5.4 %
World*	4.6 %	4.2 %

Note: * MEC-s only

Reference: [8]

Annex 8

WORLD BAUXITE RESOURCES, CLASSIFIED ACCORDING TO THEIR STATE OF DEVELOPMENT

Country/continent	Identified Resources					Undiscovered resources
	Developed		Undeveloped		Total	Hypothetical Speculative
	Mineable reserves	Potential ores	Reserves	Potential ores		
Australia	1,215	2,175	1,030	1,980	6,400	
Guinea	1,210	250	3,345	13,990	18,795	
Cameroon	-	-	680	1,320	2,000	
other Africa	50	-	720	1,885	2,655	
Africa	1,260	250	4,745	17,195	23,450	
Brazil	620	-	850	3,030	4,500	> 50,000
Jamaica	1,800	-	-	600	2,400	
Surinam	200	-	200	1,570	1,970	
Guyana	90	250	-	820	1,160	
other America	65	5	295	2,325	2,690	
America	2,775	255	1,345	8,345	12,720	
India	50	-	1,070	1,495	2,615	
Indonesia	40	40	500	500	1,080	
other Asia	35	5	160	790	990	
Asia	125	45	1,730	2,785	4,685	
Europe	805	345	-	325	1,475	
Western World	6,180	3,070	8,850	30,630	48,730	
State trade countr.		not classified			1,960	
World Total					50,690	> 50,000

Reference: [15]

Annex 8

Annex 9

CLASSIFICATION SYSTEM FOR BAUXITE RESOURCES

Resources			
Developed		Undeveloped	
Mineable Reserves	Potential Ores	Reserves	Potential Ores

Definitions:

Resources: Concentration of bauxite in or on the Earth's crust in such form that economic exploration is currently or potentially feasible. Resources = Reserves + Potential Ores.

Developed Resources: Bauxite deposits/areas currently under exploitation.

Undeveloped Resources: Known bauxite deposits/areas of bauxite, from which an economical exploitation can be expected in future.

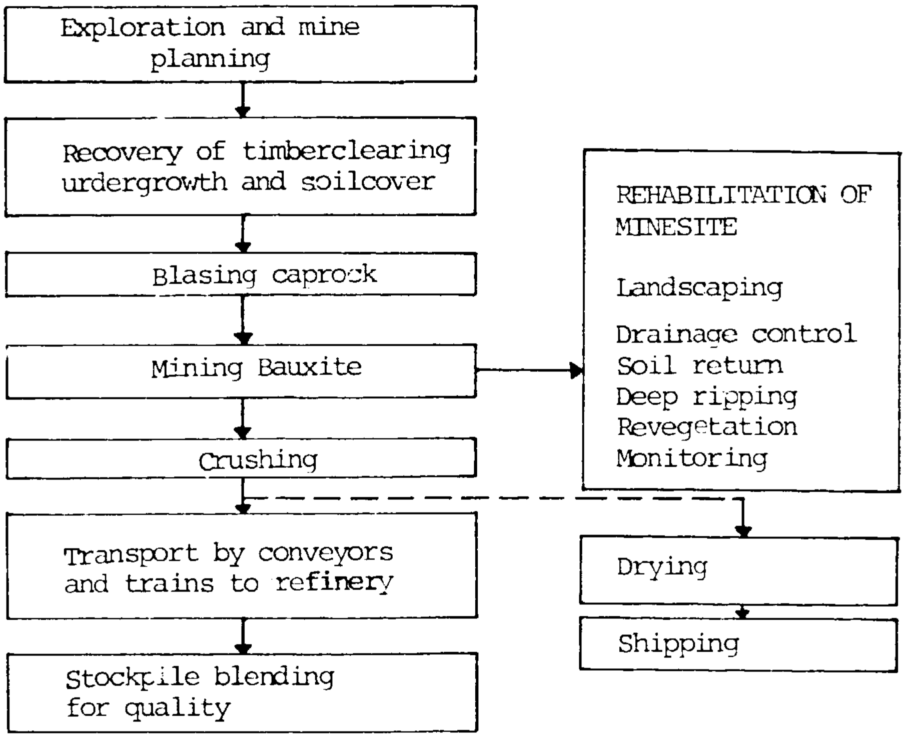
Reserves: That portion of resources from which bauxite is currently economically exploited under existing conditions, including cost, quality, geologic evidence and technology (category: Mineable Reserves of Developed Resources) or economical exploitation will be expected in future (category: Reserves of Undeveloped Resources).

Potential Ores: That portion of resources in the continuity of known deposits which are insufficiently explored at this time and for which quantitative estimates are based largely on broad knowledge (category: Potential Ores of Developed Resources) or that portion of subeconomic resources which may become reserves as a result of changes in economic conditions or after further exploration (category: Potential Ores of Undeveloped Resources).

Reference: [19]

Annex 10

MAIN PHASES OF THE BAUXITE MINING FROM EXPLORATION TO REFINERY'S GATE /AFTER ALCOA OF AUSTRALIA's LEAFLET/



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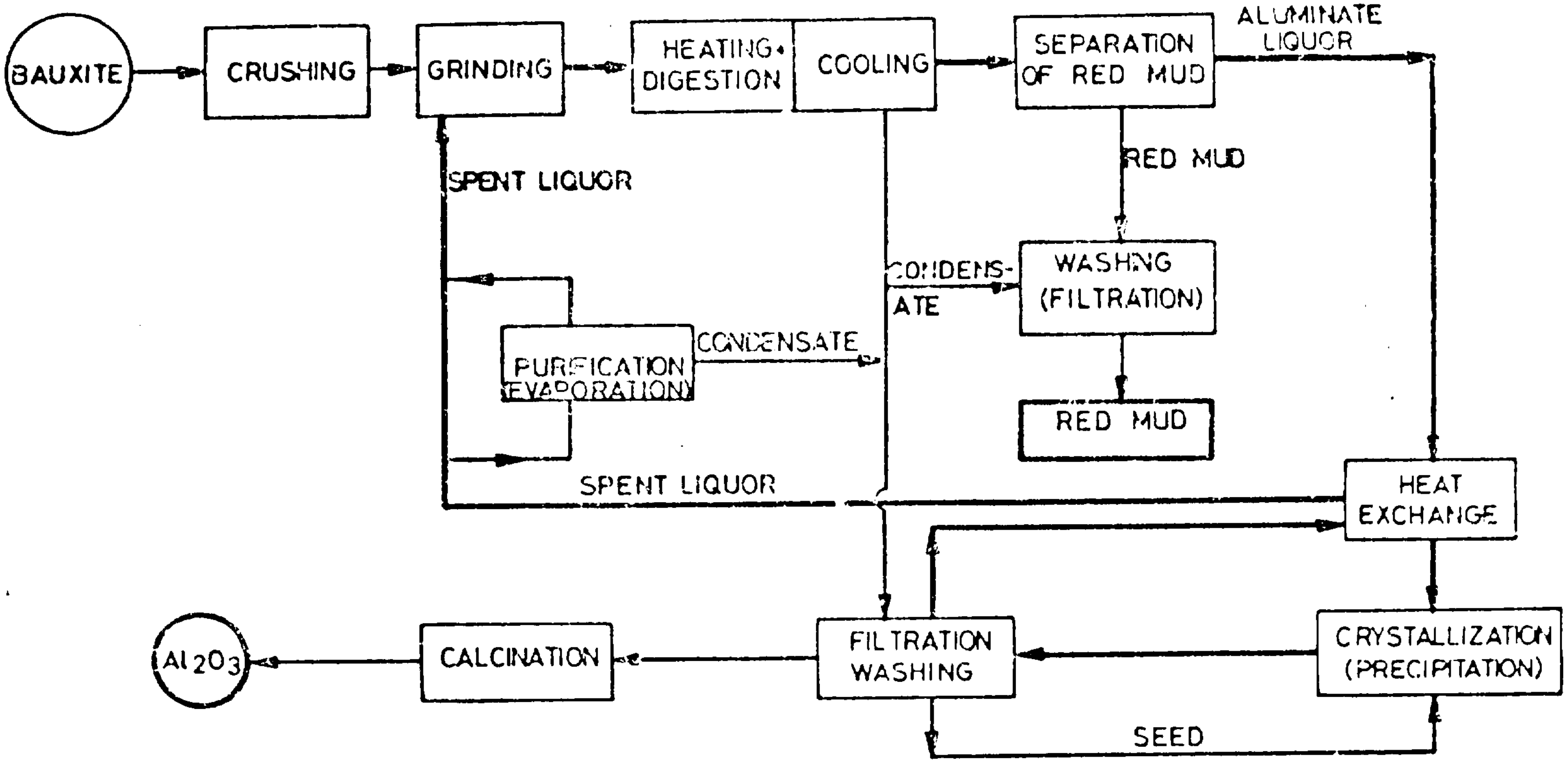


OPERATION UNITS OF THE BAYER PROCESS

CHARACTERISTICS OF FLOURY AND SANDY ALUMINA

	Sandy alumina	Floury alumina
Grain distribution %		
+ 150 µm	< 5	-
75-150 µm	60	10
45- 75 µm	25	40
- 45 µm	< 10	50
Specific surface		
m^2/g	> 30	5-10
Alfa Al_2O_3 content %	< 30	50-70
Angle of repose		
degree	~ 30	40-50
LOI %	~ 1	~ 0,5

Annex 13

CAPITAL COST FOR ALUMINA REFINERIES

(US$ 1980)

Total capital cost including infrastructure and location factors.

Refinery Size (Million tons per year)	Capital Cost (Million US$)
0 - 2.0	pf x lf x (330 + 720 x size)
2.0 - n x 2.0	pf x lf x (885 x size)
n x 2.0 -	pf x lf x (1,062 x size)

where pf: process factor

Process	Process Factor
American Bayer	1.0
Modified A. Bayer	1.06
European Bayer	1.12
Soda-Sinter	1.30

lf: location factors from Table 13.

n: diseconomy of scale factor, between 2 and 5 depending on location.

Sources: Woods, D. "Financial Decision Making in the Process Industry," Prentice Hall, New Jersey, 1975.

World Bank consultant.

Copied from: [11]

Annex 14

PRODUCTION COSTS OF SELECTED ALUMINA PLANTS (USD/t ALUMINA)

		Capacity th. tpy	Bauxite	Other material	Energy	Wages etc.	Total variable	Capital charges	Total
A. Old plants									
AoA Pinjara	Austr.	2600	26.3	13.7	56.9	39.6	136.1	41.2	177.3
Gove	Austr.	1200	25.1	14.8	54.0	36.9	130.7	49.6	180.3
VAW Lünen	GFR	430	82.1	5.6	43.8	37.7	169.2	17.4	186.6
PUK Gardanne	Fr.	710	82.0	9.6	46.0	37.9	175.5	17.5	193.0
Alcoa Pt.C.	USA	1320	80.2	5.1	50.1	42.9	178.3	17.3	195.6
Friguia	Guinea	630	26.7	8.9	92.7	47.8	176.1	39.6	215.6
Alox Stade	GFR	650	73.6	12.1	46.7	40.0	172.4	43.8	216.1
Jamalco	Jam.	495	77.0	8.6	73.3	44.3	203.1	41.5	244.6
Eurallumina	Italy	720	80.9	16.6	67.9	45.1	210.4	48.8	259.2
K.BatonRouge	USA	930	100.5	10.6	66.7	56.5	234.3	41.2	275.5
B. New plants									
Worsley	Austr.	1000	30.8	13.9	44.0	35.8	124.4	135.8	260.7
Interalum.	Venez.	1000	77.7	11.4	17.5	47.2	153.8	131.3	285.0
AlumEsp.	Spain	800	84.0	6.3	47.0	33.0	170.7	130.5	301.2
NALCO*	India	800	39.5	18.0	72.1	33.9	163.5	175.6	339.0
Aunghinish	Ireland	800	86.9	5.6	50.0	39.3	181.8	179.5	361.3
Alumar	Brasil	500	79.7	15.9	53.0	41.4	189.8	172.6	362.5

Note: * expected values only

Reference: [26]

DESCRIPTION OF SOME NON-BAYER PROCESSES

1. Sintering process

On course of the sintering process bauxite or other aluminium-ferrous materials are blended with soda and lime and on treating it at 1350 °C the Al_2O_3 content of same is converted to sodium aluminate, capable of being dissolved with low-concentrated soda solution. After leaching the sinter, the solution is separated from the insoluble residue and desilicated. The clarified solution is carbonated by the introduction of CO_2-gas. Aluminium hydroxide crystals are washed and calcined while soda solution is recycled to the process.

2. Combined processes

a) The paralelly combined process is used in cases the bauxite processed can be separated into two sorts of ores containing different percentage of silica. In such cases high silica bauxite is sintered by the soda-lime process and the solution resulting after leaching is added to the aluminate liquor of the Bayer branch.

b) A combination of the Bayer and sintering process in series is also used. In this case first the bauxite is processed by the Bayer process, thereafter the red-mud is sintered with a view to regenerate the alumina contained in it.

3. Nepheline processing

This technology results in alumina, soda, potassium salt and cement as products. The process starts with lime sintering, where the soda needed for the formation of soluble aluminate is available in the processed rock itself. The recovery of alumina and alkali from the sinter is performed by a two-stage digestion, followed by desilication, carbonization, hydrate separation and calcination. After carbonating the solution, soda and potassium salts are crystallized. The mud, containing calciumsilicate is used for cement production.

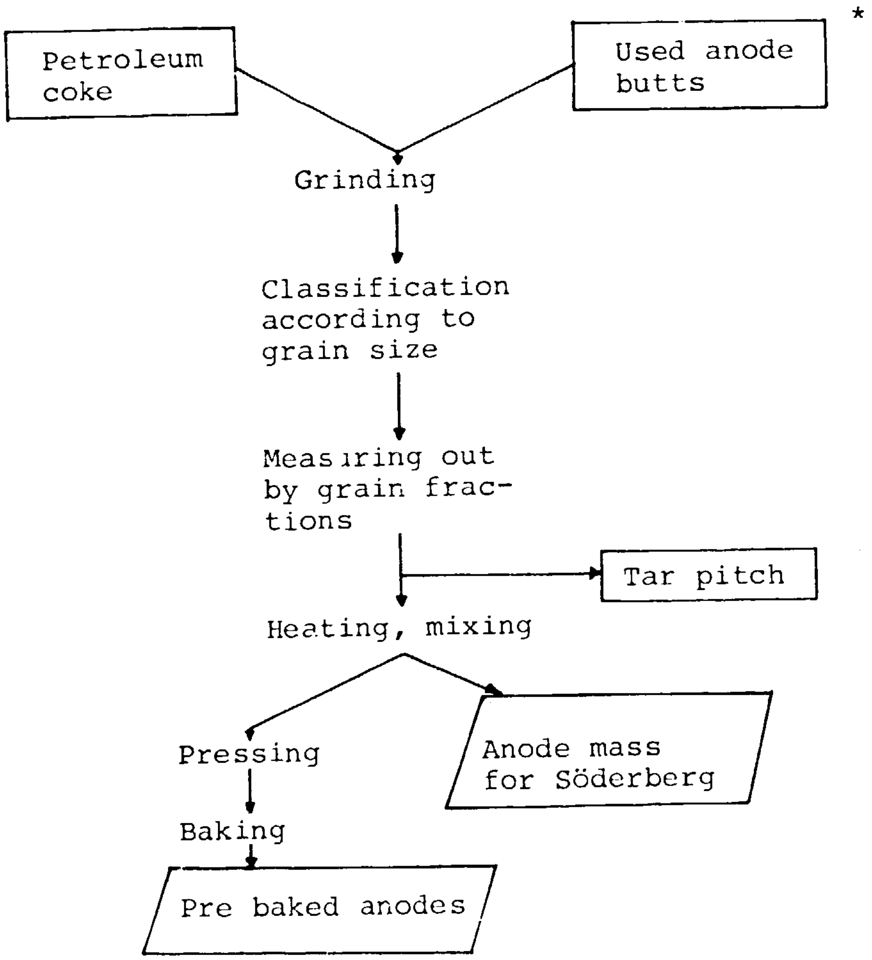
4. Alunite processing

The ore is roasted in two reactors in a fluidized bed. In the first phase an oxidizing atmosphere is used, while aluminium sulphate is decomposed by a reducing gas in the second phase. The gas products of the reaction are used to produce Sulfuric acid, while the reduced alunite is processed according to a modified Bayer technology for the recovery of alumina and sulfate salts.

About the economy of these processes see: [29]
Reference: [29]

Annex 16

FLOW SHEET OF ANODE PRODUCTION



* where applicable

Annex 17

INPUTS FOR ALUMINUM SMELTERS

(Per metric ton of aluminum)

	Prebaked System
Alumina, metric tons	1.93
Power, Kwh /a	13,500 - 14,300 (1980) 13,160 (1985) 12,800 (1990) 12,600 (1995-2000)
Labor, man-hours	8.6
Thermal energy - million Btu	4.4
Coke, metric tons	0.375
Fluorides, /b kilograms	30
Pitch, metric tons	0.10
Other costs (maintenance, overhead) US$ 1980	220

/a We assume, as Anthony Bird Associates, an improvement on electrical energy productivity of 0.5% a year.

/b Cryolite and aluminum fluoride.

Sources: Woods, Douglas and James C. Burrows, "The World Aluminum-Bauxite Market," Praeger, 1980.
Company data.
Anthony Bird Associates, Aluminum Annual Review, February 1981.
World Bank consultant.

Copied from: [11]

Annex 18

Copied from: [11]

COST OF ELECTRIC POWER FOR ALUMINUM SMELTERS
(COSTED AT GENERATING SITES)

(US$ 1980 kilowatt hour)

	Existing Low Cost	Possible Low Cost For New Smelters	Higher Cost Electricity (coal or nuclear) /a
United States West	.02 /b	-	.05
United States East	.024	-	.05
Canada West	.004	.03	.05
Canada East	.004	.03	.05
Jamaica	-	-	.05
Central America/Caribbean	-	.02	.05
Guyana	-	.02 /c	.05
Suriname	.0045 /d	.03	.05
Brazil	.02	.02	.05
Argentina	.008	.03	.05
Venezuela	.026 /e	.03	.05
Western Europe	.020	-	.05
Eastern Europe	.02	-	.05
Asian USSR	.02	.02	.05
Oceania	.012	.02	.05
ASEAN	-	.02	.05
Korea, R. Taiwan	-	.02	.05
China	.02	.02	.05
Japan	.02	-	.05
India	.02	.03	.05
Rest of Asia	.02	.03	.05
Middle East	.003	.02	.05
Northern Africa	.02	.02	.05
Ghana/Other West Africa	.0048 /g	.02	.05
Guinea	-	.02	.05
Zaire	-	.006 /h	.05
Rest of East Africa	-	-	.05
South Africa	.02	-	.05

/a See: World Bank, "Energy in the Developing Countries," August 1980, p. 43; also see Murray Lester, "The Outlook for Power in the Aluminum Industry," Light Metal Age, June 1980, p. 26. The capital cost of a coal power plant is about US$1600/kw; considering a real rate of return of 10-15% and dividing by 7000 kwh/kw the capital cost component of coal generated power would be in the range of US$0.02/kwh to US$0.03/kwh. If we add the cost of coal we obtain a total cost range of US$0.05/kwh - 0.06/kwh depending on coal mining costs, quality and transport cost.

/b Bureau of Mines, U.S. Department of the Interior, "Minerals and Materials--a Monthly Survey," July 1981, Washington, D.C., page 2.

/c IBA Review, September 1977, p. g, cites from 5-6 to 10 mils/kwh.

/d According to the Brokopondo Agreement between the Suriname Government and Suralco.

/e Metal Bulletin, February 17, 1981, p. 15.

/f Metal Week, January 19, 1981, mentions that power from the Asahan River will cost US$0.012/kwh.

/g Ghana US$0.0048/kwh, Cameroon US$0.01/kwh.

/h Project which would use electricity from the existing power plant.

Source: See footnotes above. Electricity generated with flared gas considered at US$0.02/kwh, hydroelectricity priced at US$0.02/kwh for high head rivers and at US$[illegible]/kwh for low head rivers.

Annex 19

Copied from: [11]

ELECTRICITY SUPPLIES AVAILABLE FOR ALUMINUM SMELTING

(Gigawatt hours per year)

	Currrent /a Low Cost	New /b Low Cost
United States West	23,500	-
United States East	21,300	-
Canada West	3,700	13,100
Canada East	11,700	3,000 /e
Jamaica	-	-
Central America/Caribbean	300	9,600
Guyana	-	1,700
Suriname	890	440
Brazil	3,800	26,200
Argentina	1,900	26,800
Venezuela	5,500	13,600
West Europe	37,900	-
East Europe	32,700	-
Asian USSR	14,700	4,800
Oceania	7,200	29,600
ASEAN	-	15,700
Korea - Taiwan	-	-
China	5,531	1,730
Japan	3,900	-
India	2,850	16,200
Rest of Asia	850 /c	4,200
Middle East	4,100	78,900
North Africa	1,800	9,900
Ghana - Rest of West Africa	3,600	39,600
Guinea	-	5,600
Zaire	-	2,400 /d
Rest of East Africa	-	-
South Africa	1,100	-

/a Estimated from Bureau of Mines, U.S. Department of the Interior, "Primary Aluminum Plants, Worldwide," Washington, D.C., 1981. Such report gives the sources of electric power for each aluminum plant. The low cost power is considered only as that generated by hydroelectric sources, coal and natural gas for oil exporting countries. The electric power available was estimated as Plant Capacity (thousand mt) x 0.95 (capacity utilization rate) x 14.3 gigawatt hours/thousand mt.

/b The figures shown here correspond to 10% of new hydropower potential 25% of flared gas plus 15,000 gigawatt hours considered for Australian coal (see Table 4).

/c Turkey.

/d Only currently available power.

/e Power considered available for smelters.

Sources: see footnote /a

Copied from: [8]

AUSTRALASIA

AUSTRALIA

LOCATION CASE STUDY - NEW PLANT

DATES FROM 1987
POWER COAL
ALUMINA LOW COST BAND

PROCESS PREBAKED
SOURCE ON POWER COSTS ABA ESTIMATE

MATERIAL	QUANTITY	PRICE	1985 COST	1987 COST	1989 COST	1991 COST	1993 COST
ALUMINA	1.925			585.2	629.5	659	671.3
PETROLEUM COKE	0.34			49.2	53.8	58.7	64.1
PITCH	0.09			32.8	32.8	32.8	32.8
OTHER MATERIALS				144.6	144.6	144.6	144.6
PRODUCTION LABOUR	4.1			54.6	57.3	60.2	63.3
MAINTENANCE LABOUR	1.9			25.4	26.7	28	29.5
ELECTRICITY	13693			385.1	408	429.8	450.5
MAINTENANCE MATERIALS				41.3	4.13	20.65	37.17
SALES AND ADMIN	1.4			22.5	23.6	24.8	26.1
LABOUR BENEFITS				51.2	53.8	56.5	59.4
DELIVERY				82.6	82.6	82.6	82.6
WORKING CAPITAL				32.3	33.2	35	36.4
TOTAL VARIABLE COST				1506.8	1550	1632.7	1697.7
CAPITAL SERVICING (CCA)				490.8	490.8	490.8	490.8
TOTAL COST (CCA)				1997.6	2040.8	2123.5	2188.5
CAPITAL SERVICING (HCA)				534.7	458.2	392.4	336
TOTAL COST (HCA)				2041.5	2008.2	2025.1	2033.7
MEMORANDUM ITEMS ------							
ALUMINA PRICE			182.6	304	327	342.3	348.7
ELECTRICITY COST MILLS PER KWH			18.3	28.1	29.8	31.4	32.9
WAGE RATE $ PER HOUR			8.27				
TOTAL MAN-HOURS PER TONNE			7.4				
ASSUMED DEBT RATIO			51.5 PCT				
HCA CAPITAL COST			4545.7 DOLLARS PER TONNE ASSUMED				

Annex 20

Copied from: [11]

Annex 21

ALUMINUM PRODUCTION COSTS AT SELECTED SITES, YEAR 2000 (New Plants)

(US$1980/metric ton)

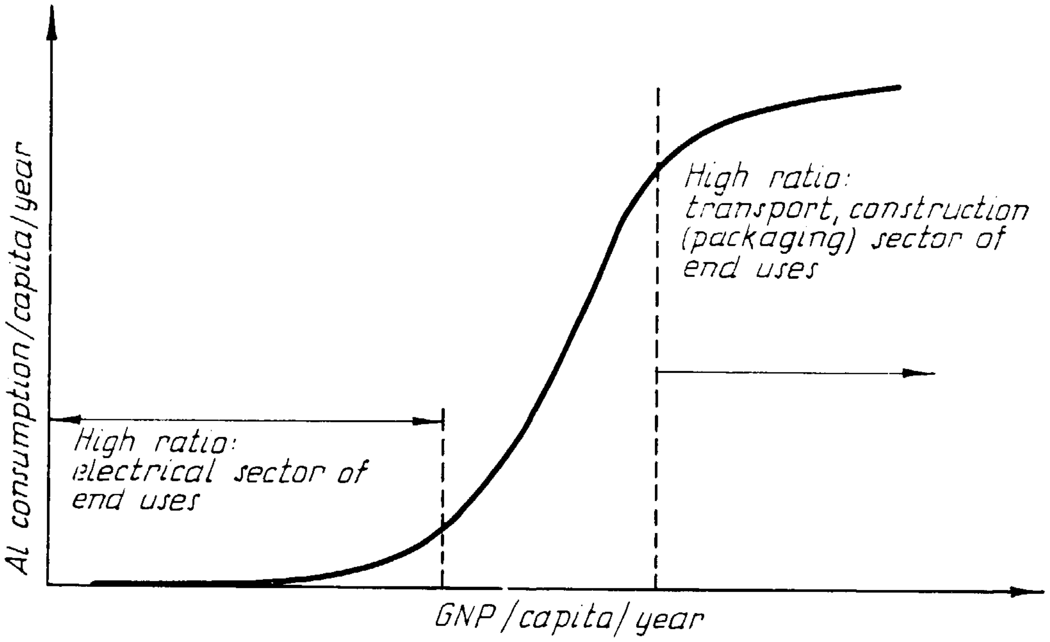
	United States	Canada	Brazil	Western Europe	Australia	Middle East	Japan
Alumina	620	620	575	670	560	580	600
Power	630	400	270	630	270	270	630
Labor	95	95	50	95	95	95	95
Thermal Energy	33	33	33	33	33	33	33
Coke	252	252	252	252	252	252	252
Fluorides	25	25	25	25	25	25	25
Pitch	25	25	25	25	25	25	25
Other	220	220	220	220	220	220	220
Capital charges /a	360	360	410	360	390	440	390
Total in US$/mt	2,260	2,030	1,860	2,310	1,870	1,940	2,270
in US$/lb	1.02	0.92	0.84	1.05	0.85	0.88	1.03

/a For a 200,000 ton per year smelter.

Source: Computed from Tables 18 to 23; Alumina costs from Table 17.

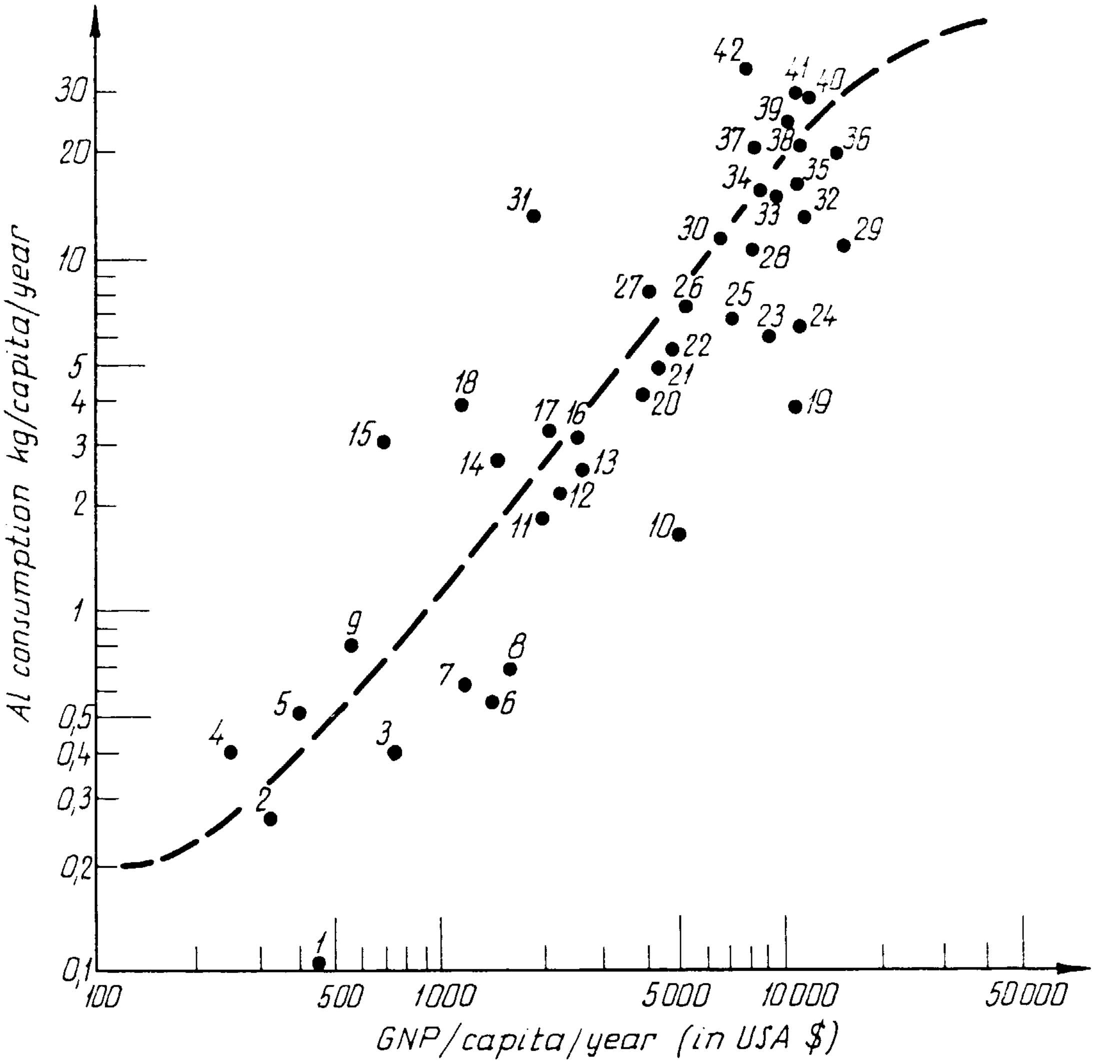
Annex 22

SIMPLIFIED DIAGRAM OF ALUMINIUM CONSUMPTION IN FUNCTION OF GNP



Annex 23

PER CAPITA Al CONSUMPTION IN FUNCTION OF GNP
(valid for 1981)



1. Indonesia
2. Pakistan
3. Philippines
4. India
5. Ghana
6. Turkey
7. Colombia
8. Malaysia
9. Egypt
10. Ireland
11. Mexico
12. Portugal
13. South Africa
14. South Corea
15. Taiwan
16. Argentina
17. Brazil
18. Cameroon
19. Denmark
20. Venezuela
21. Hong Kong
22. Israel
23. Finland
24. Netherlands
25. New Zealand
26. Spain
27. Greece
28. United Kingdom
29. Sweden
30. Italy
31. Hungary
32. France
33. Australia
34. Austria
35. Canada
36. Switzerland
37. Japan
38. Federal Republic of Germany
39. Belgium
40. Norway
41. United States
42. Bahrain

Annex 24

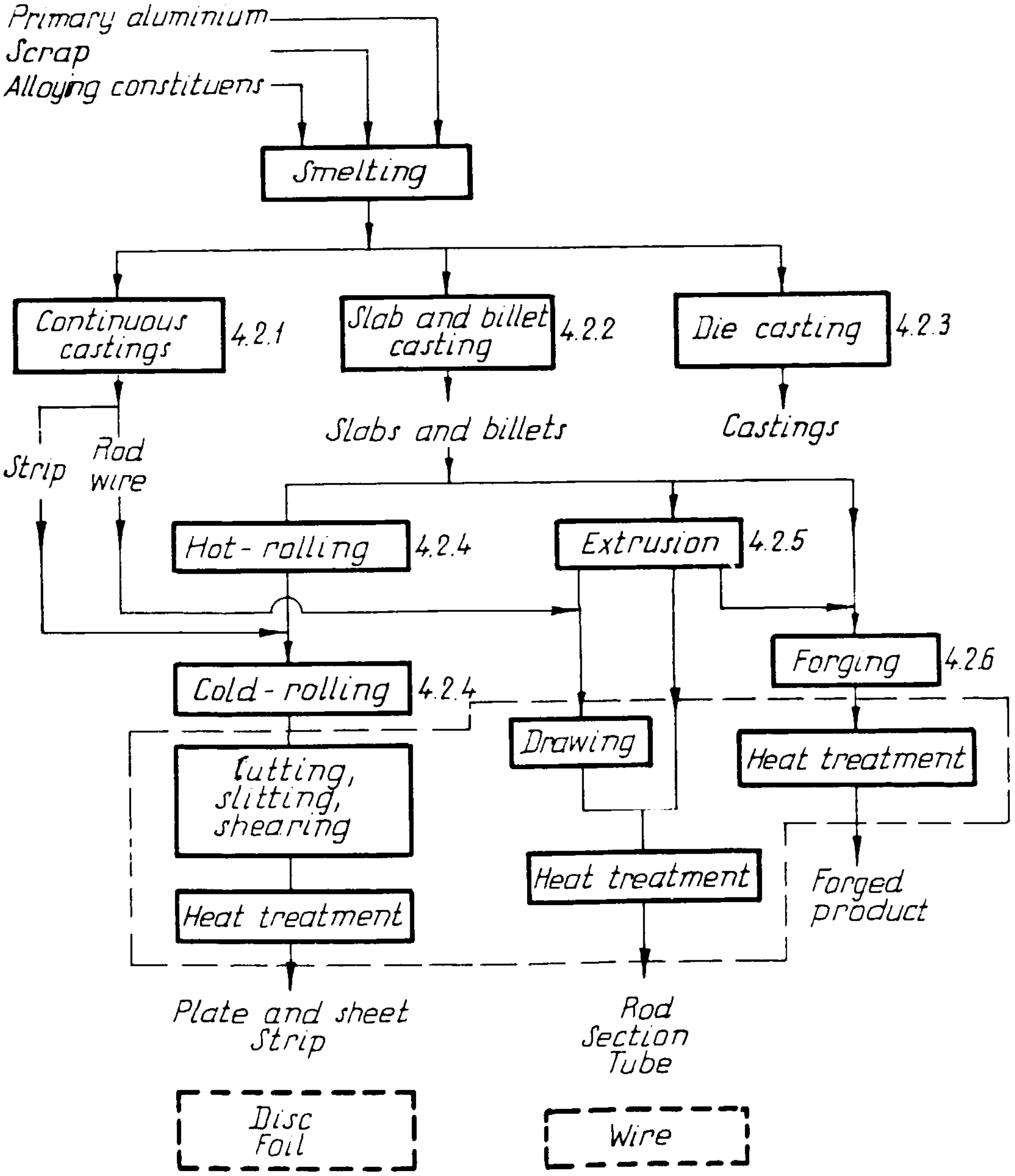
RELATIVE PRICE OF DIFFERENT SEMIS

Aluminium ingot	100 %
Continuous-cast rod wire coils	115 %
Continuous-cast strip coils	120-125 %
Unalloyed and weakly alloyed strip coils of 1.5-0.7 mm thickness	130 %
Thin strip of commercial quality	140 %
Thin strip of special quality /minimum/	150 %
Foil of commercial quality	180 %
High-finish foil	210-250 %
Low-alloyed extruded sections	180-220 %
Low-alloyed extruded sections of anodized surface	220-250 %

Reference: [41][42]

Annex 25

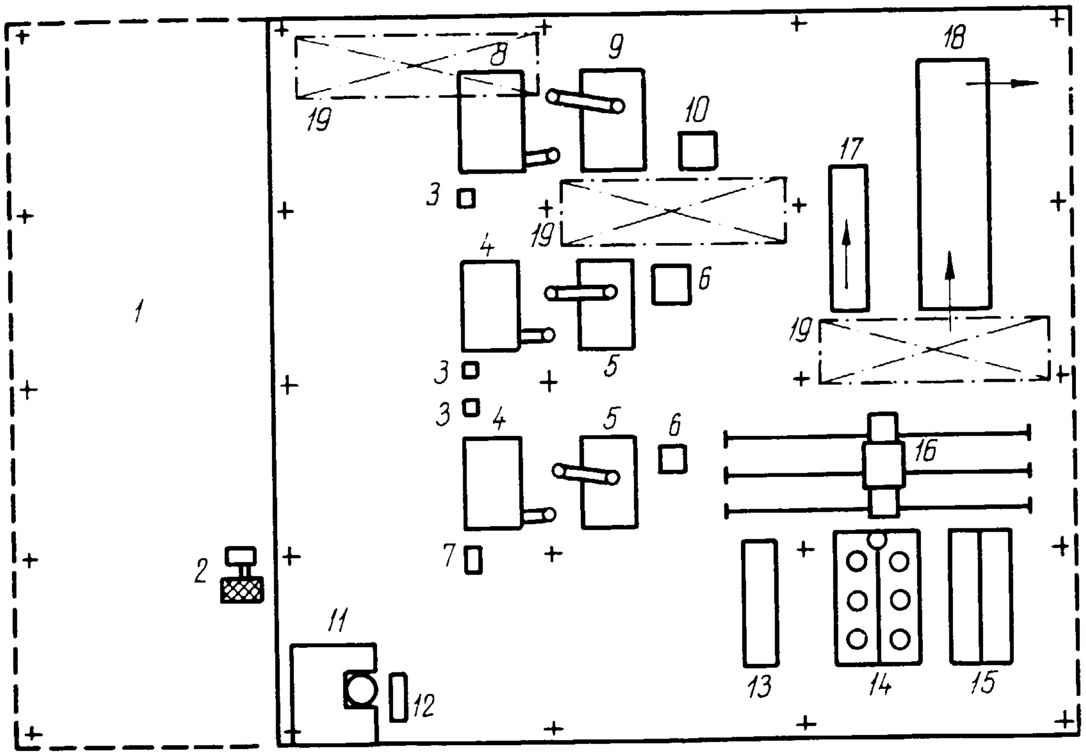
PRINCIPAL TECHNOLOGICAL OPERATIONS AND PRODUCTS OF SEMI-MANUFACTURING



Annex 26

TRADITIONAL SLAB AND BILLET CASTING SHOP WITH VERTICAL CASTING MACHINES

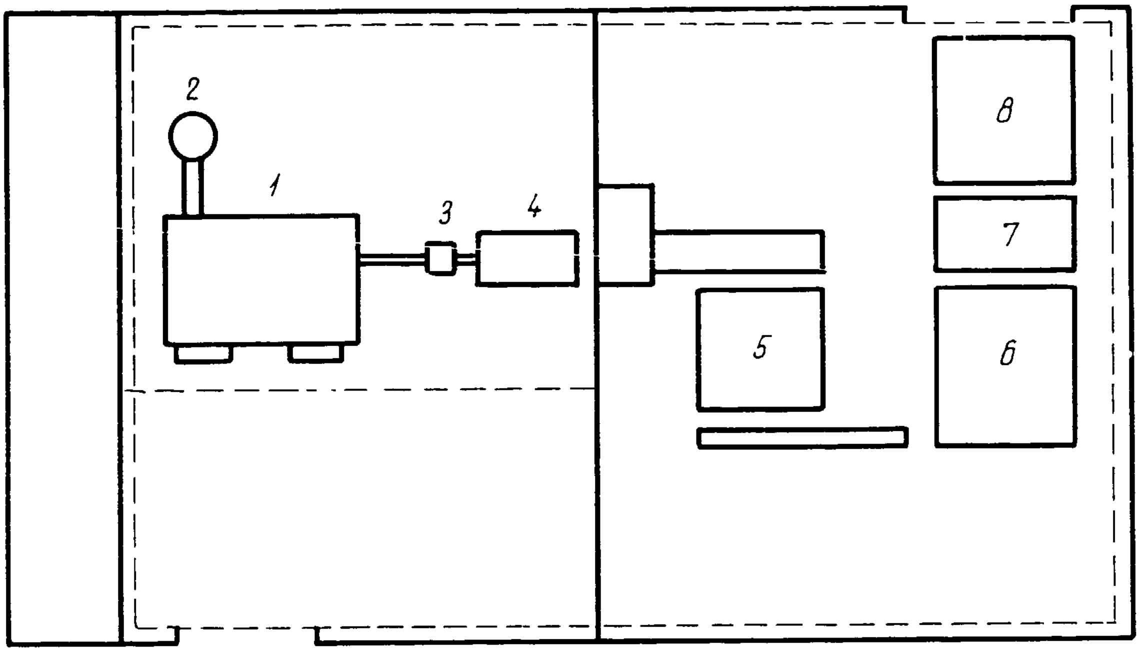
(capacity above 10,000 tpy)



1. Covered storage area for logs (base material)	10. Casting machine
2. Electronic platform scale (weigher)	11. Induction furnace (master alloy production)
3. Slag separator	12. Pig casting chain
4. Melting furnace	13. Charge preparation station
5. Casting furnace	14. Homogenizing furnace
6. Casting machine	15. Cooling bench
7. Landle preheating	16. Push Bench
8. Melting furnace	17. Billet machining lathe
9. Casting furnace	18. Billet -cutting saw
	19. Overhead crane

Reference: [42]

CASTING SHOP WITH HORIZONTAL BILLET CASTING MACHINES
(capacity about 5,000 tpy)



1. Melting and casting furnace	5. Intermediate storage place
2. Recuperator	6. Continuous homogenization furnace
3. Meltfilter	7. Billet-cooling area
4. Horizontal billet-casting equipment	8. Billet Discharge pallet

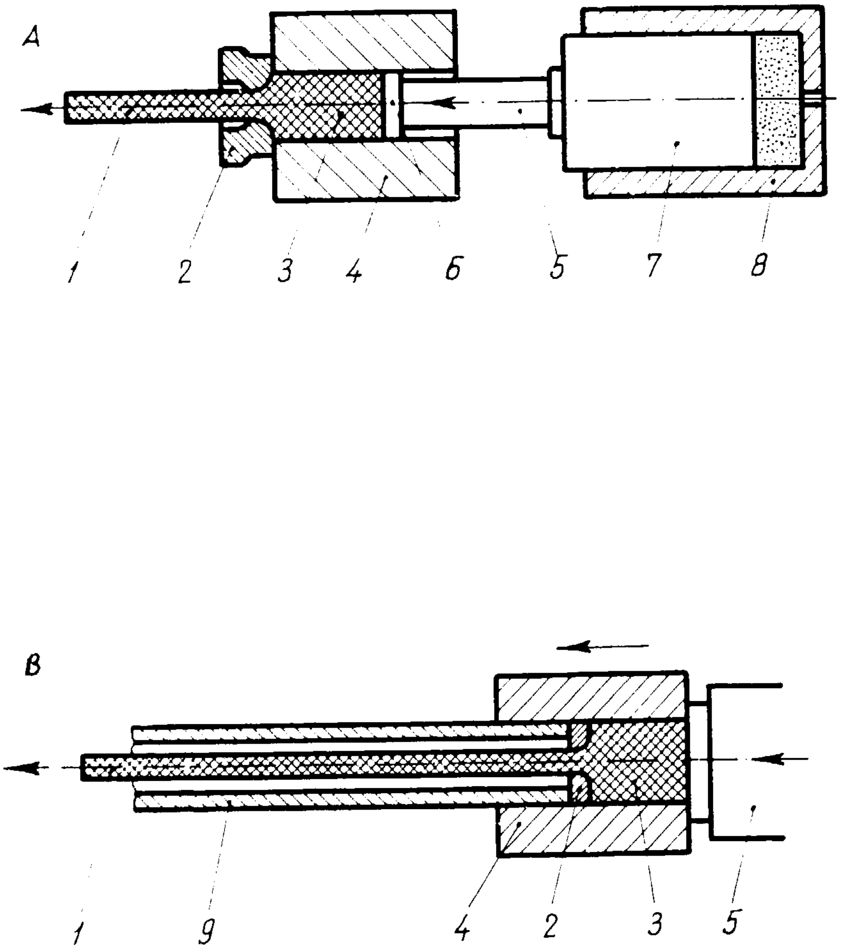
Reference: [44]

SUMMING-UP SOME FEATURES OF ROLLING MILLS

Type of plant	Production related to labour tons/head and year	Production related to operating area tons/m^2 and year
Small and medium-size plant, wide product mix, individual rolling mills. Annual production 30,000-120,000 tons	60 - 80	0.9 - 1.5
Large rolling mill, moderate product mix, multi-stand hot-rolling line. Annual production 120,000-180,000 tons	120 - 180	1.3 - 1.8
Target rolling mill, narrow product mix, tandem rolling lines. Annual production 150,000-300,000 tons	240 - 300	1.6 - 2.5

Reference: [42]

SCHEMATIC DIAGRAM OF DIRECT (A) AND INDIRECT (B) EXTRUSION

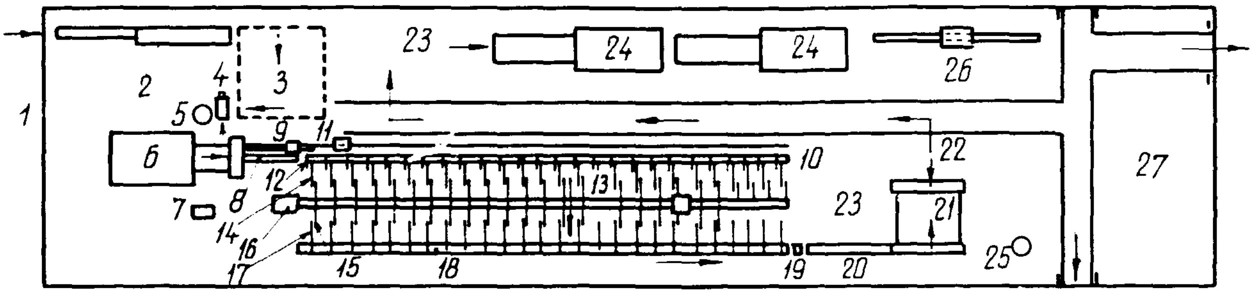


1. product
2. die
3. billet
4. container
5. pressing rod
6. pressing disk
7. ram
8. pressing cylinder
9. stem

Reference: [46]

Annex 30

LAYOUT OF EQUIPMENT IN AN EXTRUSION PLANT



1. Sloped rack for storage of logs, storage of logs and billets,
2. Gas or oil fired log-, billet preheating furnace,
2a. Induction billet preheating furnace,
3. Homogenizing chamber,
4. Hot billet shear,
5. Billet water cooler,
6. Extrusion press,
7. Die preheating furnace,
8. Initial table,
9. Hot cutting saw or shear,
10. Run-out table,
11. Puller,
12. Lift transfer to the cooling table,
13. Cooling table,
14. Transfer conveyor over the cooling table,
15. Transfer conveyor to the stretcher,
16. Stretcher,
17. Transfer conveyor to the saw table,
18. Saw table,
19. Cutting saw,
20. Saw gauge table,
21. Inspection table,
22. Palletizing,
23. Product storage before heat treatment,
24. Aging oven,
25. Wire drawing machine,
26. Profile rolling machines,
27. Product storage before anodizing.

COST OF INSTALLING CAPACITIES FOR PROCESSING THE SAME TONNAGES OF SEMI-FABRICATED AND FINISHED ITEMS COMPARED TO SMELTERING´

(Index of smeltering =100)

Type of plant or operation	Per cent
Aluminium smelter	100
Scrap processing (remelting)	10
Semi-manufacturing	
Continuous-cast wire	25
Continuous-cast strip	30
Cold-rolling (including rolling of continous-cast strip and foil)	170
Extrusion plant (including drawing)	140
Drop-forging plant	310
Pressure die-casting	220
Semi-manufacture finishing facilities	
Disc manufacture	1
Tube welding	10
Corrugated sheet manufacture	80
Strip-painting	35
Extrusion anodization	35

Reference: [34][47]

Annex 32

ECONOMICALLY FEASIBLE MINIMUM SIZE OF FACILITIES AND THEIR INSTALLATION COSTS

(Index of smeltering = 100)

Plant	Processed metal Per cent	Investment costs Per cent
Aluminium smelter	100	100
Finished product manufacture		
Kitchenware	0.1	0.6
Cans	2.25	7.2
Liquid gas bottles	2.0	3.6
Casks	0.4	1
Radiators	0.75	1.1
Lamp posts	1.22	1.8
Stranded wire,uninsulated conductor	4.4	0.9
Cables,insulated conductors	10	6
Containers and tanks	1.2	2
Collapsible tubes and aerosol bottles	5	6.5
Sandwich panels for the building industry	0.7	0.6
Portals, small buildings	1.0	0.4
Furniture frame,ladder, scaffolding	0.8	0.2

Reference: [47]

Annex 33

Copied from: [49]

MAIN TASKS OF THE TECHNICAL IMPROVEMENTS OF ALUMINA PRODUCTION

Main directions of R + D	Targets	Possible solutions
1. Improvement of efficacy of precipitation by increasing the Na_2O_k concentration of the liquor	To reach good performance in precipitation while securing requested alumina qualities	Purification of solution - removal of carbonate salts and regeneration of their Na_2O contents by . crystallizing evaporation . causticization in the washing line . complex causticization - removal of organics by . feeding magnesium salts . evaporation of hydrate wash water, oxalate separation . liquor and/or salt ignition . wet oxidation Development of technology . agglomeration . hydrate classification . multistage seeding . cooling during precipitation
2. Increasing the digestion temperature at the processing of monohydrate bauxites	To improve kinetics, to reach the theoretical yield, to conserve energy, to obtain well handable red mud	In autoclaves at 240-250 °C in tube digestor at 260-280 °C

Main directions of R + D	Targets	Possible solutions
3. Increasing efficacy of existing digestion lines	To release the limitations of the equipment by increasing the temperature and by modifying the technology	Technology using additives
4. Energo-technology, increase of capital productivity, optimization of the process	To minimize production costs, to increase plant productivity	Coordination of digestion and precipitation parameters and of the quantity of water to be evaporated
5. Reduction of caustic consumption	To reduce chemical and attached losses	- Carbonate salt causticization - Red mud causiticization - Complex causticization - Hydrotermal (high temperature) treatment of red mud (in case of medium and poor quality bauxites). - Modernization of red mud washing by . modification of settlers . heavy-duty filters . up to date flocculants

ALUMINIUM CONTINUOUS FILTERING PROCESSES AND FIRMS PRODUCING THEIR EQUIPMENT

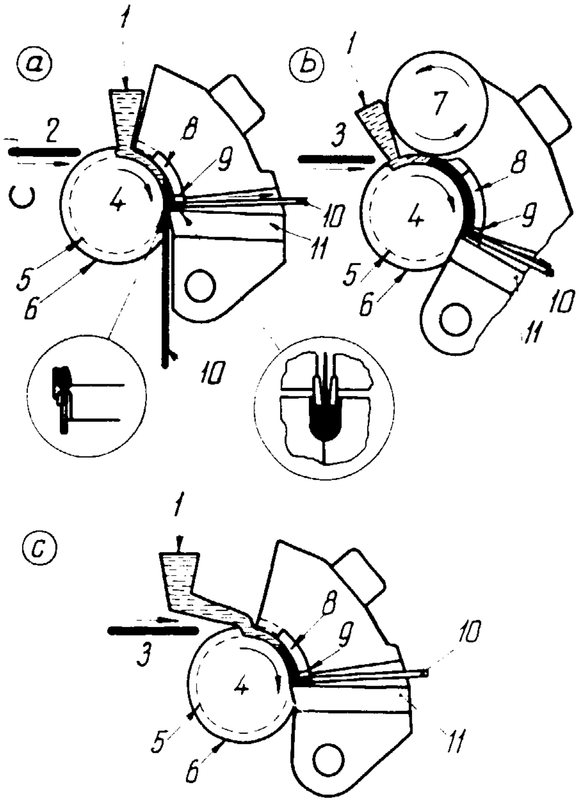
Trade name	Process name	Firm	References
SNIF	Spinning Nozzle Inert Flotation Process	Union Carbid Co.	[64]
ALPUR	-	Pechiney	[65]
MINT	-	Consolitated Aluminium Corporation	[66]
TAC	Treatment of Al in crucibles	Alcan Smelters and Chemicals Ltd.	[67, 68]

ALUMINIUM SEMI CONTINUOUS CASTING PROCESSES AND FIRMS PRODUCING THEIR EQUIPMENT

Trade name	Process name	Firm	References
LFRT	Level Feed Reservoir Top	Kaiser Aluminum	[69]
	New Hot Top	Showa Aluminium Industries	[70]
	Maxi Cast	Wagstaff Co.	[71]
EMC	Electro-magnetic casting	Swiss Aluminium Ltd.	[72]

Annex 36

OPERATIONAL ARRANGEMENTS OF CONFORM EXTRUSION MACHINE



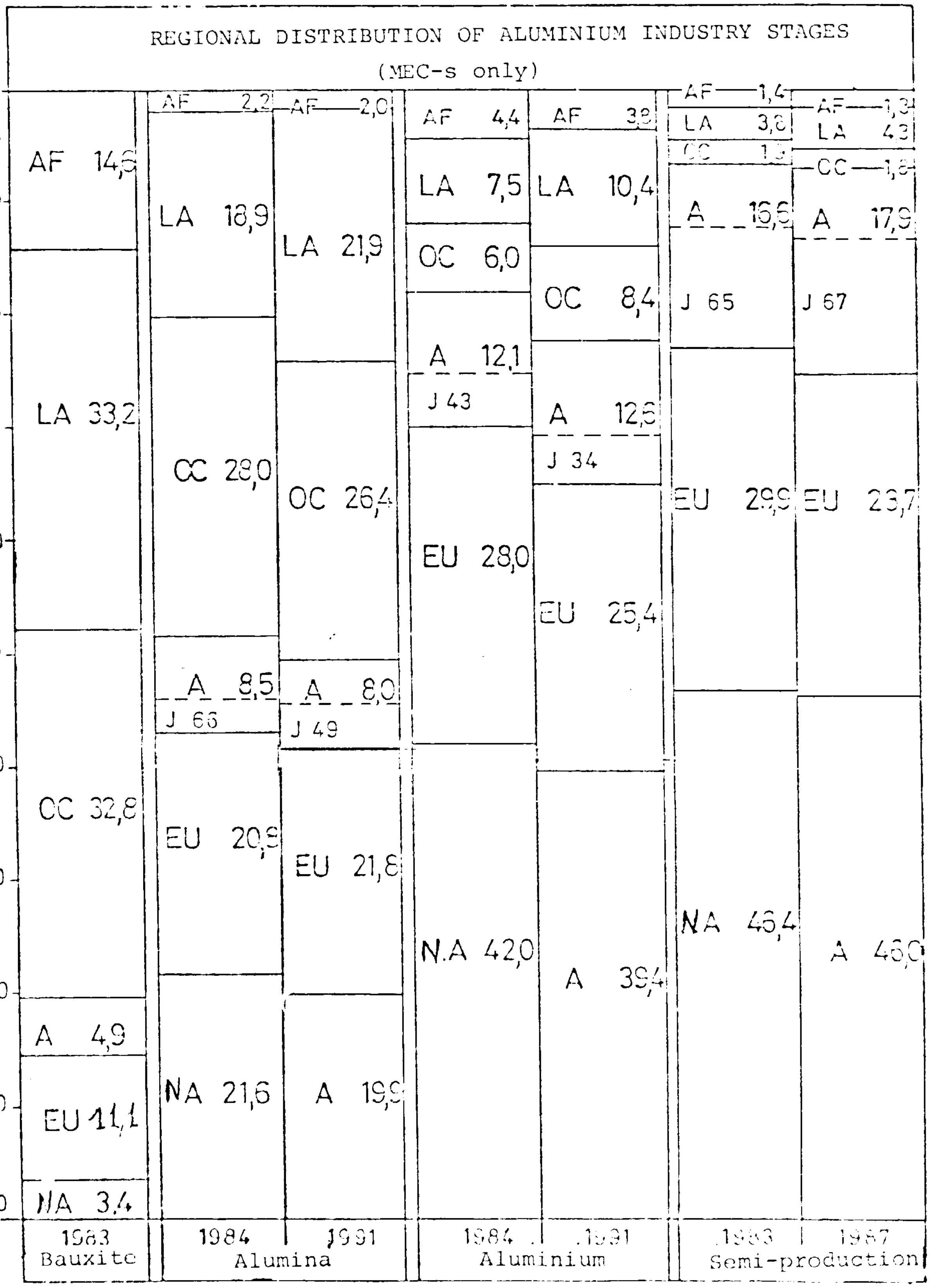
a) gravity feed

b) feed precompaction

c) tangential feed

1. particulate feed
2. preformed solid feed
3. solid feed
4. extrusion wheel
5. groove root
6. wheel face
7. driven roll to assist feeding
8. grip segment
9. die
10. product
11. abutment

Reference: [59][60]


REGIONAL DISTRIBUTION OF ALUMINIUM INDUSTRY STAGES
(MEC-s only)

EU = Europe NA = North America A = Asia J = Japan*
OC = Oceania LA = Latin America AF = Africa

*percentage within Asia

SEMI-PRODUCT TRADE IN [illegible]
(*total without "others")

Annex 38.

Annex 39

SEMI-FABRICATION IN SELECTED DEVELOPING AREAS

(in thousand tonnes)

	Primary semi-manufacturing capacity *		Consumption of primary aluminium ingot
	1983	1987	1981
Latin America			
Brazil	281.8	381.8	240.9
Chile	5.-	5.-	3.-
Colombia	35.1	35.1	14.2
Costa Rica	10.-	10.-	5.-
Cuba	5.-	5.-	1.5
Equador	(cold rolling mill only)		-
El Salvador	6.-	6.-	2.-
Jamaica	4.-	4.-	3.-
Mexico	130.-	138.-	99.6
Panama	3.-	3.-	2.-
Peru	11.-	11.-	10.-
Puerto Rico	13.3	13.3	10.-
Trinidad-Tobago	(cold rolling mill only)		-
Uruguay	5.1	5.1	3.-
Venezuela	58.1	63.1	73.6 (?)
Total	653.3	766.3	520.3
Africa			
Algeria	5.-	8.-	4.-
Angola	(foil and wire prod.only)		-
Cameroon	35.-	35.-	27.7
Egypt	50.-	50.-	45.-
Ghana	(cold rolling mill only)		-
Ivory Coast	0.5	0.5	0.5
Morocco	(cold rolling mill only)		
Nigeria	11.-	11.-	9.-
Tanzania	9.-	9.-	6.-
Zambia	(wire drawing only)		-
Zimbabve	9.3	9.3	8.-
Total	119.8	122.8	101.2

Annex 39 (cont.)

	Primary semi-manufacturing capacity *		Consumption of primary aluminium ingot
	1983	1987	1981
Asia			
Bahrain	29.-	69.-	17.3
Bangladesh	(cold rolling mill only)		-
Hong Kong	34.7	40.7	21.6
India	352.-	355.7	249.6
Indonesia	7.- (?)	7.- (?)	14.-
Iran	34.- (?)	34.- (?)	30.1
Irak	21.-	21.-	26.4
Israel	26.5	26.5	9.5
Jordan	6.-	6.-	5.-
Korea, Republic	211.8	211.8	111.6
Kuwait	9.6	9.6	8.-
Lebanon	16.-	16.-	11.7
Malaysia	41.6	41.6	25.-
Philippines	31.6	31.6	17.-
Pakistan	10.8	13.8	6.-
Saudi Arabia	10.5	10.5	6.-
Singapore	1.6	1.6	1.5
Syria	5.-	5.-	4.-
Taiwan	70.3	110.3	77.8
Thailand	52.2	52.2	45.-
Unites Arab Emirates	3.-	3.-	2.-
Total	974.2	1067.2	689.1

Notes: * hot rolling mill, extrusion and rod (for wire) capacities only

Reference: [10]