THE FIRST PROGRESS REPORT
FOR
THE STUDY RELATED TO
THE REGIONAL DEVELOPMENT PLAN
OF THE GREAT CARAJAS PROGRAM
OF
THE FEDERATIVE REPUBLIC OF BRAZIL

Vol. 4
MINING PRODUCTS

NOVEMBER 1983

JAPAN INTERNATIONAL
COOPERATION AGENCY

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[1] BAUXITE, ALUMINA AND ALUMINUM

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[1] BAUXITE, ALUMINA AND ALUMINUM

Introductory Notes

1. Unless otherwise specified, the unit of weight is metric tonne in this report.

2. List of plants for bauxite, alumina and aluminum in the world is attached as the appendix of this report.

3. The following abbreviations are used for sources of this report:

AME ------- Australian Mineral Economics Pty. Ltd.
IBA QR ---- International Bauxite Association Quarterly Review
IPAI SS --- International Primary Aluminium Institute Statistical Summary
JAF -------- Japan Aluminium Federation
MB --------- Metal Bulletin
MS --------- Metal Statistics issued by Metallgesellschaft
MW --------- Metals Week
USBM ------ The U.S. Bureau of Mines

[1] BAUXITE, ALUMINA AND ALUMINUM

A. RESOURCES AND PRODUCTION PROCESSES OF ALUMINUM

I. Characteristics and Usage of Aluminum

Although the history of aluminum as an industrial material covers only about 100 years, it has acquired the second position of metal behind iron thanks primarily to the excellent characteristics it displays. The following characteristics are utilized in a wide array of uses:

a. Lightweight: The specific gravity of aluminum is about 1/3 that of iron or copper.[1] Thus it is suitable as a structural material for aircrafts, vehicles, ships and other structures that require lightweight.

b. High strength: Aluminum has an advantage that if alloyed with magnesium, silicon, copper, manganese or other elements, then heat-treated and mechanically processed, it increases its strength. In addition, the strength is maintained even at extremely low temperature.

c. Excellent resistance against corrosion: Natural oxidation in the atmosphere creates a solid oxide film on the surface of aluminum to prevent corrosion. Furthermore, it is possible to produce artificially the corrosion resistant film by the anodizing method.

d. Good forming property: Because of its superior plasticity for forming, aluminum can be processed into complicated shapes by the unique extrusion technique, such products being used widely, for example, as window sashes.

e. High electrical conductivity: Comparing with copper, electrical conductivity of aluminum is approxmately 60% [2], but its weight is

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1) Specific gravity		
	Aluminum	2.7
	Iron	7.9
	Copper	8.9

2) Electrical conductivity: 36.36 $m/\Omega \cdot mm^2$

only 1/3. Therefore, aluminum conducts twice the electricity which copper of the same weight can conduct, and has almost replaced copper in the use of power transmission lines.

f. High thermal conductivity: Aluminum has about three times the thermal conductivity of iron, and is suitable for heat exchangers.1)

g. Good casting property: Because of small specific gravity, low melting point 2) and high heat capacity, aluminum can be cast into any complicated, desired shapes with various casting methods.

h. Recycling: Aluminum can be recycled easily since its melting point is low. The energy input to recycle aluminum is only about 1/28 of that consumed to produce primary aluminum, and the recycle cost is low accordingly.

The quality of recycled aluminum is nearly comparable to that of primary aluminum. If the recycling is also taken into account, it can be said that aluminum is produced with a relatively small energy usage and is contributing to efficient use of resources.

In addition, aluminum is non-toxic, non-magnetic and easily recycled, and can be finished on the surface in various ways with different treatment methods. As explained above, aluminum has a wide range of superior characteristics.

Alumina, the intermediate raw material, is used mostly to produce aluminum by smelting. It is also used widely for refractories, heat resistant ceramics and electric and electronic components making use of its unique properties; very high melting point (about 2,050°C), being chemically stable if ignited and high electrical insulation. Furthermore, alumina can exists in various types of crystal and, for this reason, is widely used in items such as catalyst carriers and adsorbents. Aluminum oxide is used also in the form of aluminum hydroxide, and a variety of aluminum salts (sulfate, chloride, sodium aluminate etc.) are produced from aluminum hydroxide. Use as filler for plastics is also a part of its wide range of applications. These non-metallurgical uses today average more than one tenth of world consumption of alumina, and this ratio is expected to rise in the future.

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1) Thermal conductivity: 0.568 cal/cm.s.deg

2) Melting point: 660°C

II. Bauxite

As an element, aluminum is one of the most plentiful of all the elements on the earth. Its Clarke Number, which represents its ratio of quantity in the surface layer of the earth's crust, is third (7.56%) behind oxygen and silicon, and ahead of iron's 4.76%. It is one of the principal constituent elements of the earth's crust.

Almost all the minerals containing aluminum are oxides. Among many aluminum-bearing minerals known to us, which are clays, shales, feldspars, mica, aluminum phosphate, alunite etc. (Reference Table A-1), the only one currently used economically in industrial aluminum production is bauxite, whose alumina content is high enough and silica content is low. Some nepheline and aluminous shale are used exceptionally in the limited regions.

1. Types and Origins of Bauxite

1.1 Types

Bauxite was named after Les Bau region in France that produced the reddish-white rock-at that time thought to be a type of clay - whose primary mineral was confirmed to be alumina. Nowadays, laterite with particularly high alumina content enough to use as an aluminum ore is called bauxite. In the strict mineralogical sense of the word, bauxite is not a single mineral. It is an ore that contains alumina minerals and also iron oxides, titanium oxide, silicon oxide and other components. The alumina, a primary component, usually takes the forms of gibbsite ($Al(OH)_3$), boehmite ($AlO(OH)$) and other crystals. These two can also be expressed as $Al_2O_3.3H_2O$ and $Al_2O_3.H_2O$ respectively, hence the former is often called trihydrate and the latter monohydrate. On occasion, bauxite contains diaspore ($H.AlO_2$) monohydrate.

Correspondingly, bauxite is generally designated trihydrate bauxite (gibbsite) or monohydrate bauxite (boehmite). Silicates exist as clay minerals such as kaolinite ($Al_2O_3.2SiO_2.2H_2O$) and halloysite ($Al_2O_3.2SiO_2.2H_2O$) and often exist freely in quartz particles, and they are the most significant impurities when bauxite is used as the raw material in the Bayer process. Usually the less they are, the better. The iron in bauxite exists as hematite (α-Fe_2O_3), limonite (Fe_2O_3) etc. and is the reason for the unique reddish color bauxite almost always has. Bauxite is sometimes dark red or brown.

1.2 Origins

Bauxite is said to have been created by decompostion of rocks by chemical weathering. For bauxitization and laterization to progress, an environment that promotes the action of chemical weathering is necessary. Bauxite is ofter produced in the tropical and subtropical regions that have such environment.

An outline of the main bauxite beds on the earth according to their parent rocks is as follows:

a. Alkaline aluminum silicate (e.g. nepheline and leucite)

This type of rock is exposed in loose, rolling tropical areas and weathered.
Examples: The Los Islands (Guinea), Arkansas (USA)

b. Limestone

Limestone is weathered, and the alumina present as a residue is concentrated.
Examples: Mediterranean region (France, Italy, Hungary, Yugoslavia etc.), Caribbean region (Jamaica, Haiti, Dominican Republic etc.)

c. Sedimentary clay

Examples: Georgia, Alabama (USA)

d. Neutral - basic igneous rocks (diorite, diabase, basalt)

These rocks are well-weathered and alumina is separated to form a deposit of high grade bauxite.
Example: India

e. Other rocks made of aluminum silicates (granite, syenite, gneiss, shale)

These rocks with relatively high alumina content are extremely weathered.
Examples: Guinea, Surinam, Indonesia, Malaysia, Australia

1.3 Types of Deposits

The forms of bauxite deposits can be classified into the following four main types:

a. Blanket deposits

This type of deposit exists thinly on the surface or as a thin layer spreading near the surface of the flat tablelands, hills or plateaus, in tropical and subtropical areas. Most of these deposits were formed during or after the Tertiary period.

b. Interlayered deposits

These deposits are found as part of the strata, taking a layered or lens shape either in sedmentary rocks or between sedimentary and igneous rocks. These develop as deposits on top of the blanket bauxite layers which were formed earlier and then subsided.

c. Pocket deposits

Pocket deposits can be found in the parent rocks such as limestone, clay and igneous rocks, often along with blanket deposits and layered minerals. The pocket deposits have irregular shapes.

d. Detrital deposits

These are the secondary deposits formed by redeposition of material which was eroded from deposits of the other three types and mechanically decomposed and transported.

2. Distribution and Reserve of Bauxite

Bauxite reserve (including proven and inferred reserves), rather than being diminished by consumption, is actually increasing as new deposits are discovered. In 1945, the world reserve was barely one billion tonnes, but since 1950, with the discovery of extensive deposits in Australia and Brazil and the discovery of additional deposits in Guinea, this figure has soared and is now estimated to top 25 billion tonnes. At the current annual consumption rate of 88 million tonnes, this would last nearly 300 years. Leaving aside any issue of uneven distribution, bauxite can be considered an unusually abundant resource.

Reference Table A-2 gives the USBM estimate of bauxite reserves by country and shows the bauxite type. Reference Table A-3 shows the grade of bauxite in different deposits. Here is an outline of the region-by-region bauxite reserves:

Africa	10,160	million tonnes
America (North and South)	6,360	"
Asia	2,180	"
Western Europe	1,260	"
Oceania	4,620	"
(Total Free World)	(24,580	")
(Total C.P. Economies)	(510	")
World Total	25,090	"

Here is an outline of the deposits in each region:

a. Africa

(i) Guinea: It has nearly 8.2 billion tonnes, one-third of the world's reserve. Boke, Tongue, Dabola and Fria have large deposits. The Boke deposit is over 25 meters thick and is the world largest single deposit: The alumina is mainly gibbsite, with boehmite included in the top and bottom layers. The alumina content is as high as 60%.

(ii) Other African areas: Cameroon, Ghana and Sierra Leone have deposits of several hundred million tonnes, but serious development has not yet taken up. It is reported that bauxite has also been discovered in South Africa but detailed information is not available.

b. Latin America

(i) Brazil: There are large deposits in the Amazon River basin (Trombetas, Paragominas), along the Atlantic coast (Pocos de Caldas) and elsewhere. The Trombetas deposit is covered by a relatively thick layer of topsoil, about 6 meters. Under this is 1 meter of nodular bauxite, then 1 meter of laterite rich with iron, then a further 5 meter massive bauxite layer. The alumina is mostly gibbsite.

(ii) Surinam: Moego region has 3-5 meter deposits with a layer of a high iron content in the surface and is easy to be mined. On the other hand, the surface layer in Lelydrop has an upper layer that reaches 6-12 meters and a lower layer that reaches 6-30 meters, and 5 tonnes of topsoil must be removed for each tonne of bauxite mined. The alumina is gibbsite.

(iii) Guyana: The particular characteristic of Guyana's deposits is the extreme depth of topsoil under which they lie. The East Montgomery deposit is up to 77 meters down and requires various measures for mining. The alumina content in the bauxite - mostly gibbsite - is up to 65%. Since the iron content is low, it is used for production of refractories and abrasive materials without particular refining.

(iv) Jamaica: The topsoil cover is unusually thin. The deposits are pocket or blanket type and the deposits are quite dense and hard. The alumina is mainly gibbsite. The high iron content (18-20% Fe_2O_3) is a characteristic of these deposits.

c. Australia

There are large deposites as below:
Weipa (Queensland)
Darling Range (Western Australia)
Kimberley (Western Australia)
Gove Peninsula (Northern Territory)

Australia's reserve is second after Guinea's. Among these deposits, the Weipa deposit has a lot of gibbsite but with some boehmite mixed in. The topsoil is extremely thin (less than 1 meter). The bauxite layer is 1 - 10 meters. The Gove deposit is mostly gibbsite with a little boehmite. Its thickness is about 3.5 meters. The Darling Range deposit having about 4 meters topsoil is gibbsite, and although the alumina content is relatively low (30-40%), the reactive silica is particularly low. The Cape Bougainville and Mitchell Plateau deposits are in the Kimberley region. In both deposits, the alumina contains 80-85% gibbsite. The topsoil averages 9.3 meters in Cape Bougainville and less than 1 meter in Mitchell Plateau.

d. Other regions

(i) Arkansas (the United States): The deposits in this area hold the majority of the bauxite reserve in the United States. The alumina is mostly gibbsite. The topsoil is made up of sand and clay.

(ii) India: In the Deccan plateau, Orissa, Andhra Pradesh and elsewhere, there are lens deposits between laterite layers.

(iii) Southern Europe: In Greece, Yugoslavia, Rumania, Hungary, Italy, France and elsewhere, there are deposits which mostly coexist with limestone. They are almost all boehmite, but there are deposits of gibbsite (Hungary) and diaspore (Greece) too. Many of these deposits are deep underground and are extracted by underground mining. The alumina content is 45-65%, and 1-10% silica and a relatively high content of iron (15-30%) are found.

III. Production Processes

1. Bauxite Mining

1.1 Mining

Because bauxite deposits often occur relatively close to the surface, they are usualy open-pit mined, but some of the deposits such as those in France and Arkansas are extremely deep and are extracted by underground mining.

1.1.1 Open-pit mining

Many of the large scale deposits in tropical and subtropical areas are usually under the topsoil of 2 meters or less and are 2-15 meter thick layers. In these layers, massive or nodular bauxite is contained in the matrix of clay or fine sand. Here is an outline of the mining process: First, the trees and shrubs are removed. Then the topsoil is removed with bulldozers and other heavy-duty machines. It is said that for economical mining, the ratio of the thickness of the topsoil to that of bauxite should be no more than approximately 1:15. Depending on the hardness of the deposits, it is sometimes necessary to blast the deposits with a weak explosive such as ANFO. Then the bauxite is mined with shovels and haulers and transported with large trucks, railways, conveyor belts or overhead ropeways. Mining actually goes on simultaneously with blending process. Blending is to elminate the differences in grade of bauxite existing horizontally and vertically along the deposits. This operation is necessary to supply a fixed grade of bauxite. For this reason, bench-terracing technique may also be used. Frequently, the topsoil removed is piled up at the mine site and returned after the bauxite has been removed in order to help preserve the natural environment.

1.1.2 Underground mining

European deposits are often pocket or lens type and mined underground. The depths of the deposits are widely varied. Deposits are mined at 700 meters in the USSR and at 300-400 meters in France, Hungary and Yugoslavia.

1.2 Ore Dressing

Frequently, the impurities in bauxite (e.g. iron and silicon) are quite finely and evenly dispersed, making it difficult to separate them with physical methods. Sand and clays contained, however, are removed by crushing and washing as below.

a. Crushing

As a method to up-grade bauxite, crude ore is first crushed, then the gangue material is reduced to obtain enriched rock ore. Separation of the ore uses the sieves with the most appropriate mesh size. Oversize rock is then crushed again.

b. Washing

Washing with water removes impurities, mainly fine-particle clay and sand, from the crushed bauxite to upgrade it.

In addition, when bauxite with a high moisture content is to be transported over a long distance, it is dried at relatively low temperature in a rotary kiln for easiness in handling.

2. Production of Alumina and Aluminum

2.1 Alumina Production Process

At present, almost all commercial production of alumina uses the Bayer process. This process is based on the principle that the solubility of alumina in caustic soda solution changes with the temperature and the concentration.1) Because some of the silica in the ore is also dissolved by caustic soda, this process is inappropriate for processing bauxite with a high silica content (e.g. when the reactive silica is 5% more) or for processing nepheline etc. The Bayer process basically comprises the following operations:

a. Grinding: Ordinarily, some caustic soda solution is added and the bauxite is wet ground in a ball mill.

b. Digestion: The bauxite is processed with caustic soda solution at high temperature and pressure and the alumina is extracted

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1) The chemical reaction in the Bayer process is expressed as:

$$Al_2O_3 \cdot 3H_2O + 2NAOH \underset{\text{precipitation}}{\overset{\text{dissolution}}{\rightleftarrows}} 2NaAlO_2 + 4H_2O$$

as sodium aluminate. The other components in the bauxite are left as indissoluble residue.

c. Separation: Settling, washing and filtration separate the residue and the pure sodium aluminate liquor is obtained.

d. Precipitation: The sodium aluminate solution is cooled, the seed of aluminum hydroxide is circulated, the particle size is controlled, and the aluminum hydroxide is precipitated.

e. Calcination: The aluminum hydroxide is calcined at high temperature and the chemically bonded water is released to obtain stable anhydrous alumina.

The conditions of the dissolution operation must change according to the type of alumina in the bauxite, i.e. the crystal form. Specifically, gibbsite (trihydrate) can be dissolved at a relatively low temperature (about 150°C), but boehmite (monohydrate) must be processed at a higher temperature (220-250°C). Furthermore, diaspore (monohydrate) requires even higher temperature (over 270°C).

The conditions of the precipitation operation vary considerably depending on whether the alumina to be produced is the small-particled floury alumina or the large-particled sandy alumina. Besides, the calcining processes are developed to suit each type of alumina. Fig. A-1 shows an example of a flowsheet for the Bayer process.

The raw material requirements for the Bayer process are shown below. However, these quantities vary according to the grade of bauxite, the form of alumina in bauxite and the operating conditions. For example, the caustic soda usage depends largely on the reactive silica in the bauxite, and is also affected by the amount of washing water used. The steam consumption is affected by the efficiency of the heat exchanger etc.

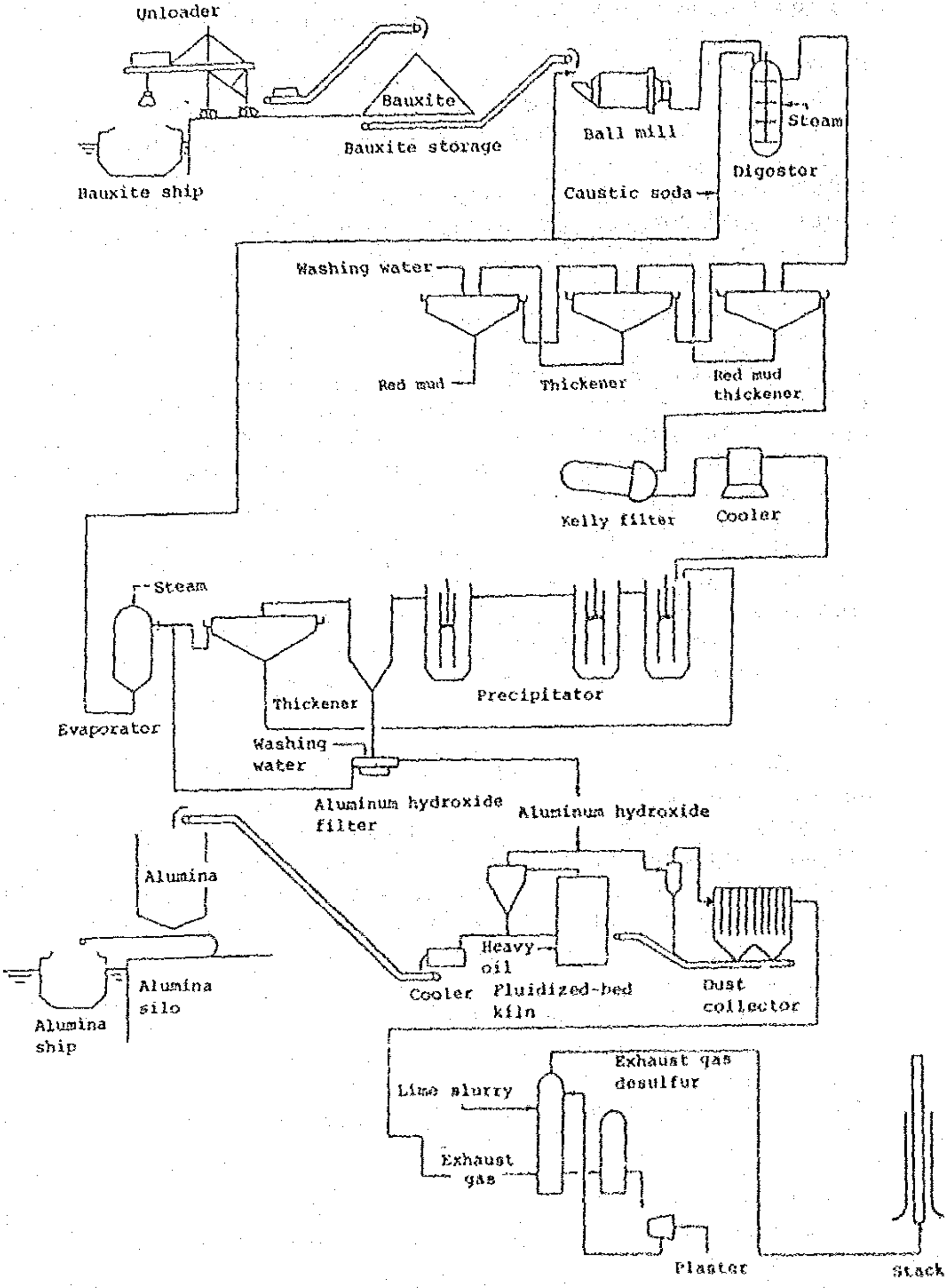
Consumption of raw materials per tonne of alumina:

Bauxite	1.9 - 3.0 tonnes
Caustic soda	0.09 - 0.14
Lime	0.03 - 0.04
Steam	1.5 - 3.0
Crude oil	0.08 - 0.16

2.2 Aluminum Production Process

Presently, the commercial production of primary aluminum uses

Fig. A-1 The Process for Producing Alumina



the Hall-Héroult process without exceptions. The fundamental mechanism is to dissolve alumina in molten cryolite and to electrolytically separate it into aluminum metal and oxygen. The separated oxygen combines with the anode carbon to form carbon monoxide and some carbon dioxide which are released.[1]

This electrolysis operation takes place in a specially structured electrolytic furnace. Fig. A-2 shows examples of this structure. Here are the main components:

Carbon anode
Molten cryolite bath
Carbon cathode
Anode bus bar
Cathode iron bar

The electrolytic furnace can be classified into Soederberg and prebake types according to the anode structure. The former self-bakes the anode (green anode) with the Joule heat generated by applying electric current, so continuous anode operation is possible. The latter is a method that bakes the anode in a separate operation in a specially built baking plant and uses the already baked anode in the electrolytic furnace. Due to the nature of the anode, its anode operation in the furnace is non-continuous.

The main component of the molten bath is cryolite, to which are added aluminum fluoride, calcium fluoride, lithium fluoride etc. in order to increase the current efficiency. The operation progresses at 960 - 1,000°C and the dissolved alumina is on the level of 3 to 6% concentration. The voltage applied per furnace is normally 4 - 5 volts, which includes decomposition voltage of alumina plus voltage drops of bus bar, anode, cathode and bath. However, in some of the modern plants, below 4 volts is achieved to cut down electricity consumption. The amperage per furnace ranges from 50,000 or 60,000 amperes to over 200,000 amperes, which is more expanded as newer smelters are built.

The cost of electricity accounts for a large part of the cost of aluminum. The reduction of electricity consumption, therefore, is an essential technological challenge. In relatively new plants, it is estimated to be 13,000-15,000 kWh (DC) per tonne of aluminum, while in some of old-type plants the level is 17,000 - 20,000 kWh. Here is an outline of consumption of the raw materials other than electricity:

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1) The chemical reaction is: $Al_2O_3 + 3C \longrightarrow 2Al + 3CO$

Fig. A-2(a) Soederberg Anode Cell

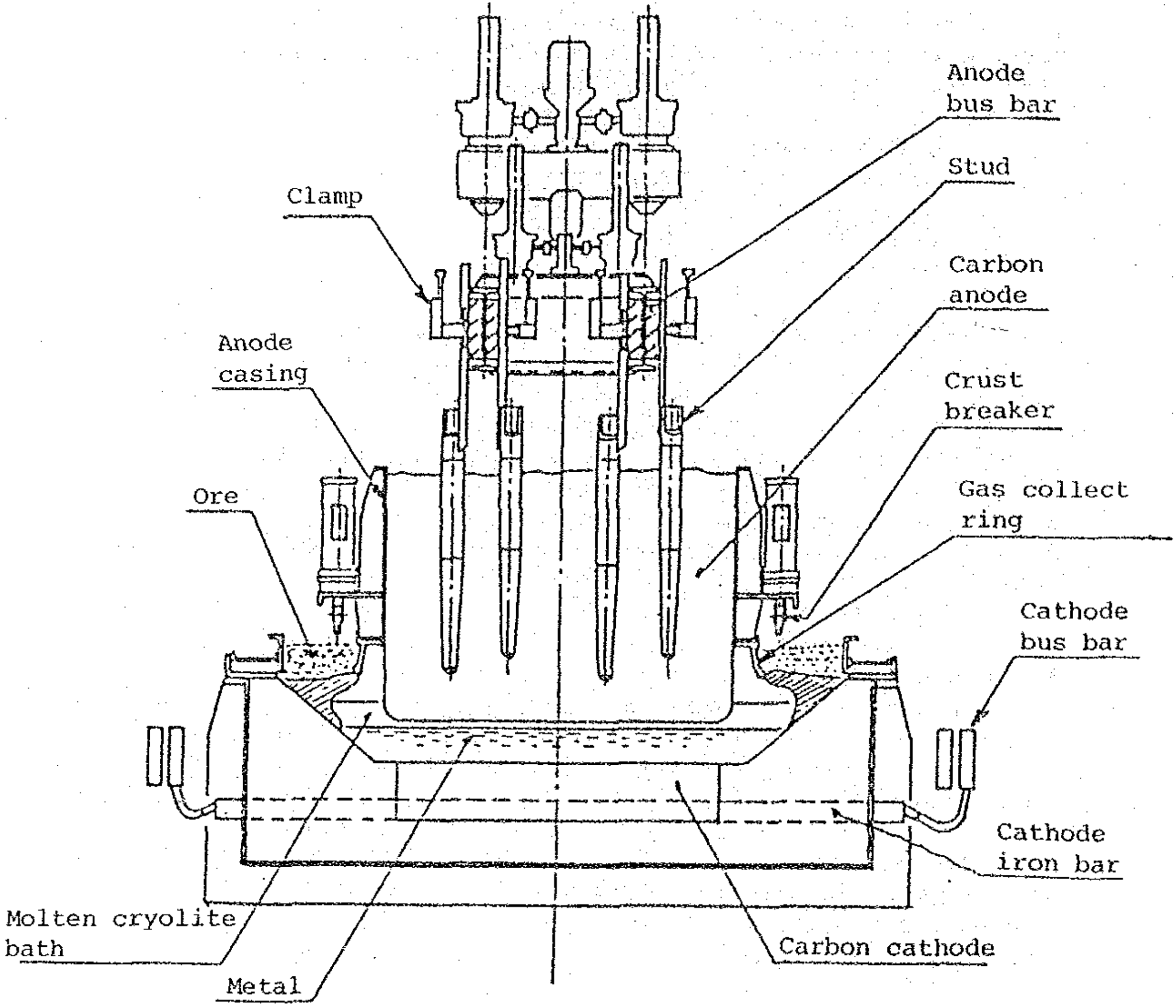
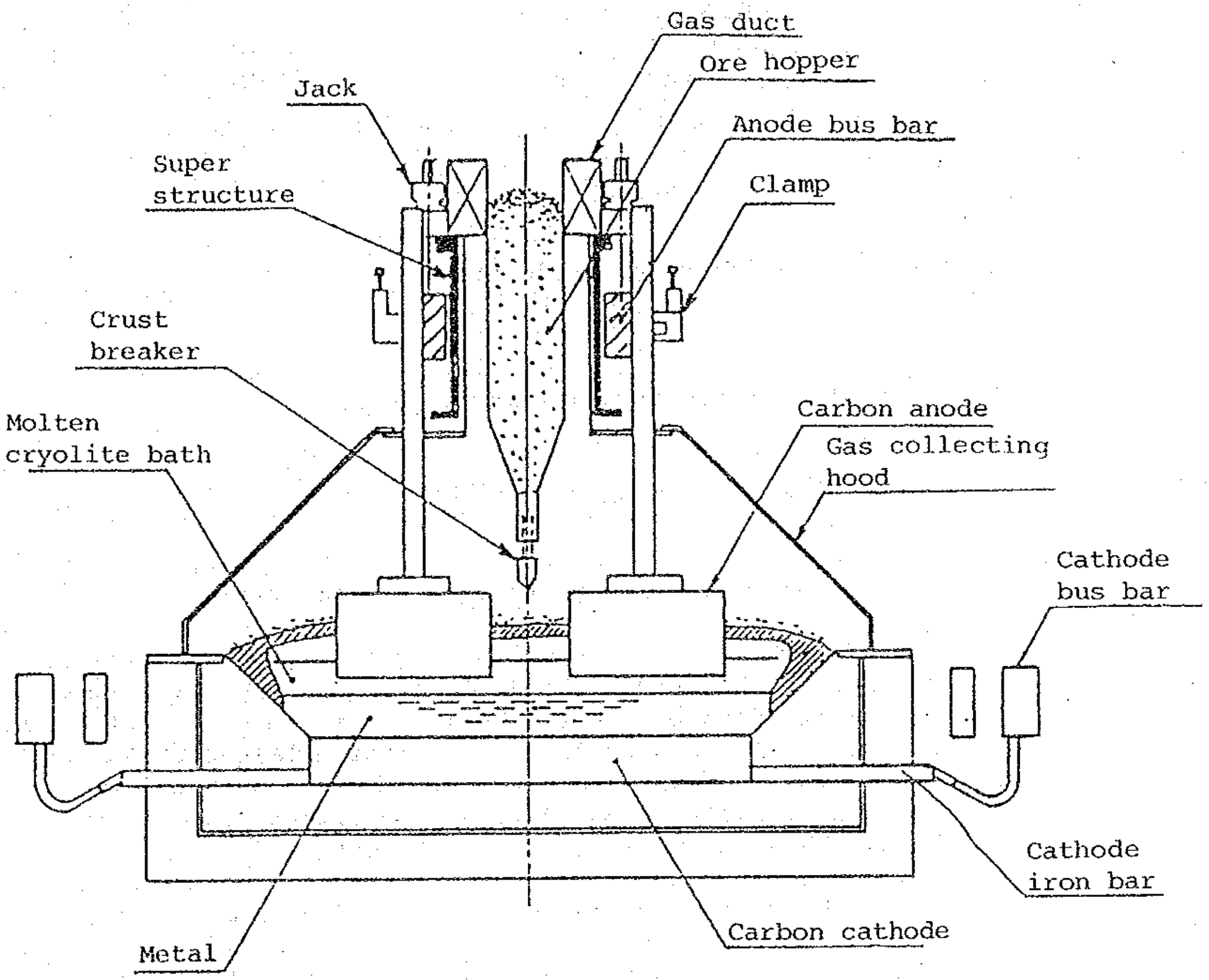


Fig. A-2(b) Prebaked Anode Cell



Comsumption of raw materials, per tonne of aluminum

	(tonnes)
Alumina	1.90 - 1.98
Cryolite	0.02 - 0.03
Aluminum fluoride	0.03 - 0.04
Coke	0.40 - 0.45
Coal tar pitch	0.10 - 0.15

IV. Present and Future of Production Technology

1. Present Refining and Smelting Technology

1.1 Alumina Production Technology

1.1.1 Valuation of bauxite as a raw material

The value of the bauxite used in the Bayer operation depends on the content of alumina and of impurities such as silica and also on their crystal forms. When highly reactive silica exists in such form as kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$), the silica is first dissolved by alkali and then forms in soluble sodalite compounds and precipitates in digestion operation. This causes loss of caustic soda and alumina. For the purpose of an attempt to evaluate the value of different bauxites, Table A-1 shows the content of alumina and of impurities such as silica in the typical bauxites,and Table A-2 calculates the raw material usage to produce alumina. Based on these data, Table A-3 compares the relative value of bauxites, taking Bintan ore as 100. Comparing the price of bauxites on an assumption that alumina production cost is made identical among bauxites, Boke ore is evaluated to be competitive even when its price is 2.14 times that of Bintan ore, for example.

1.1.2 Refining technology

The future trends of technologies in the Bayer process are thought to be the following:

Table A-1 Compositions of Typical Bauxites (examples)

(%)

Type / Composition	Gibbsite				Boehmite			Diaspore
	Bintan	Surinam	Trombetas	Jamaica	Weipa	Boke	Arkansas	Greece
Al_2O_3	53	55	54	49	55	60	49	56
SiO_2	5	4	5	1	5	1	15	4
Fe_2O_3	12	9	11	18	11	6	7	22
TiO_2	1	1	1	2	3	4	2	3

Table A-2 Raw Material Consumptions in Alumina Production

(per tonne of alumina)

Material (kg)	Bintan	Surinam	Trombetas	Jamaica	Weipa	Boke	Arkansas	Gove	Guyana
Bauxite	2,180	1,980	3,100	2,290	2,050	1,760	2,810	2,200	1,910
Caustic soda	102	72	101	29	97	25	313	70	86
Steam	1,560	1,490	1,490	1,600	1,550	1,410	1,810	1,610	1,480
Red mud	680	460	600	780	610	280	1,540	820	431

Table A-3 Comparative Value of Bauxites

	Bintan	Surinam	Trombetas	Jamaica	Weipa	Boke	Arkansas	Gove	Guyana
Bauxite value	100	144	110	135	108	214	67	118	138

a. A change in smelting grade alumina toward sandy type

In recent years, the fluoride gas recovery system used in electrolysis operation moves to prefer the dry scrubbing method making use of adsorbency of alumina. In line with this alumina with greater adsorbency (sandy type) is becoming the predominant type to be produced.1)

b. Improvements in each step of the Bayer process

Here are main items of process improvements to reduce energy consumption.

- o Digestion area: Developments of tube reactor system, bauxite slurry preheating by double tube, etc which help to save steam consumption
- o Precipitation area: Developments of intermediate cooling system, 2-stage precipitation and removal methods for organic impurities in the process to improve precipitation efficiency
- o Calcination area: Implementation of fluid flash calcining process etc. to replace the conventional rotary kiln method to save fuel consumption

1.1.3 Alumina production scale

The relationship between the scale of production and capital cost of alumina plants is shown in Fig. A-3.

As the scale of production increases, the production cost decreases. Similarly, concerning the number of process lines in one plant, larger scale per line is more economical when the plant capital cost is kept the same. In Australia, a plant of about 2.5 million tonne capacity per annum is already in operation.

1.1.4 Non-Bayer processes

Of the non-Bayer processes, the USSR's soda-lime process

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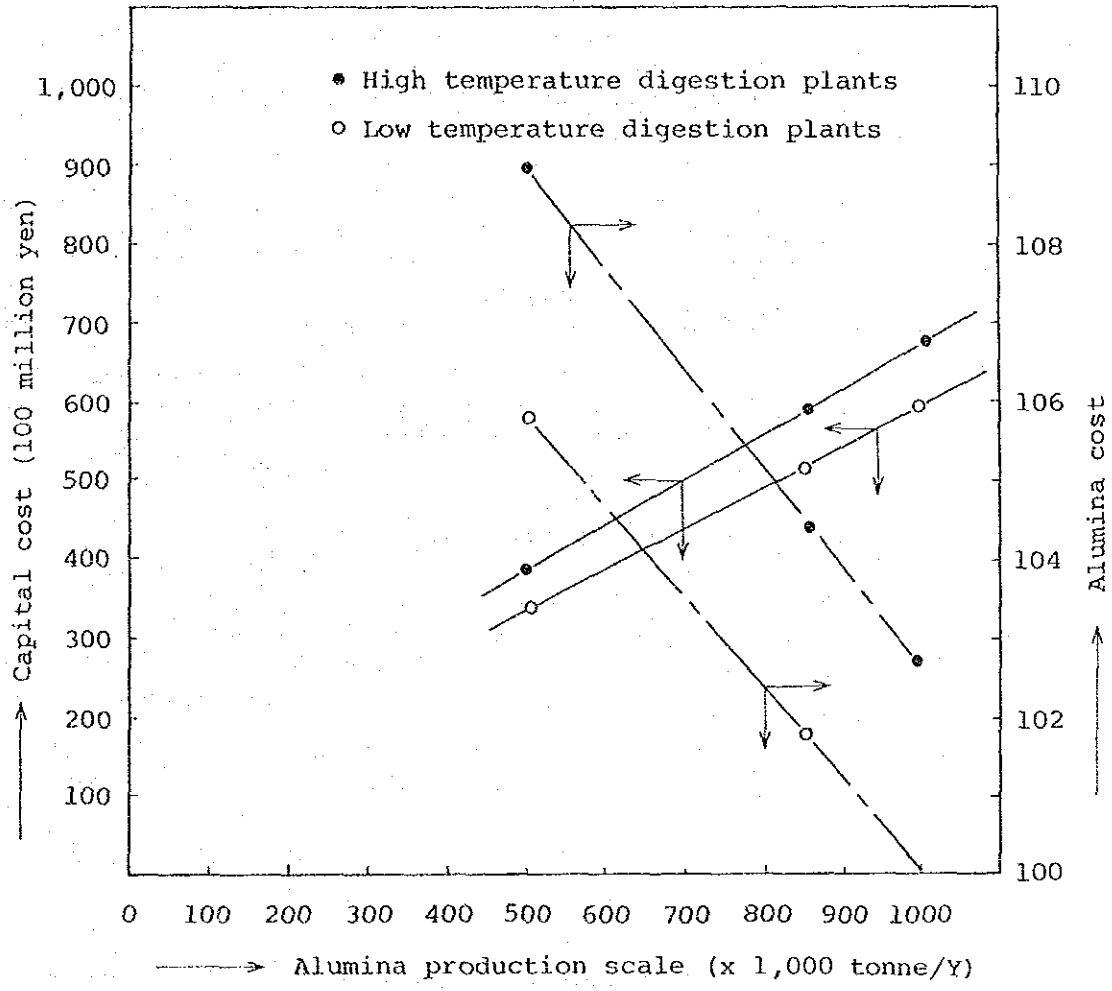
1) A comparison of the characteristics of floury and sandy aluminas

	Floury	Sandy
Predominant particle diameter	about 50 microns	about 80 microns
Angle of rest	over 40°	below 40°
-alumina content	80% or more	50% or less

Fig. A-3 Relationship of Alumina Production Scale, Capital Cost and the Cost of Alumina

(The alumina cost at 1 million tonnes per year capacity with low temperature digestion is taken as 100.)



using nepheline as the raw material is one of the few cases in operation on an industrial scale. Other than this, in recent years, various alumina production processes have been suggested that do not use bauxite, and some have been tested on an intermediate scale, but none have actually been implemented because they have not been able to progress to the point at which they could compete with the Bayer process economically and technically. Table A-4 shows examples of non-bauxite alumina production processes.

Table A-4 Non-Bauxite Alumina Production Processes

Process	Alkali Hydrochloric acid	H^+	Alunite	Nitric Acid
Raw material	Clay Anorthosite	Clay, Shale	Alunite	Clay, Alunite
Development progress	o Improved Bayer process, pilot plant construction planned o Information exchange with Anaconda and ALCOA	o Cooperation with Alcan; 7000 tonne/year plant started in August 1976 o Capital cost 20% higher than for the Bayer process o Joint development with Pechiney and ALCAN	o 10 tonne/day pilot plant construction o Development by Alumet Co. with finance from National Steel Corp., Southwire Corp. and Earth Science Inc.	o 300 kg/day pilot plant in operation o Full-scale plant construction planned for 1990 or later o The U.S. Bureau of Mines plus 8 smelters

1.2 Aluminum Smelting Technology

This sub-section covers trends and problems in present smelting technology.

1.2.1 A comparison of prebaked anode type and Soederberg anode type

In recently constructed plants, the prebaked anode type furnace is becoming predominant for such reasons as:

- A large size furnace is available (220,000-230,000 ampere furnace has been developed).

- o Automation system and mechanization in operation can be easily introduced.

- o It has a cost advantage above a certain level of production scale.

- o Good working environment is maintained. Along with this trend, the dry scrubbing process is often adopted especially in prebake plants for treatment of exhaust gas from smelting operation. This process uses sandy alumina as an absorbent. As for Soederberg anode type furnace, expansion of furnace size is limited because of the restrictions from its anode structure, and the typical size is 100,000-120,000 amperes. However, in the Soederberg plants, it has recently become possible to satisfactorily eliminate the problem of tar-fume in working places by implementing new technology developments like "Dry Anode" technique.

The economics of these two furnace types being compared, first, the capital cost of the prebake plants is lower in unit production scale if the electrolytic furnace is large-scaled and the production scale goes over a certain level.[1) Fig. A-4 shows an example of the relationship between estimated construction cost and scale of production assuming a location in Japan. According to this figure, the unit construction costs of the two types cross at a yearly production of 170,000-180,000 tonnes, but if the dry scrubbing system is adopted for the exhaust gas cleaning, the cross point comes down.

Considering the production costs, once again the prebaked anode type is profitable in large-scale plants 2). Fig. A-5, comparing production scale and hot metal cost in the two types, indicates that the prebaked anode type is advantageous above 210,000 tonnes per year capacity.

1.2.2 Reduction of consumption of electricity

To reduce electricity consumption, the operation voltage of the furnace is lowered by improvements of furnace structure which comprise increased thermal insulation, improved cathode carbon materials, improved anode etc. At the same time, as a different approach, the computer control technique has been developed and is applied to produce higher current efficiency by

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1) 150-180 KA furnaces predominate, and 220-230KA furnaces have been put into operation (Messana of ALCOA, Høyanger of ÅSV).

2) Many of newly built plants produce over 200,000 tonnes per year.

Fig. A-4 The Relationship between Production Scale of Plant and Capital Cost (excluding the casting shop) per unit Production Scale

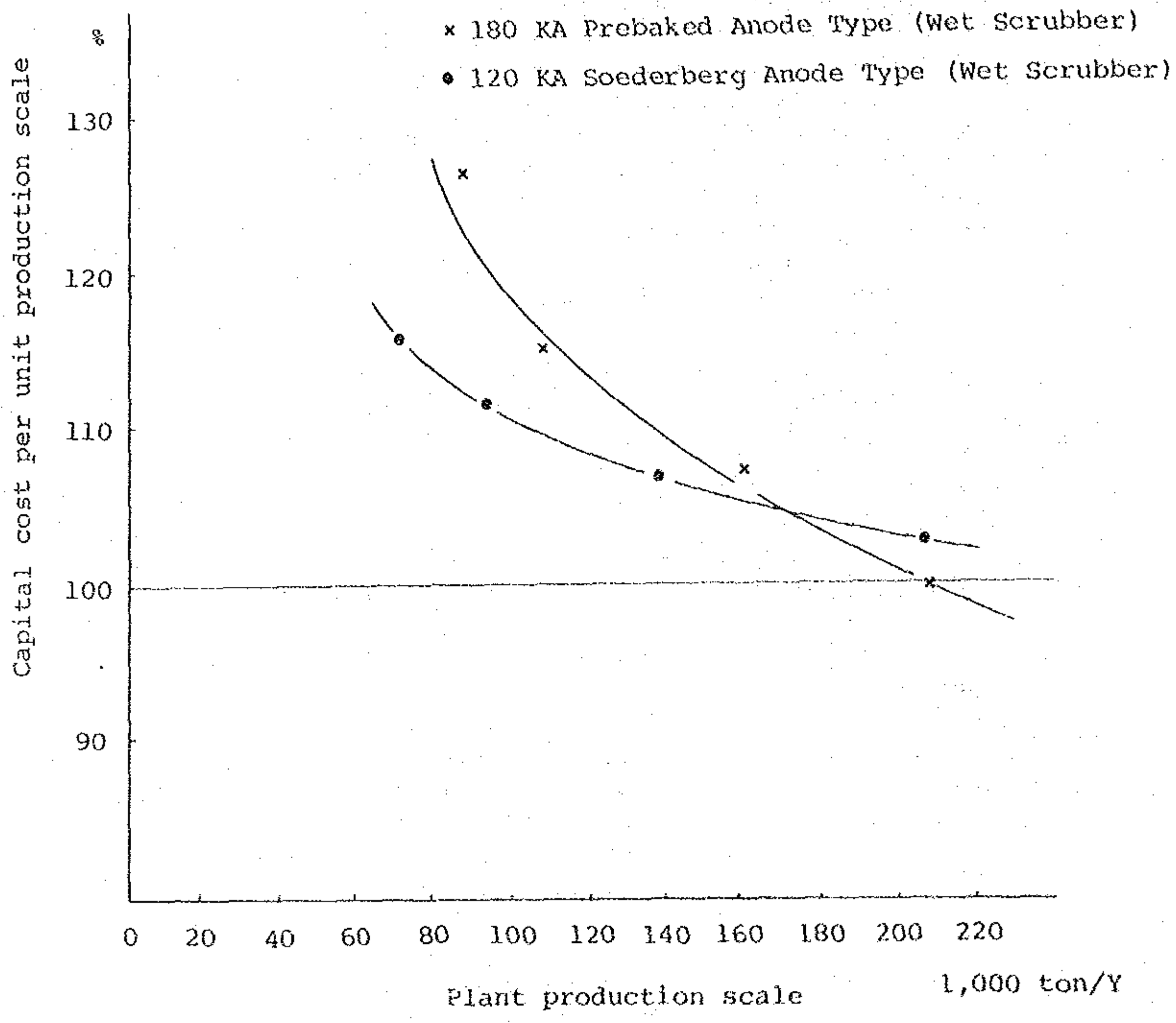
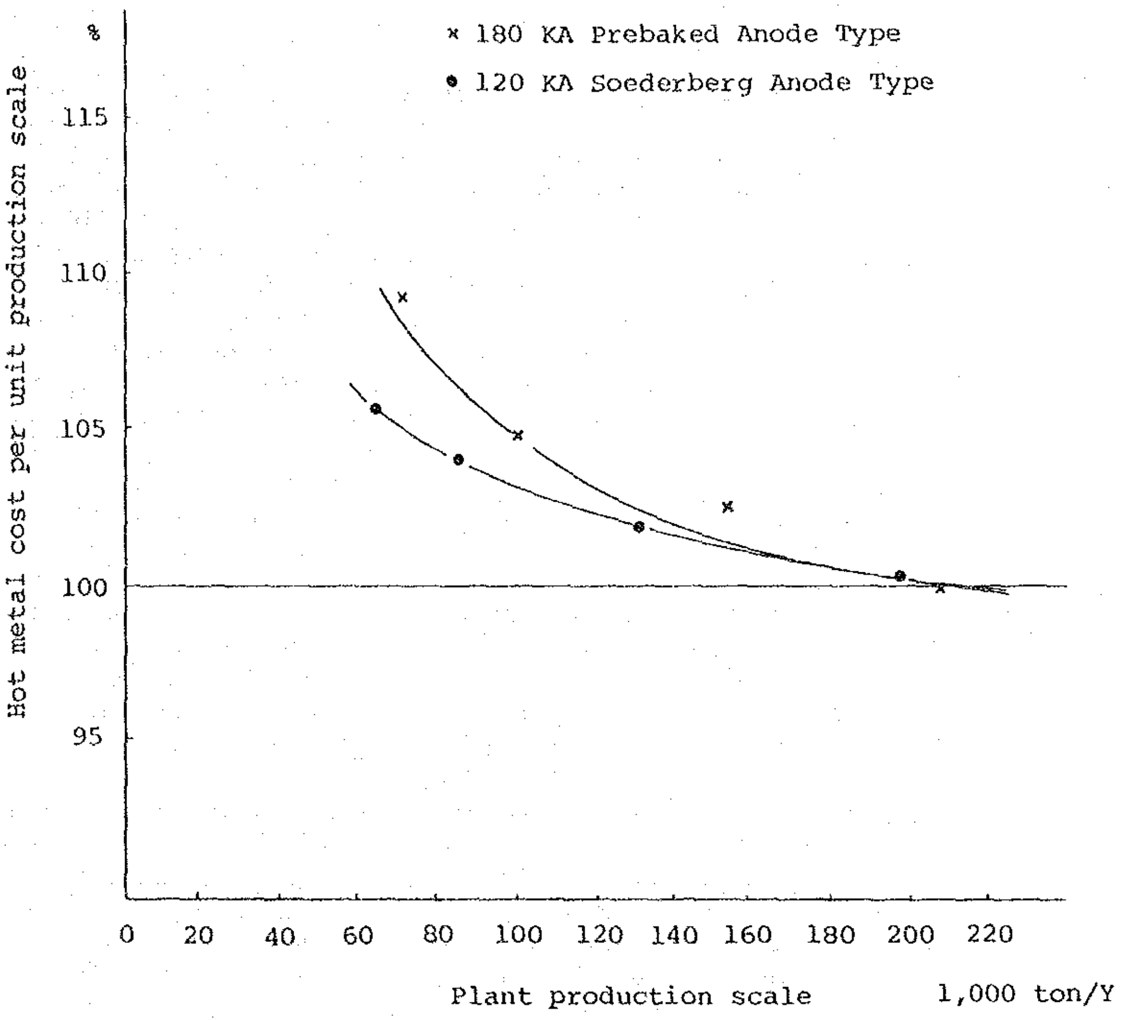


Fig. A-5 The Relationship between Production Scale and Hot Metal Cost



improving furnace operation control. In the latest technology, there is little difference between the prebake and Soederberg types in the consumption of electricity, which is on the level of 13,000-13,500 kWh/T (DC) for both types. The limit of the electricity consumption with the current process is said to be 12,3000 kWh/T (DC) as a practical target under various restrictions of the process.

1.2.3 Mechanization and automation

In the last 10-15 years, the electrolysis operations have been greatly mechanized and automated mainly with the installation of a special crane to perform anode changing and metal tapping (prebake type) and the computerized operation which controls alumina feed, anode effect prediction and suppression, furnace voltage, detection of abnormal furnace conditions etc. There have been developments also in the operations particular with Soedeberg type. For example, a technique using a special crane for anode stud pulling, anode paste charging etc. is adopted.[1]

1.2.4 Technology for environmental control

The innovative change in the technology for cleaning effluent gas from the smelting plant is caused by the advent of the dry scrubbing method which uses sandy alumina as an adsorbent. Today, this method is widespread among newly built plants, because it offers relatively low construction cost, recovers fluoride in the effluent gas as aluminum fluoride, releases no waste water, and accomplishes high scrubbing efficiency etc. However, in the areas where the regulations on sulpheroxides are strict, there may require wet-scrubbing or a combination of wet and dry methods to remove them. Table A-5 shows recent levels of furnace exhaust gas collection efficiency and fluoride emission.

2. New Smelting Methods

Many different methods have been suggested for aluminum smelting, as Table A-6 shows, but since the establishment of the Hall-

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1) An example of the reduction in labor requirement (average of all the Japanese smelter plants)

1965	2.60	man.day/tonne
1970	1.82	"
1980	0.91	"

Table A-5 Furnace exhaust gas collection efficiency and Fluoride Emission Level

	Levels of 10-15 years ago		Recent levels	
	Soederberg	Prebake	Soederberg	Prebake
Collection efficienty	80%	90%	95%	98%
Fluoride emission				
- Without roof scrubbing	3-5 kg/T-Al	1-3 kg/T-Al	0.9 kg/T-Al	0.4-0.5 kg/T-Al
- With roof scrubbing	0.8-1.2 "	0.7-1.1 "		

Héroult process, almost no other processes have been seriously implemented. Among the examples that have been seriously researched recently on a large scale or that are still being developed, there are the monochloride process and the carbide process of the 1960s and, since the 1970s, the aluminum chloride electrolysis process has been in operation in the United States on a pilot plant scale.1) On the other hand, the carbothermic reduction process by a blast furnace with no use of electricity has attracted attention in the USA and Japan. This section discusses especially the aluminum chloride electrolysis process and the blast furnace process whose future development is expected.

2.1 Aluminum Chloride Electrolysis Process

This process comprises the production of alumina, the production of aluminum chloride and the electrolysis of aluminum chloride. In this process, alumina particles are first coated with thermally-cracked carbon from heavy resin oil and chlorinated on a fluid bed to produce aluminum chloride on a large scale. Next, the electrolysis operation uses a horizontal or gradient electrode type multi-cell electrolysis furnace with the bath of sodium chloride - aluminum chloride as a basic composition to which is added lithium chloride and magnesium chloride. The electrolysis takes place at 700°C. The chlorine generated circulates to the aluminum chloride production. Table A-7 compares the aluminum chloride process and the presently used Hall-Héroult process. Here are the distinctive features of the aluminum chloride process:

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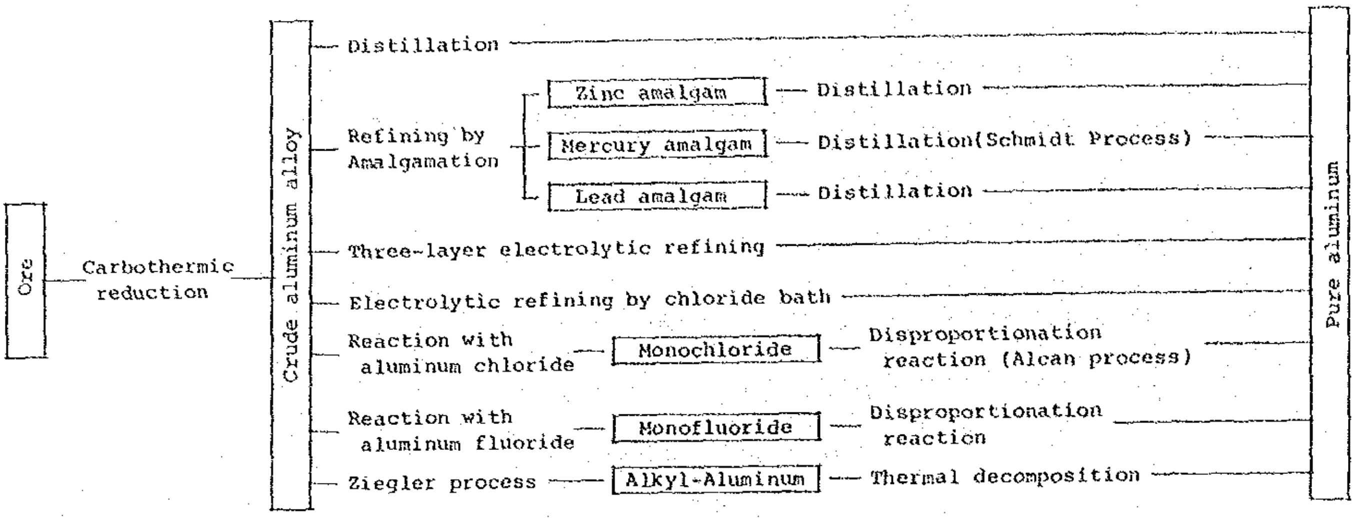
1) ALCOA is operating a plant in Anderson, Texas whose output is about 7,500 tonnes annually.

Table A-6 Classification of Aluminum Smelting Processes

(I) Methods: reduction operations precede



(II) Methods: refining operations precede

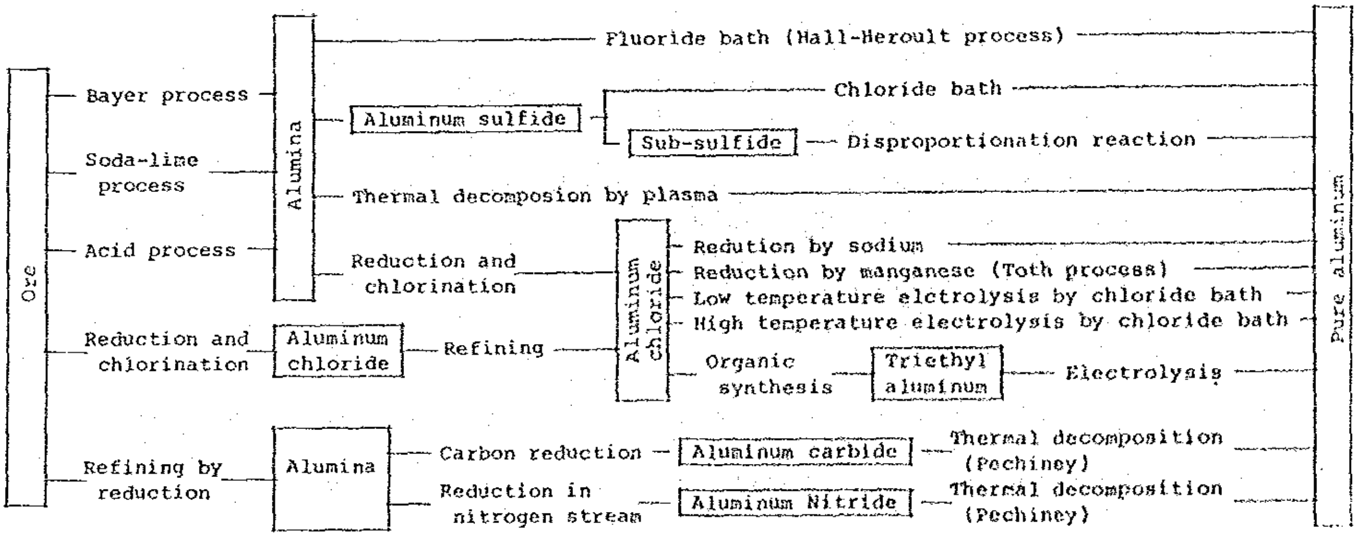


Table A-7 Comparison of Aluminum Chloride Electrolysis and Hall-Héroult Electrolysis

		Aluminum Chloride Process	Hall-Héroult Process
Furnace Design		Multi-Cell	Single-cell
Electrolysis Temperature	°C	700	960
Ore Concentration	%	$\sim$ 5% $AlCl_3$	2 - 7% Al_2O_3
Bath Composition		$AlCl_3$-NaCl-LiCl	Al_2O_3-Na_3AlF_3- AlF_3
Current Density	A/cm^2	0.8 - 2.3	0.6 - 1.0
Interpolar Distance	cm	1 - 2.5	4
Decomposition Voltage, (Theoretical)	V	1.8	1.2
Operating Voltage (Theoretical)	V	2.2	1.9
Anode Overvoltage	V	$\sim$ 0	0.5
Difference in Specific Gravity, Bath/Metal		0.8	0.2
Electrical Conductivity of Bath	$\Omega^{-1}cm^{-1}$	1.7 - 2	2.3
Vapour Pressure of Bath	Torr	< 30	2
Viscosity of Bath	cp	< 1.5	4
Viscosity of Aluminum	cp	3	0.6
Anode Consumption Rate	cm/day	$\sim$ 0	1
Voltage per Cell	V	3	4
Current Efficiency		0.85	0.89
Voltage Efficiency		0.74*	0.47*
Energy Efficiency		0.63*	0.42*
Electricity Consumption	kWh/t Al	10,500	13,400
Production Capacity (Per day per cell)	tonne	10 - 30	1
Anode Material		Graphite	Carbon

* Voltage efficiency and energy efficiency are based on theoretical operating voltage and theoretical electricity consumption respectively.

a. Compared to the Hall-Héroult process, the consumption of electricity is about 25% lower.

b. The productivity per unit of equipment is high.

c. The electrolytic furnace is tightly closed, so good working environment is maintained.

However, the following have become subjects for further research and development:

a. The development of construction materials for the electrolytic furnace which are resistant to bath attack.

b. Aluminum chloride's absorbency of moisture

c. Resources and cost of lithium chloride

d. The establishment of technology for a large scale production of aluminum chloride

2.2 Blast Furnace Process

Since high temperature over 2,000°C is required to reduce aluminum ore with carbon, an electric arc furnace had been used and the possibility of obtaining crude alloy containing aluminum had been tested. The blast furnace method uses a blast furnace instead of an arc furnace. It burns coke or other carbons in the air enriched with oxygen to obtain high temperature and lets carbon reduction take place. A characteristic of this process is that, unlike an arc furnace, it does not use electricity.

Two methods have been suggested recently for refining aluminum from the crude Al-Si-Fe alloy thus obtained. The first method is to expose the crude alloy, obtained from the blast furnace, in a molten lead bath of about 1,200°C, and after extracting aluminum, separate the lead with reduced-pressure distillation. The second method is to apply segregation operations to the crude alloy to eliminate most of Fe-Si, then electrorefine the remaining Al-Si alloy by using a chloride bath (e.g. lithium chloride - sodium chloride - aluminum chloride) and through a diaphragm made of porous graphite etc. to extract aluminum. Before the process can be put to practical use, there are many technologies to be further developed in future research developments, such as the technology for producing the Al-Si-Fe crude alloy with a blast furnace, the technology for extracting aluminum from this crude alloy and the technology for efficient use of the byproducts of Fe-Si alloy and a large quantity of carbon monoxide.

2.3 New Smelting Processes and Resources of Aluminum Ore

Bauxite is no more than one of many varieties of aluminum bearing minerals, but at present it is almost the only one used as aluminum ore. The following cases could be imagined in which the use of bauxite as aluminum ore would be eliminated:

a. If alumina is to be produced by a process other than the Bayer process, in which minerals such as clay are to become usable;

b. If aluminum production convert to a process that does not require alumina. In direct reduction, ores other than bauxite, such as clay or some other minerals, might be usable.

However, bauxite reserves are quite abundant and the quantity of this resource should present no problem in the future. Furthermore, it seems quite certain that the cost superiority of alumina obtained from bauxite will remain almost unchanged barring any extreme political raise of the price of bauxite.

The reason why a process other than the Hall-Héroult process is needed is that this process consumes a large quantity of electricity. In areas where electricity price has skyrocketed, processes that use no electricity, or only a little electricity, are being seriously investigated. However, the establishment of a non-Hall-Héroult process that can compete economically with the Hall-Héroult process in locations where cheap electricity is obtained from water power (hydroelectricity), coal, natural gas or other resources seems certain to be many years away.

Thus, the possibility of case "a" or "b" manifesting itself in a short term is still slight. In the future, it seems certain that bauxite will continue to play its role as the main raw material for aluminum.

Reference Table A-1 Mineralogy and Alumina Content of Non-Bauxite Rocks and Materials that are Possible Sources of Aluminum

Rock Mineral	Major Aluminous Minerals and Formula	Theoretical % of Al_2O_3 in Mineral	% of Mineral in Whole Rock or Material	% of Al_2O_3 in Whole Rock or Material
Aluminum phosphate rock	wavellite $Al_3(PO_4)_2\ (OH)_3 \cdot 5H_2O$	37.1	-	-
	millisite $(NaK)CaAl_6(PO_4)_4(OH)_9 \cdot 3H_2O$	37.4	variable	5-15
	kaolinite $(OH)_8SiO_4Al_4O_{10}$	39.5	-	-
Aluminous shale	illite $(OH)_4K_2(Si_6Al_2) \cdot (Mg.Fe)_6O_{20}$	38.5	variable	15-30
Alunite rock	alunite $KAl_3(SO_4)_2(OH)_6$	37.0	15-40	5.5-14.8
Coal washings	illite and kaolinite	38.5-39.5	variable	25-30
Coal ash	mullite $Al_6Si_2O_{13}$	84.0	minor	5-35
Dawsonite in oil shale	dawsonite $NaAl(OH)_2CO_3$	35.4	8±	3
High-alumina clay	kaolinite	39.5	75-95	> 30-35
Igneous rocks	plagioclase feldspar			
Anorthosite	$NaAlSi_3O_8$* $CaAl_2Si_2O_8$**	19.4 36.6	65-95	22-30
Nepheline syenite	nepheline $(Na,K)\ (Al,\ Si)_2O_4$	35.9	-	-
	alkalic feldspar $KAlSi_3O_8$	18.4	80±	20-25

* Albite $Na_2O \cdot Al_2O_3 \cdot 6SiO_2$
** Anorthite $CaO \cdot Al_2O_3 \cdot 2SiO_2$

Source: AME

Reference Table A-2 Estimates of World Bauxite Reserves (million tonnes bauxite)

Country	USBM 1976a)	USBM 1978b)	Otherc)	Main Bauxite Type	Grade Al_2O_3 (%)
WEST BLOC:					
Africa:					
Cameroon	762	1,016		gibbsite	44
Guinea	4,572	8,332	8,200 IBA Mar. 1979	gibbsite	44-62
			3,572 Measured IBA June 1980		
Ghana	335	580	780 IBA Sept. 1977	gibbsite	50-54
			450 MB 11 May 1976		
Sierra Leone	122	132	100 ACDC 1978	gibbsite	52
South Africa	nas	nas	20 Min J 14 Oct. 1977		
			50 ACDC 1978		
Other nas	102	102			
Total	5,893	10,162			
USA:	40	40		gibbsite	50-58
Latin America:					
Brazil	2,540	2,540	3,072 Measured IBA June 1980	gibbsite	40-59
			2,500-5,000 MB 5 Dec. 1980		
Costa Rica	nas	nas	136 ACDC 1978		
Colombia	nas	nas	400 Reuters 22 Mar. 1979		
Dominican Republic	nas	nas	32 Measured IBA Mar. 1977	gibbsite/ boehmite	25
Guyana	152	1,016		gibbsite	35-65
Haiti	nas	nas	7 IBA Dec. 1975	gibbsite/ boehmite	50av.
Jamaica	1,016	2,032	2,000 EMJ Nov. 1977	gibbsite/ boehmite	50av.
			>1,500 IBA Sept. 1976		
Surinam	508	498		gibbsite	45-60
Venezuela	nas	nas	37 Measured IBA June 1980	gibbsite	49av.
			500 EMJ Nov. 1977		
Other nas	213	234			
Total	4,429	6,320			

Reference Table A-2 (cont'd.)

Country	USBM 1976a)	USBM 1978b)	Otherc)	Main Bauxite Type	Grade Al_2O_3 (%)
Asia:					
India	305	1,422	1,600 Ind Min Nov. 1978	gibbsite	52-58
			122 Measured IBA June 1980		
Indonesia	406	711	700 IBA Dec. 1975	gibbsite	53av.
Malaysia	nas	nas		gibbsite	56-58
Philippines	nas	nas	63 MW 7 Apr. 1980		40-50
			100 ACDC 1978		
Turkey	nas	nas	21 Measured IBA June 1980		60
South Korea	nas	nas	10 Min Mag June 1976		
Other nas	50	50			
Total	761	2,183			
Western Europe:					
France	nas	nas	25-30 IBA Sept. 1978	boehmite (some gibbsite and diaspore)	55-60
Greece	762	762	119 Measured IBA June 1980	boehmite	53-65
			1,000 Min Mag Dec. 1980	(some gibbsite	
			900 Ind Min Dec. 1979	and diaspore)	
Yugoslavia	203	406	200 Measured IBA June 1980		
Other nas	102	91			
Total	864	1,259			
Oceania:					
Australia	4,572	4,572	4,600 IBA June 1980		
			4,443 Aus Min Ind Quart 32 (1979)	gibbsite (minor boehmite)	30-62
			4,440 BMR 1980		
Other nas	50	50			
Total	4,622	4,622			
Total Free World:	16,609	24,586			

Reference Table A-2 (cont'd.)

Country	USBM 1976[a)]	USBM 1978[b)]	Other[c)]	Main Bauxite Type	Grade Al_2O_3 (%)
The Centrally Planned Economies					
China	152	152	100 EMJ Aug 1978	diaspore/ boehmite	
Hungary	152	203	230-240 Min J 28 May 1976	boehmite/ gibbsite/ diaspore	45-60
Romania	nas	nas		boehmite/ gibbsite/ diaspore	45-60
USSR	152	152	250 ACDC 1978	boehmite/ diaspore (some gibbsite)	26-52
Total	456	507			
World Total	17,268	25,093			

a) USBM, 1976. Mineral Facts and Problems

b) USBM, 1978. Aluminum (Mineral Commodity Profiles MCP - 14)

c) ACDC = Aluminum Conductor Development Corp.; for other abbreviations, see the list at the beginning of Part A.

Reference Table A-3 Range of Chemical Constituents (% content) of Bauxite

(from Shaffer, 1975; EMJ Nov. 1975 for Trombetas; IBA QR Mar. 1979 for Guinea; IBA QR Mar. 1977 for Dominican Republic; and IBA QR Sept. 1980 for Jamaica)

Country and Location of Deposit	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	LOI*
Australia:					
Cape York	52-60	2-10	5-13	2.1-3.1	21-29
Gove	48	3-4	17	3-4	26
Darling Ranges	30-48**	n.a.	n.a.	n.a.	n.a.
Kimberley	47-50	2.5-3.5	n.a.	n.a.	n.a.
Brazil:					
Trombetas Nodular	47.1	7.1	8.2	1.3	27.9
Trombetas Massive	49.9	4.8	9.3	1.4	28.6
Minas Gerais	55-59	1.6-5.6	6.9-9.6	1.1-2.0	25-30
China	50-70	9-15	1-13	2	n.a.
Dominican Republic	50	5	20	n.a.	25
France	55-70	3-16	4-25	2-3.5	n.a.
Ghana:					
Awaso	48-61	0.4-2.4	4-22	0.8-2.1	26-33
Kibi	32-60	0.3-2.9	6-45	2.0-6.2	13-30
Nyinahin	41-63	0.3-3.1	1.2-30.9	1.5-5.3	
Guinea:					
Fria	48	2.5	21	2.2	25
Sangaredi	60-61	0.3-0.7	2-4	3-5	30
Guyana	51-61	4-6	1-8	2-3	25-32
Haiti	48.6	3.4	21.9	2.8	24.1
Hungary	50-60	1-8	15-20	2-3	13-20
India	45-60	1-5	3-20	5-10	22-27
Indonesia	53	4-5	12	n.a.	n.a.
Jamaica:					
St. Ann	47.3	1.3	19.8	2.4	27.9
Clarendon	48.5	0.5	18.8	2.4	26.4
Average Jamaica	49-51	0.7-1.6	19-21	2.5-2.7	25-27
Malaysia	38-60	1-13	3-21	1.2	n.a.
Sierra Leone	51-55	1.5-2	10-18	1.5	27-31
Surinam	50-60	2-6	2-15	2-3	29-31
Turkey	55-60	5-7	15-20	2-3	12-14
USA:					
Arkansas	45-57	5-24	2-12	1.6-2.4	22-28
Oregon & Washington	31-35	5-11	33-35	5-6	16-20
Southeast states	51-56	12-15	1-5	1.5-3.5	22-30
USSR	26-52	2-32	1-45	1.4-3.2	n.a.
Yugoslavia	48-60	1-8	17-26	2.5-3.5	13-27
Romania	55	5	22	1-2	n.a.

* loss on ignition

** available

B. PRODUCTION

I. Trend of Aluminum Production

1. Bauxite Production

The world total production of bauxite was 37.292 million tonnes in 1965 and 92.623 million tonnes in 1980, showing an increase of approximately 2.5 times over the level of 1965. The average annual rate of growth during that period is 6.3%. Reference Table B-1 gives details on bauxite production for all major producing countries during the period.

The most remarkable characteristic in the growth of bauxite production is that, while the rank among major producing countries has been changed, the production has been concentrated to the major producing countries and their share have increased. The five major producing countries in 1965 were Jamaica, the USSR, Surinam, Guyana and France, and the total share of these five countries was 62.4%. As of 1980, the five major producing countries were Australia, Guinea, Jamaica, the USSR and Surinam in that order, with the total share of 68.9%. Table B-1 summarizes the changes in the shares of world bauxite production of the major producing countries for every five year.

Production increased significantly in Australia, which started commercial production in the second half of the 1960s, rising from a little over 1.1 million tonnes in 1965 to more than 27 million tonnes in 1980. Similarly, production in Guinea grew from 1.6 million tonnes in 1965 to more than 13 million tonnes in 1980. Jamaica's production also increased from slightly more than 8.6 million tonnes in 1965 to 12 million tonnes in 1980. Jamaica, which once enjoyed the position of the largest producing country in the world, has been overtaken by growing Australia and Guinea, and currently ranks third. Reference Fig. B-2 indicates the changes in production levels of the main producing countries.

As the data indicate, the largest bauxite producing country in the world is currently Australia followed by Guinea, Jamaica, the USSR, Surinam, Brazil, Greece and Yugoslavia. These eight countries now account for more than 80% of total world production. Above all, Australia now ranks as the world's single largest producer and accounts for approximately 30% of total world production. Guinea is the second largest producer, accounting for 14% and Jamaica 13%. Of the world total bauxite production of 92 million tonnes, the output

Table B-1 Changes in Production Share of Major Bauxite Producing Countries
(Percentage share of total world production)

Figures shown in ( ) indicate the ranking.

	1965	1970	1975	1980
Australia	-	(2) 15.2	(1) 27.2	(1) 29.3
Guinea	4.3	4.1	(3) 11.0	(2) 14.4
Jamaica	(1) 23.2	(1) 19.8	(2) 15.0	(3) 13.0
USSR	(2) 12.6	(3) 10.7	(4) 8.5	(4) 6.9
Surinam	(3) 11.7	(4) 9.9	(5) 6.1	(5) 5.3
Brazil	-	-	-	4.5
Greece	3.4	3.8	3.9	3.5
Yugoslavia	4.2	3.5	3.0	3.4
Guyana	(4) 7.8	(5) 7.3	5.0	3.3
Hungary	4.0	-	3.7	3.2
France	(5) 7.1	5.0	3.3	-
USA	4.5	3.5	-	-
Total share of the first 5 major producers	62.4	62.9	67.8	68.9
Total share of the first 10 major producers	82.8	82.8	86.7	86.8

Source: Metal Statistics, 1965-75, 1970-80

of these three major countries reaches 52 million tonnes, or approximately 57% and approximately 65% of the free world production. In conclusion, the most obvious characteristic of bauxite production is its concentration to a limited number of countries abundant in natural resources.

2. Alumina Production

As described above, the demand for alumina is divided into two categories, metallurgical and non-metallurgical. The demand for non-metallurgical alumina accounts for approximately 10% of the total alumina production.[1] Due to a lack of published data for the

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[1] On the basis of the 1981 Statistical Survey of the International Primary Aluminum Institute (IPAI), free-world production of alumina in 1981 totaled 26.648 million tonnes, of which metallurgical alumina was 24.461 million tonnes and non-metallurgical alumina 2.187 million tonnes.

breakdown of alumina production, this Section shows the trend of alumina production based on total alumina production including non-metallurgical alumina. The world alumina production in 1966 [1] was 14.784 million tonnes and 35.053 million tonnes in 1980, showing an increase of 2.4 times over the 1966 level. The average annual rate of growth between 1966 and 1980 was 6.3%, being the same rate for bauxite recorded between 1965 and 1980.

Reference Table B-2 shows the production data for the period 1966-1980.

As the data indicate, the characteristic of alumina production is that the major producing countries have not changed at all since 1970.

Table B-2 Changes in Production Share of Major Alumina Producing Countries (Percentage share of total world production)

Figures shown in ( ) indicate the ranking.

	1966	1970	1975	1980
Australia	2.1	(3) 10.2	(2) 19.2	(1) 20.7
USA	(1) 35.9	(1) 28.5	(1) 19.2	(2) 20.0
USSR	(2) 17.6	(2) 12.7	(3) 11.2	(3) 9.3
Jamaica	(5) 5.4	(4) 8.1	(4) 8.5	(4) 6.8
Japan	4.5	(5) 6.1	(5) 5.9	(5) 6.3
Germany, Fed. Rep.	4.1	3.6	4.7	4.6
Surinam	2.8	4.9	4.3	4.1
France	(4) 5.7	4.7	4.1	3.8
Yugoslavia	-	-	-	3.6
Canada	(3) 6.1	5.2	4.3	3.4
Hungary	-	-	2.8	-
Guinea	3.6	2.9	-	-
Total share of the first 5 major producers	70.7	65.6	64.0	63.1
Total share of the first 10 major producers	87.8	86.9	84.2	82.6

Source: Metal Statistics, 1965-75, 1970-80

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[1] World production figures for alumina in 1966 was used as the base data from Metal Statistics (MS) 1965-1975.

The five major producing countries in 1966 were the United States, the USSR, Canada, France and Jamaica, and since 1970 they have consisted of the United States, the USSR, Jamaica, Japan and Australia. There have been the changes in the share of these five countries. Particularly production of Australia showed remarkable growth, increasing from slightly more than 0.3 million tonnes in 1966 to 7.25 million tonnes in 1980. Australia has now become the largest producing country for both alumina and bauxite. It has an overwhelming alumina share, accounting for approximately 20% of total world production and roughly 25% of that of the free world. The United States and the USSR, the major alumina producing countries next to Australia, showed increases in production but their share fell down under the pressure of Australia's rapid growth. However, the United States still maintains its position of a major alumina producing country and can compete with Australia. These two countries account for approximately 40% of the world production and approximately 50% of the free world production.

Reference Fig. B-3 summarizes the changes in production for these main producing countries. As the data indicate, world alumina production is concentrated to the major producing countries, as in the case of bauxite. For bauxite, the ten major countries produce approximately 87% of the world total, while the ten major countries account for approximately 83% in the case of alumina. Furthermore, excluding countries such as Japan and the Federal Republic of Germany which produce only small quantities of bauxite or do not produce it at all, the major bauxite producing countries are also the major alumina producers. In the major bauxite producing countries, bauxite, being the primary resource, tends to be further processed to alumina, being the industrial product, to add the value.

Attention should be paid to the fact, however, that the degree of concentration to the major producing countries has been steadily decreasing since 1966. The shares of five and ten major countries were approximately 71% and 88% respectively in 1966 and fell down to approximately 63% and 83% respectively in 1980 as the result of continuous decline in shares for that period. This change in shares indicates the decentralization of world production and such trend can be also seen in the case of primary aluminum production as referred to in Subsection 3 below.

3. Primary Aluminum Production

Needless to say, the production of bauxite and alumina changes in response to primary aluminum production. Therefore, more detailed observation of the changes in primary aluminum production is necessary.

Primary aluminum production was 6.586 million tonnes in 1965 and 16.064 million tonnes in 1980, showing an increase of about 2.4 times over the level of 1965. The average annual growth rate between 1965 and 1980 was 6.3%. Reference Table B-3 shows the production data by country for the period 1965-1981.

Latin America grew at the highest rate for these 15 years. In contrast lower growth rates were recorded in North America and the centrally planned economies. The growth of production between 1965 and 1981 is summarized as follows.

Latin America	15.5 times
Africa	8.7 times
South Asia	6.2 times
Oceania	6.1 times
Europe	2.9 times
East Asia	2.6 times
The C.P. Economies	2.2 times
North America	1.8 times

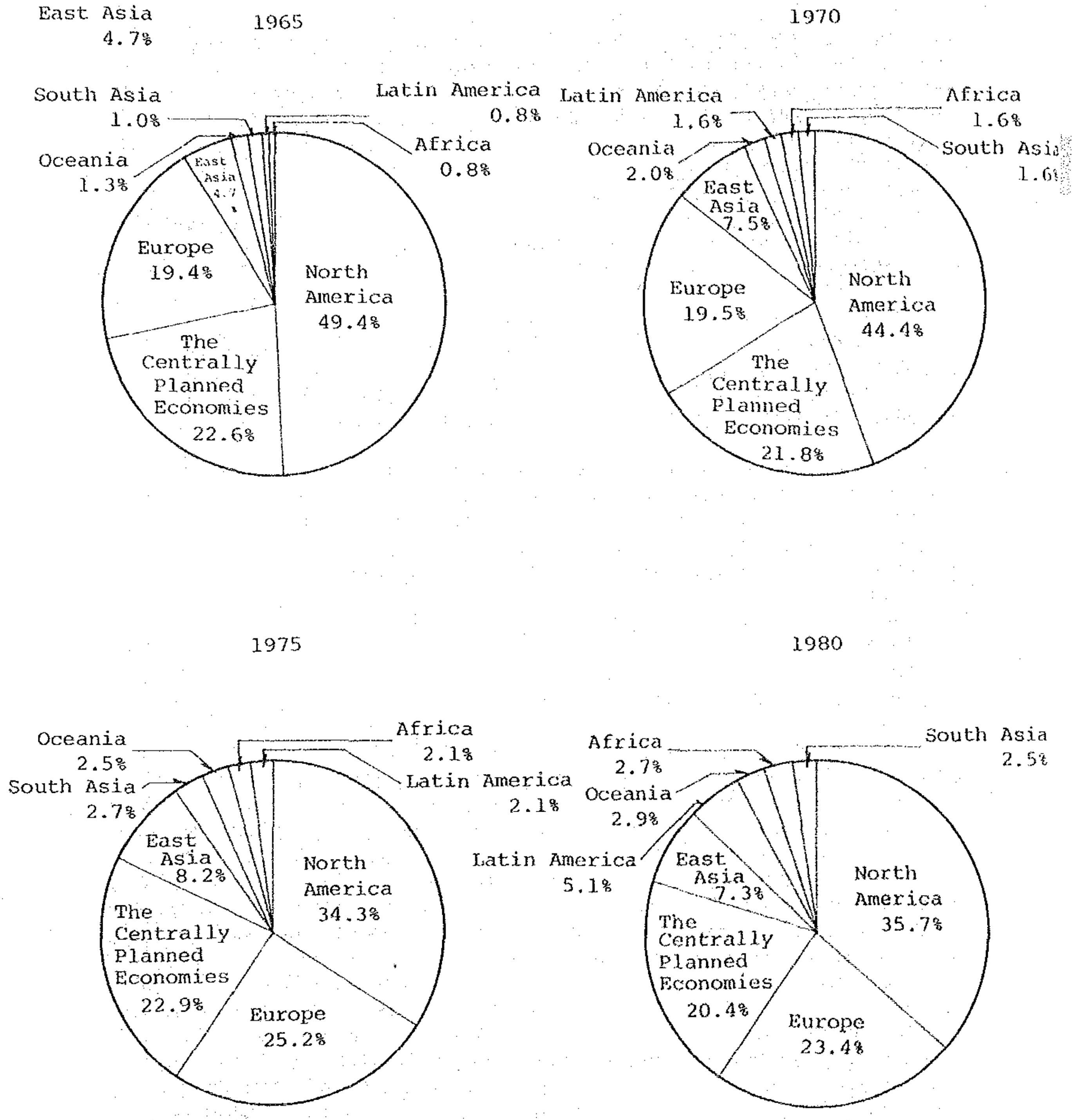
Fig. B-1 shows the changes in the percentage shares of world primary aluminum production by geographical area.

Primary aluminum production, which has grown rapidly, is characterized by a concentration of production to the developed countries. Assuming the developed regions in the free world consist of North America, Europe and East Asia (mainly Japan), the change in total share of these regions is summarized as follows:

1965	95%
1970	91%
1975	88%
1980	83%

In particular, the position of the United States is so strong that it has remained in the first rank since the beginning of aluminum smelting industry. With the development of production in other countries, the share of the United States has been declining every year, but it still produces almost 30% of total world production. The combined share of the United States and Canada is almost 36%, with their combined annual production capacity amounting to more than 6 million tonnes. The major producing countries next to them are the USSR, Japan, the Federal Republic of Germany, Norway, France. Each of these is stably keeping the share of production. As stated above, the main primary aluminum producing countries have remained almost unchanged, as in the case of alumina. Table B-3 indicates the changes in the percentage share of production for the major producing countries, showing the above-mentioned trend, and Reference Fig. B-4 shows changes in production for these major producing countries.

Fig. B-1 Percentage Share of World Primary Aluminum Production by Geographical Area



Source: Metal Statistics, 1965-75, 1970-80

Table B-3 Changes in Production Share of
Major Primary Aluminum Producing Countries
(Percentage share of total world production)

Figures shown in ( ) indicate the ranking.

	1965	1970	1975	1980
USA	(1) 37.9	(1) 35.0	(1) 27.4	(1) 29.0
USSR	(2) 18.2	(2) 16.5	(2) 16.7	(2) 15.1
Japan	(5) 4.4	(4) 7.1	(3) 7.9	(3) 6.8
Canada	(3) 11.4	(3) 9.3	(4) 6.8	(4) 6.7
Germany, Fed. Rep.	3.6	3.0	(5) 5.3	(5) 4.5
Norway	4.2	(5) 5.1	4.6	4.1
France	(4) 5.2	3.7	3.0	2.7
Spain	-	-	-	2.4
UK	-	-	2.4	2.3
China (mainland)	1.4	1.7	2.3	2.2
Netherlands	-	-	2.0	-
Australia	1.3	2.0	-	-
India	-	1.6	-	-
Italy	1.9	-	-	-
Total share of the first 5 major countries	77.1	73.0	64.1	62.1
Total share of the first 10 major countries	89.5	85.0	78.4	75.8

Source: Metal Statistics, 1965-75, 1970-80

Table B-3 also indicates that the share of the major producing countries has been declining every year. As the shares of the developed regions have been falling, the share of ten major producing countries has also been slowly declining. The share of the ten major producing countries was about 90% in 1965 and about 76% in 1980. This trend indicates that the world production of both primary aluminum and alumina has been decentralizing. Namely a number of new producers appeared, having undermined the position of traditional main producing countries. Reference Fig. B-5 shows the main primary aluminum producing countries. (Regional grouping is based on IPAI statistics as shown in note 1) and difinition is explained in Reference Fig. B-5.)

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1) Regional area is based on IPAI statistics which divides the free world into seven geographical areas, and the centrally planned economies is added as Area 8 (See Reference Fig. B-6).

Reference Fig. B-5 shows the following countries commenced primary aluminum production between 1960 and 1970.

Africa : Ghana
Latin America : Mexico, Surinam, Venezuela
Europe : Greece, Netherlands, Iceland
The C.P. Economies: Romania, Poland

Furthermore, countries which began producing primary aluminum production between 1971 and 1982 are as follows:

Africa : South Africa, Egypt
Latin America : Argentina
East Asia : South Korea, Indonesia
South Asia : Bahrain, Iran, Turkey, Dubai
Oceania : New Zealand

Besides these, countries such as Brazil, India, Spain, Australia and Yugoslavia have been steadily increasing their production.

It should be noted that new producers of primary aluminum appeared mainly in the so-called developing countries. The production capacity of the countries mentioned above totals approximately 4 million tonnes (About 20% of 1982 world production capacity) and their position has become very strong.[1]

In fact, the trend of such decentralization of primary aluminum production is changing the situation of world aluminum production and creating significant changes in the structures of world aluminum industry.

4. Recent Trend in Production

Based on the above study, primary aluminum production seems to have experienced a continuous high rate of growth, along with alumina and bauxite production after the Second World War. Certainly, such was the case until 1974. Primary aluminum production continued to expand and this brought about corresponding increase in alumina and bauxite production.

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[1] UNCTAD (United Nations Conference on Trade and Development) Report regards Argentina, Brazil, Venezuela, Yugoslavia, Egypt, Ghana, Bahrain, India and others as developing countries, and the production share of these developing countries has increased as follows:

1960 - 2.6%   1975 - 7.9%
1965 - 3.5%   1977 - 8.3%
1970 - 5.7%   1979 - 10.4%

However, world aluminum industry faced the necessity of a large production cutback in 1975 for the first time in its history due to the worldwide recession after the first oil crisis. Free world primary aluminum production in 1975 decreased by as much as 11% over the previous year, to the level of 1972. In 1975, the operating rate sharply fell to a level of 81%, from 92% in 1974.

Nevertheless, this cutback in production caused relatively little damage, since business activity again began an upswing from the bottom of 1975, and in 1977 returned to the level of 1974, the previous peak year. The rising curve of increased production returned to the past pattern, and this growth trend continued for about 4 years until 1980. (See Reference Fig. B-1)

During this period of growth, however, it must be noted that a fundamental change was in progress in the world aluminum smelting industry. In other words, in spite of the decline in 1975, new projects were established one after another and commenced production. Especially, the developing countries showed a striking trend towards the opening of new smelters. The annual production capacity in the developing countries which newly commenced production between 1975 and 1980 reached 820,000 tonnes, exceeding such capacity of the developed countries in the same period.1)

Consequently, annual free world production capacity, which was 12 million tonnes in 1975, increased by 15% to 13.83 million tonnes in 1980. As a result, the level of free world operating rate of 1974 was restored finally in 1980.

Under such circumstances, the aluminum industry encountered the further recession of world business activity in the wake of the second oil crisis. From the first half of 1981, free world primary aluminum production began to show a steep decline month after month.

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1) Countries which newly commenced production between 1975 and 1980 were as follows:

	Developing countries	Annual capacity	
1975	Egypt	(166,000 T/y)	
	Argentina	(140,000 ")	
	India	(100,000 ")	
1978	Venezuela	(280,000 ")	
1979	Dubai	(135,000 ")	(Total 821,000 T/y)
	Developed countries		
1975	Japan	(100,000 T/y)	
1978	Spain	(180,000 ")	
1980	USA	(179,000 ")	
	Canada	(171,000 ")	(Total 630,000 T/y)

In addition, new smelters began production in Brazil (86,000 T/y), Indonesia (225,000 T/y) and Australia (204,000 T/y) for 1981-1882.

This decline was so drastic that as of July 1982, the average operating rate of the free world fell down to 73%, far more sharp decline than 1975. The present level of production is equal to that of 1976, six years ago, or that of 1973, nine years ago. Recent free world annual production capacity, actual production and operating rate in terms of daily production basis are shown in Fig. B-2, which provides a vivid picture of these circumstances. It seems that the aluminum industry of the free world which appeared to overcome the decline in 1975, have run into real stagnation.

Nevertheless, if such a state of stagnation was purely a result of the business recession, the problem would not be so complicated. The problem is, however, serious because the various difficulties which the free world aluminum industry has been compelled to face in the present business recession have been deeply connected with the structure of the aluminum industry itself. Reference Figs. B-6-1 to B-6-7 illustrate the recent situation of free world aluminum production by region (Based on IPAI regional grouping). As shown clearly, the decline is most serious in North America, Europe and East Asia, and the situation is particularly desperate in East Asia (mainly Japan), where production capacity itself is steadily decreasing. Production cutbacks are also severe in North America (mainly the United States), where the operating rate has declined to 72%. Compared with those regions, Europe is in a more stable position, keeping the operating rate of as much as 82%.

In contrast, the four regions of Africa, Latin America, South Asia and Oceania show no sign of production cutbacks at all. The low operating rate in certain regions (Latin America and South Asia) is mainly caused by operational problems, and is not likely to indicate voluntary production cutback. For example, the full operation continues in Africa and Oceania in spite of the prevailing difficult circumstances.

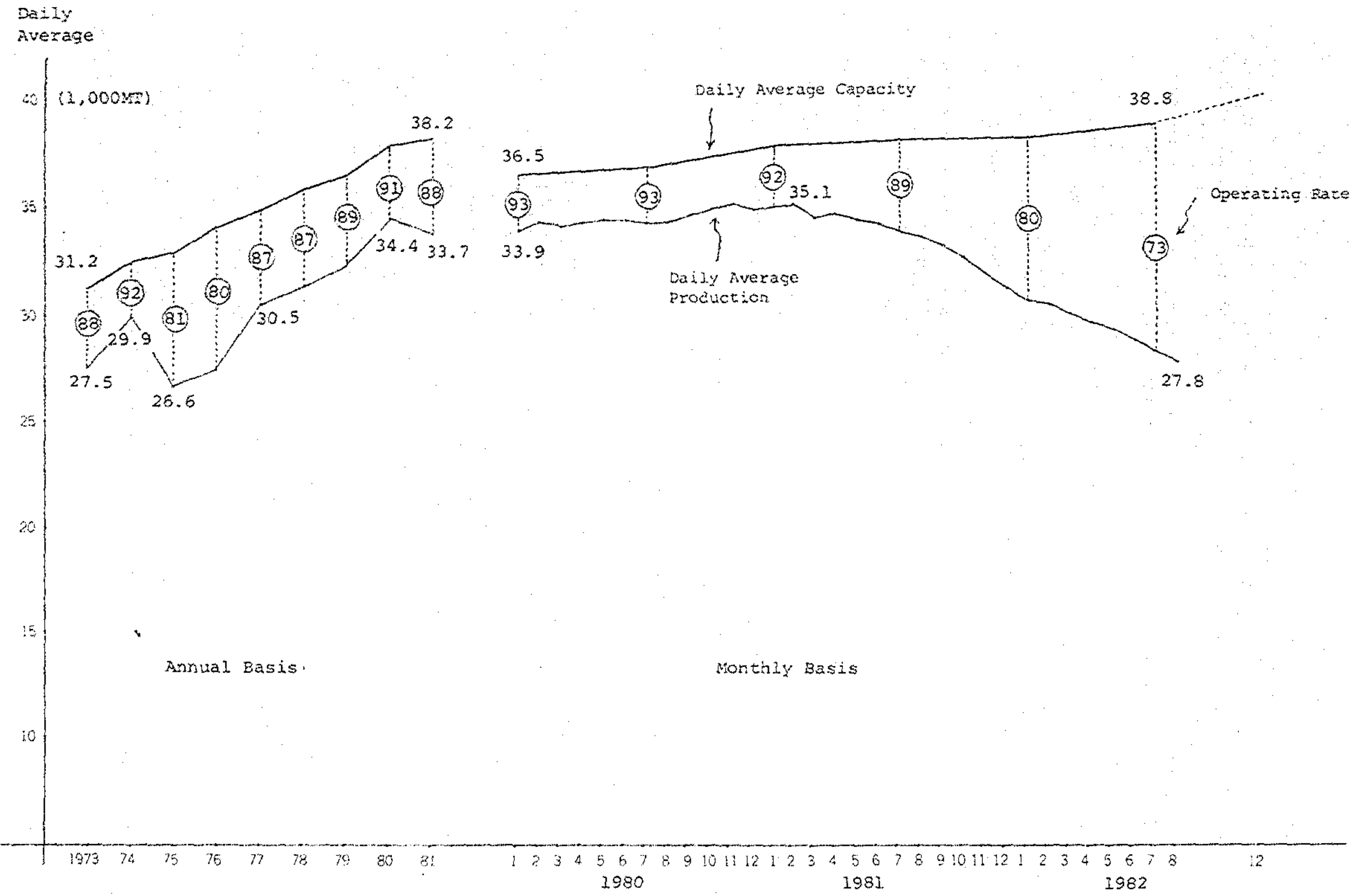
In summary, the current business recession has struck a blow to the developed countries, where almost all smelters fell into a relatively disadvantageous position, and it has on one hand given a chance of getting a larger market share to the developing countries with relatively advantageous smelters.

II. Structure of the Aluminum Industry

1. Balance of World Supply and Demand

The level of world production, as already discussed, changes

Fig. B-2 Trend of Primary Aluminum Production and Capacity in Free World



Source: IPAI, Statistical Summary

dependent upon the actual conditions of demand and consequently cannot give a true picture of world supply and demand. The world supply and demand should, therefore, be discussed in terms of surplus and shortfall, based on the production capacity of individual countries. A comparative study is made below on the actual supply and demand balance and the balance based on capacity of bauxite, alumina and aluminum in the main countries, referring to Reference Tables B-1 to 3 and Appendix Table 1.[1]

1.1 Bauxite

Actual Balance

(million tonnes)

	Surplus in producing countries	Shortfall in consuming countries	Balance
1977	36.1	27.6	+8.5
1980	39.6	33.6	+6
Balance Based on Capacity (1981)			
Rated capacity	50	33.7	+16.3
Operating rate 90%	45	30.3	+14.7
Including stockpiles	42	32	+10

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[1] The method of calculation is as follows:

[Bauxite]
Surplus in producing country:
Bauxite production (actual or capacity)
- Domestic consumption for alumina production [= alumina production (actual or capacity) x 2.55]
Shortfall in consuming country:
Bauxite demand [= alumina production (actual or capacity) x 2.4] - Domestic bauxite production

The unit consumption is the weighted average value of AME (Australian Mineral Economics Pty Ltd.) data. Reference Table B-4-1 shows the unit consumption for individual countries.

[Alumina]
Surplus in producing country:
Alumina production (actual or capacity)
- Domestic consumption for aluminum production [= aluminum production (actual or capacity) x 1.95]
Shorfall in consuming country:
Alumina demand [= aluminum production (actual or capacity) x 1.95] - Domestic alumina production

It is noted that above calculatioin is applied only to the main countries.

Though details cannot be discussed based on the above simple calculation, it will be possible to grasp a rough trend. Bauxite is now in the situation of a worldwide surplus of capacity. Even if the operating rate is regarded as 90%, taking stockpiles into account (5% for both producing and consuming countries), surplus amounts to about 10 million tonnes. This supply and demand situation almost applies to entire free world. If free world production, 80 million metric tonnes for 1980, grew at an annual rate of 5%, this 10-million tonne surplus capacity would be sufficient to cover the growth in demand for about 3 years. As already mentioned, since demand has drastically cooled after 1981, five to six years may be easily covered by this surplus capacity, if taking into account the recovery period from this sluggish demand. Needless to say, the major supplying countries are Australia, Guinea, Jamaica, Surinam, etc. Reference Table B-4-1 indicates the balance of supply and demand for the major countries.

1.2 Alumina

Actual Balance (including non-metallurgical use)

	Surplus in producing countries	Shortfall in consuming countries	Balance
1977	12	9.1	+2.9
1980	14.7	11.8	+2.9
Balance Based on Capacity (1981)			
Rated capacity	15.9	11	+4.9
Operating rate 90%	14.3	9.9	+4.4
Including stockpiles	13.6	10.4	+3.2
Excluding non-metallurgical use	12.2	9.4	+2.8

To study supply and demand balance for alumina is quite difficult because of the following reasons. First of all, the operating rate for alumina production plant varies considerably, and, in some cases, alumina may be produced at the rate exceeding the rated capacity by as much as 20%. As for demand side, there are many smelters whose actual capacities are unknown. Furthermore, demand for non-metallurgical alumina fluctuates by roughly 10% in terms of overall demand of alumina. Consequently, the table above may contain some contradiction. For example, the shortfall of alumina in consuming countries estimated from the rated capacity in 1981 was 11 million tonnes, but the shortfall estimated from the actual production in 1980 was a higher figure at 11.8 million tonnes.

Despite such minor inaccuracy, it can be said that there exists a surplus capacity in the alumina supply and demand. The greater part of this surplus capacity is in the free world and is estimated to be in the vicinity of 3 million tonnes. This estimate is supported by the fact that demand for alumina in 1980, the peak year, was approximately 27 million tonnes 1) while production capacity in 1980 was approximately 30 million tonnes.

A surplus capacity of 3 million tonnes, if calculated in the same way as for bauxite, represents the quantity of about 2 years' growth of demand. Taking the estimated recovery period from present sluggish demand into consideration, the surplus capacity is sufficient for covering the demand for 4 to 5 years. As indicated in Reference Table B-4-2, the major supplying countries are Australia, Jamaica, Japan, Surinam, and others.2)

1.3 Primary Aluminum

For primary aluminum, an estimate similar to that for bauxite or alumina cannot be made. This is because the balance of supply and demand is mainly related to consumption. The balance of primary aluminum production and consumption for the major countries is given in Reference Tables B-5-1 and 2. For the purpose of the study, Tables above are based on the years of 1977 (supply and demand recovered to the normal level from the decline in 1975) and 1981 (an example of the recent decline). The main points are summarized as follows:

(1) In 1977, the world supply and demand was balanced (production: 14.3 million tonnes; consumption: 14.5 million tonnes), but in 1981, overproduction reached 1.15 million tonnes (production: 15.7 million tonnes; consumption: 14.55 million tonnes).

(2) The United States had a shortfall of 0.64 million tonnes in 1977; but conversely a surplus of 0.35 million tonnes in 1981.

(3) Japan experienced a shortfall of 0.23 million tonnes in 1977, but production cutbacks were progressively carried out resulting in a dramatic increase of shortfall to 0.8 million tonnes in 1981.

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1) Primary aluminum production in 1980 (12.8 million tonnes) x 1.95 → Alumina for metallurgical uses (25 million tonnes) + Alumina for non-metallurgical uses (2 million tonnes)

2) According to AME, the surplus supply capacity for bauxite and alumina are as follows:

Bauxite: (from 1980 to 1985)
From 8 million tonnes to 25 - 26 million tonnes
Alumina: 1981: 2 to 3 million tonnes
1985: 5 million tonnes

(4) Surplus supply position has been continued in the countries which have small or almost no domestic consumption. The main supplying countries in terms of surplus and shortfall in 1981 were as follows:

Supplying countries having a surplus production over consumption:

Canada	(820,000 tonnes)
Norway	(530,000 ")
USA	(350,000 ")
Venezuela	(240,000 ")
Spain	(190,000 ")
Ghana	(190,000 ")
Australia, New Zealand, Bahrain, UAE, Egypt, Argentina and others	

Total surplus: 4 million tonnes

Supplying countries showing a shortfall production against consumption:

Japan	(800,000 tonnes)
Germany, Fed. Rep.	(290,000 ")
Belgium	(210,000 ")
China	(210,000 ")
Italy, France, South Korea and others	

Total shortfall: 2.60 million tonnes

As shown above, the supply surplus in the major countries reached 1.40 million tonnes. This quantity almost equals the total annual production capacity of new plants which have commenced production since 1975.

To summarize the above data, the balance of world bauxite supply and demand stands at a supply surplus position, and alumina is also in a supply surplus position to a smaller degree. The balance of supply and demand for primary aluminum, which depends on consumption, is now in a significant over-supply position. There is no sign of recovery from this supply surplus position.

2. The Major Producers of the Aluminum Industry

The aluminum industry is not a simple aggregate of companies operating independently with each other. In the history of the development of the aluminum industry, enormous power has continued to be exerted by the existence of the big companies known as the six Major Producers. Two companies, in particular, the Aluminum Company of America (ALCOA), formerly the Pittsburgh Reduction Company, established in 1888 by C.M. Hall to commercialize his patent, and the Aluminum Company of Canada (ALCAN), an offshoot of ALCOA to make use of the abundant hydroelectric power resources in Canada, are gigantic companies accounting for 23, 33 and 24% of the free world production capacity for bauxite, alumina and primary aluminum in 1980 respectively. At the same time, in Europe where M. Héroult's technology was developed, France and Switzerland established their aluminum industries to have two Major Producers, Aluminium Pechiney and Swiss Aluminium Company (ALUSUISSE). In 1980, the share of these two companies reached 8, 12 and 13% of the free world production capacity for bauxite, alumina and primary aluminum respectively.

Before the Second World War, the production capacity of these four big companies was so large as to account for about 60% of total world capacity, including the USSR. With the post-war economic recovery, both the Reynolds Metals Company and Kaiser Aluminum and Chemical Corp. commenced production of primary aluminum in the United States, breaking the monopoly of ALCOA and ALCAN. These two companies thereafter increased production steadily and, their share in the free world production capacity in 1980 reached 13, 19 and 16% for bauxite, alumina and primary aluminum respectively. Table B-4 shows the percentage share of production capacity for these six Major Producers. The aggregate of their shares has reached enormous proportions, i.e., 43, 64 and 52% for bauxite, alumina and primary aluminum respectively. Judging from these figures, the world aluminum industry is definitely dominated by the six Major Producers.

The main points to explain the strong position and the effective strategy of the Major Producers are summarized as below. The first is the efforts of the Major Producers to secure relatively low-cost energy. Their utilization of the abundant hydroelectric power resources and the relatively low-priced energy such as coal-fired electric power in the United States, Canada and Europe have resulted in their profit margins growing and their position strengthening further.

Table B-4 Percentage Share of Six Major Producers in Free World Production Capacity (1980)

(Unit: Ownership percentage in production capacity)

	Bauxite	Alumina	Aluminum
ALCOA	16.6	20.7	13.3
ALCAN	6.4	11.8	10.5
Kaiser	7.8	10.2	7.7
Reynolds	4.9	8.9	8.0
Pechiney	2.7	7.5	8.1
ALUSUISSE	5.0	4.5	4.7
Total for these 6 companies	43.4	63.6	52.3

Source: Compiled from Spector Report, UNCTAD Report, etc.

The second is the securing of sources of cheap raw materials. Originally, each Major Producer started as an aluminum smelter and then gradually continued to expand its activity into raw material sources. For example, to procure cheap bauxite from overseas sources, ALCOA acquired a mining area in Guyana as early as 1912, and subsequently acquired mines in Surinam, the Caribbean countries and other countries one after another. Kaiser and Reynolds, latecomers as Major Producers, also made positive efforts to secure overseas sources, such as Jamaica.

This industrial structure, known as vertical integration, constituted a formidable barrier to newcomers. This is because new companies were forced to purchase relatively highly-priced raw materials from the Major Producers whereas the Major Producers could obtain their raw materials at a low cost. The vertically integrated companies established self-sufficient system ranging from the raw materials to finished products, and they enjoyed profits at each stage of production process, i.e., bauxite, alumina, primary aluminum and finished product. To illustrate this situation of vertical integration established by each of the six Major Producers, Reference Tables B-6-1 to 3 list the bauxite mining companies, alumina producing companies and aluminum smelting companies related to the six Major Producers. In addition, Reference Figs. B-7-1 to B-7-3 summarize the state of vertical integration.

The third point is the economy of scale of production. In case the technology reaches a certain level, the increase of scale is classically the most effective method for reducing the unit production cost. The Major Producers have pursued and gained profits from this economy of scale in each stage of bauxite, alumina and aluminum production respectively.

The fourth point concerns variety of products and strong securing their markets. Diversified production structure of the Major Producers have increased the type of products marketed by them and increased their added value. This has been made possible by the monopolitical markets controlled by the Major Producers. Therefore, it is a significant handicap for newcomers to have to overcome the problem of finding their way through the markets of the Major Producers to obtain their own new markets.

In addition to the above-mentioned strategies and sources of power of the Major Producers, there are two points which must be borne in mind. One of these is superior technology. Concerning the capability of technological development, there is few company in the world which has ample resources of funds and accumulated experience equivalent to those possessed by the Major Producers. The second point concerns ample reserves of funds. In the case of the new investment of bauxite, alumina or aluminum, enormous funds, amounting to a figures of anywhere between several hundred million dollars and several billion dollars, must be invested during the period from development to production. This remains the greatest obstacle in the path of newcomers. Privately owned company capable of investing such large amounts of funds are limited to the Major Producers.

In spite of the capability of the Major Producers, however, the funds necessary for projects such as the development of bauxite and construction of plants for alumina and aluminum are so huge that the risk of the new investment is great. Accordingly, an organization of mutual cooperation among the Major Producers or of cooperation between Major Producers and non-Major Producers has been developed. Such joint ventures, which may be called horizontal integration, gain the advantages of large-scale operation while reducing the financial burden and risk on a single company, so as to give greater flexibility to the development of the project. For example, a joint venture for developing bauxite in Guinea comprises ALCOA, ALCAN, Pechiney, Martin Marietta —— a middle-level company in the United States —— and Vereinigte Aluminium Werke (VAW) of the Federal Republic of Germany and is exploiting the mine with an annual production capacity of 9 million tonnes 1) which is one of the largest mine of bauxite in the world. In Australia also, ALCOA, by means of

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1) HALCO Mining Inc.
Shareholders: ALCOA (27%), ALCAN (27%), Martin Marietta Aluminum (USA) (20%), Pechiney Ugine Kuhlmann (France) (10%), Vereinigte Aluminium Werke (Germany, Fed. Rep.) (10%) and Alumetal (Italy) (6%).

joint capital investment with the Australian interests, successfully developed the world's largest project with an annual production capacity of 13 million tonnes of bauxite and 4 million tonnes of alumina [1]. In the area of aluminum smelting, such examples of horizontal integration are too numerous to mention. It may be certainly concluded that the horizontal integration is the most flexible and promising form of organization to raise necessary funds, which is expected to increase in future, and to avoid the risk in making new investment.

3. Decline of the Major Producers and Nationalization

In spite of the various handicaps of entering the aluminum industry, its rapid growth has been attractive to newcomers. The remarkable increase in new companies and the decline in share of the Major Producers in, for example, the United States are indicated in Table B-5. The share of the Major Producers in the free world continuously declined from 65% in 1970 to 56% in 1975 and 52% in 1980.

Companies under the direct or indirect control of a national government or local government body (hereinafter generally called government-owned company) and independent companies have been emerging in place of the Major Producers. Particularly government-owned companies have grown so strikingly that their share of the free world primary aluminum production capacity calculated by ownership percentage, which was only 13% in 1970, reached 16% in 1975 and 20% in 1980. For bauxite and alumina, the government-owned companies share calculated by ownership percentage reached 22 and 10% respectively. Fig. B-3 provides details of the respective shares.

In addition, Reference Table B-7 indicates the government-owned companies shares in each of the free world countries.

Nationalization is especailly progressing in the developing regions, mainly South Asia and Latin America, where the government-owned companies share 40 to 60%. These regions control a production capacity amounting to 2.4 million tonnes (government-owned capacity is 1.2 million tonnes). In Europe also, due to national energy policies for the effective utilization of state-owned electric power corporations and the recognition of aluminum as a strategic material, government-owned companies are not uncommon, like in West Germany, Italy, Norway, Spain and Austria. In North America, Oceania and Japan, however, no government-owned companies exist.

Further examination of the recent production trends mentioned

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[1] ALCOA of Australia
Shareholders: ALCOA (51%), Australian interest group consisting of 4 companies (49%).

Table B-5 Percentage Share of Aluminum Companies in the USA[a][b]

(%)

	1948	1957	1964	1973	1974
ALCOA	50.7	43.1	33.0	32.1	32.0
Reynolds	29.3	26.6	27.9	19.9	19.8
Kaiser	20.0	27.1	25.0	14.5	14.7
Anaconda	-	3.3	2.6	6.1	6.1
Ormet [c]	-	-	6.9	5.1	-
Howmet	-	-	-	4.4	4.4
Martin Marietta	-	-	3.3	4.1	4.2
National-Southwire	-	-	-	3.7	3.7
Conalco	-	-	1.2	3.6	7.0
Alumax	-	-	-	2.7	2.7
Revere	-	-	-	2.3	4.0
Noranda	-	-	-	1.4	1.4
Total	100	100	92.8	72.7	73.6

Notes : a) Each share may not add up to total due to rounding.
b) Based on year-end production capacity.
c) Ormet's production capacity in 1974, 250,000 tonnes is not shown but divided and included in the capacity of Revere (34%) and Conalco (66%), both partners in Ormet.

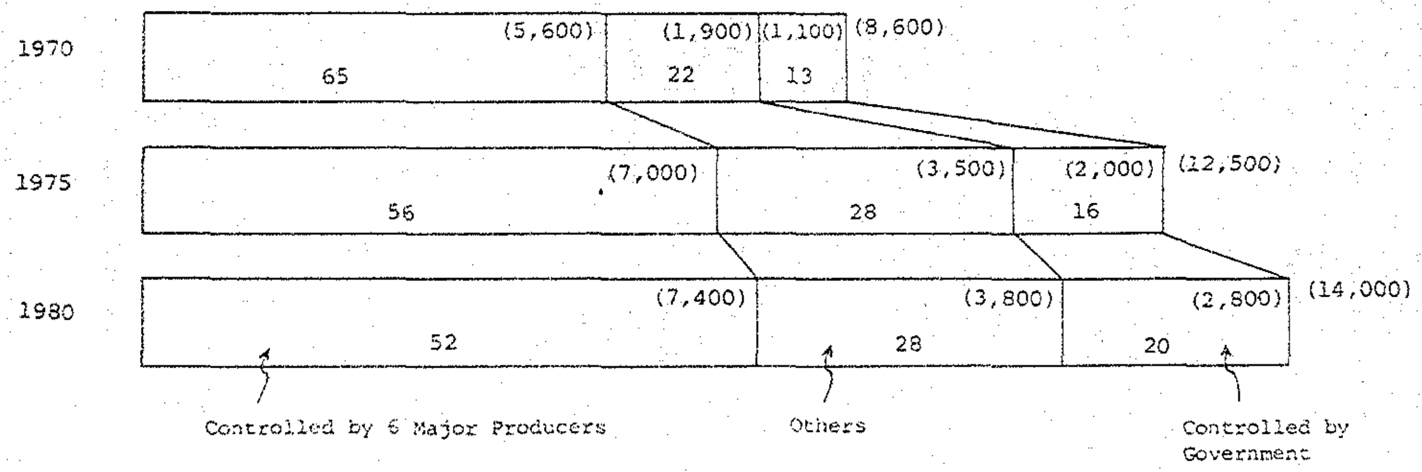
Source: The Aluminum Association, Aluminum Statistical Reviews; 1973, 1974.

above shows that the countries in Africa, South Asia and Latin America do not show any sign of production cutbacks even under the present adverse circumstances, and Europe has managed with a relatively small production cutback. In fact, these are the areas where government-owned comapnies are dominant. This is not mere coincidence, but rather a situation to be expected. Particularly these companies in the developing countries are forced to continue production at any rate because of the necessity of acquisition of foreign currencies for their national development plans or social conditions peculiar to these countries. This is a characteristic of government-owned companies.

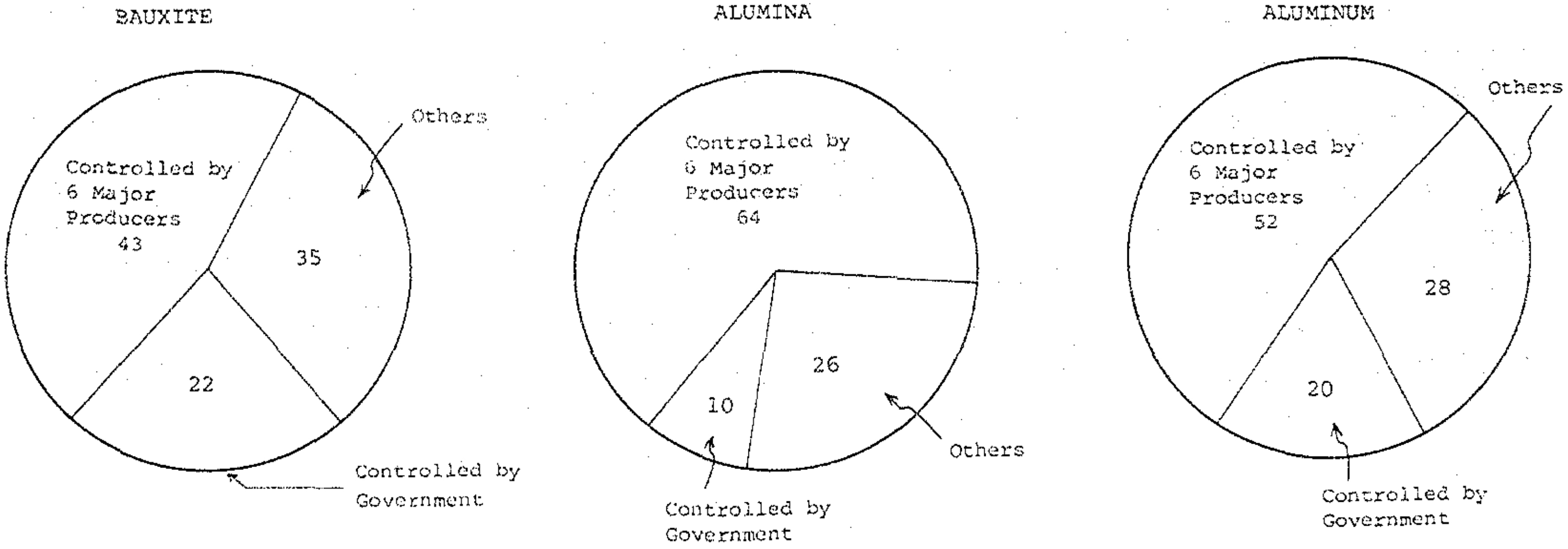
A government-owned company naturally has a strategy different from that of a private company. The viewpoint of the government-owned company toward the competitiveness is clearly different from that of a private business. It is natural in a sense that decisions made from such a different viewpoint, or the keeping of high level of the production irrespective of the actual market situation, may put pressure on the private company which must consider the market situation and the profitability.

Fig. B-3 Trend of Ownership Percentage in Free World Primary Aluminum Industry

(%; Figures in ( ) show production capacity (1,000 tonnes))



Ownership Percentage in Free World Aluminum Industry, 1980



Sources: Spector Report, AME and others

In addition, it should not be overlooked that another type of aluminum producer is acting to encourage such trend. Although aluminum quantity produced by such producers is now small, it is noteworthy that this small quantity adds the further complexity to the existing structure of the aluminum industry. These producers are the third type of producer different from both the Major Producers and government-owned companies. This type of producers have been so far purchasers of primary aluminum or holder of markets for primary aluminum and they venture for themselves into primary aluminum production. When demand is on the ebb, consumers whose demand for primary aluminum exceeds their production capacity try to maintain their production levels by reducing purchase quantity from outside sources, in order to safeguard against losses due to their own production cutbacks. In any case, this results in the disregard of market conditions. The continuous full production in Oceania, which has no government-owned companies, shows this situation. Such producer may be properly called an independent producer (company) and creates another factor to put pressure on aluminum market.

The important fact is that government-owned companies and independent companies are keenly interested in keeping production level high regardless of the relationship between the production cost and the market price. The continuation of production irrespective of the balance of supply and demand naturally confuses the market price. It is a serious problem that production level is maintained even though the market price falls to the level below the production cost. Chapter I has already described the world aluminum production trends on a regional basis and the relative advantages and disadvantages of the production facilities by regional area. It should be noted that such regional trends of aluminum production implicate not only comparative advantages or disadvantages of the production cost but also the difference of basic strategy concerning production level.

The share of the Major Producers has declined every year, and in contrast the share of the government-owned companies has increased. The production of independent companies has also contributed to the decline of the share held by the Major Producers. It can be argued that this situation shows a strong trend of structural change in the existing aluminum industry.

What has made possible such change? The first point is the effort of newcomers to secure low-priced sources of electric power has consequently weakened the relative advantages of the Major Producers. Particularly, the recent development of hydroelectric power and power generated by low-cost gas in the developing countries have enabled these newcomers to materialize the development plans successfully.

In the second point, however, the situation has not been favorable for newcomers to easily obtain cheap raw materials. The Major Producers have the sufficient technology and the planning capability necessary for bauxite exploitation and are still in a dominant position with outstanding power. The companies in the developing countires, large portion of which share was once held by the Major Producers, were nationalized as the nationalism advanced. In this connection the government-owned companies are still forced to rely on the Major Producers in respect of their marketing. Such being the case, it can be concluded that most of the free world bauxite resources are still under the control of the Major Producers and newcomers have to take this structure into consideration.

Thirdly, from the standpoint of the economy of scale, even small-scale production for primary aluminum becomes competitive if relatively low-priced electric power is available. Accordingly, as long as the price of electric power is low, small-scale production become competitive against large-scale production. Here is one of the reasons for the emergence of newcomers who have been able to utilize low-priced electric power.

Fourthly, a remarkable growth to date of demand for aluminum has greatly helped newcomers to obtain a share of the market. The rapid increase of aluminum demand, outpacing the rather slow increase of production capacity of the Major Producers, has given great incentive to newcomers to enter aluminum industry.

In addition to the above four points, it should be noted that the superiority of technology once held by the Major Producers has been no longer monopolistic to them. In this regard, since companies other than Major Producers, being forced to rely on high-priced electric power, have devoted themselves to the development of energy-saving technology, they are almost on a level with the Major Producers in technology. Above all, Japan's technological improvements on energy and labor saving are so remarkable that a certain Japanese smelter's technology has been exported to the Major Producers. However, the Major Producers are still in a dominant position with significant power in terms of overall technological superiority and development capability.

Lastly, consideration should be given to the capability for raising funds. In fact, this is the main factor for the share increase of the government-owned companies. It is impossible for a single newcomer to raise enormous funds required for new project development. Therefore such big project is to be treated as a national project. In this connection, development projects in the developing countries can be only carried out as the national project, if taking the risks of investment into account. It is obvious, however, that the required funds cannot be always provided even for the national project and the project cannot be materialized only by the funds. Naturally, the necessary cooperation must be provided by companies with the superiority in technology and the development capability. It is even more important to secure stable markets. For this purpose, the mutual cooperation not only with primary aluminum producers but also with the consumers or purchasers is required. Such cooperation among the parties in different position of the industry, which has already been realized as horizontal integration in many cases, is one method to fill the gaps in the industry created by the structural changes mentioned above, and indicates a suitable direction for future development projects.

III. Production Cost of Aluminum

1. Bauxite

1.1 Production Cost

Needless to say, bauxite, being a resource mined from the earth, has a production process different from a product manufactured in a factory.

The elements of cost, however, are basically similar to those of the manufactured products. The cost (ex-works base) comprises the following elements:

- Direct (mining) cost
  - Raw materials and fuel
  - Labor
  - Maintenance
  - Administration
- Indirect (mining) cost
  - Interest on capital cost
  - Depreciation

The costs, such as royalties, levies and so on, imposed under the fiscal regimes of various countries are further added, so as to give the total bauxite production cost. Based on the published data, each cost element is explained as follows 1):

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1) Bauxite is usually transported in terms of wet-base with about 10% moisture. The description below is on this usual wet-base.

1.1.1 Capital cost

The deciding factor for interest and depreciation costs is capital costs, the approximate levels of which are given in Table B-6.

Table B-6 Reported Capital Costs for Mines

Company and Location	Capacity (1,000 tonnes/ year)	Date of Cost Estimate	Cost/tonne annual output (US$ 1980)
Completed:			
* CBG, Boke (1973)	6,000	1973	123
* Min. Rio do Norte, Trombetas, Brazil (1979)	3,350	1975	120
Guymine, E. Montgomery, Guyana (1979)	800-1,000	1979	45- 56
* Comalco, Weipa, Australia (1979)**	11,000	1979	29
Under Construction:			
Nat'l. Aluminium Co., Orissa, India	2,400	1979	31
Planned:***			
* Min. Vera Cruz, Paraogominas, Brazil	2,000-4,000	1978	95-190
ALPART, S. Coast Mines, Jamaica	1,500-2,500	1979	45- 75
* Bauxiven, Los Pijiguaos, Venezuela	3,000	1980	183

* Includes cost of infrastructure.
** Costs over the period from the early 1960s.
*** Estimates based on various stages of feasibility studies.

Source: AME

As far as shown in this Table, no specific trend is found in bauxite capital costs. In other words, this shows that bauxite capital costs greatly vary in accordance with the availability of infrastructure and natural conditions.

1.1.2 Direct (mining) cost

There are not so many data on the levels of direct (mining) cost. Metals Week of 1968, though a little out of date, estimated the net cost at US$3-10/T. The Oppenheimer Report of 1975 estimated the cost of as much as US$6/T. Recent information obtained from the Metal Bulletin of 1980 indicates approximately US$4-7/T, as shown in Table B-7.

Table B-7 Comparative Direct Mining Costs of Bauxite in Jamaica, Brazil, and Australia

Item	Costs in US$/tonne		
	Jamaica	Brazil	Australia
Labor	1.18-1.30	1.95-2.15	1.53-1.69
Fuel oil	0.37-0.41	0.51-0.56	0.37-0.41
Internal transport	0.72-0.79	1.23-1.35	0.72-0.79
Maintenance	1.17-1.28	1.37-1.51	1.18-1.30
Misc. costs	0.83-0.91	1.32-1.45	0.86-0.94
Total direct mining costs	4.27-4.69	6.38-7.02	4.66-5.13

Source: Metal Bulletin (Sept. 1980)

1.1.3 Fiscal regimes; bauxite levy and royalty

There are three distinct measures by which bauxite producing countries obtain a share in the profits from the development of their resources.

The first is the corporation tax and dividend withholding tax as practised by countries such as Australia. In addition, the royalty — the tax imposed on mining — is levied in many countries based on the quantity of ore extracted from the ground. This may be compensated, as in Australia, by investment allowances and government finance to infrastructure or as in Brazil, by the exemption from taxation for a certain period. Secondly, there is the system taken by Jamaica, Surinam and other countries which is to impose a tax or levy on bauxite production. Thirdly, there is the direct equity participation or control by the Government, as found in Indonesia and the planned economy countries. Of course, these three measures are not independent and more than one measure are employed together in many cases.

The levels of these royalities and levies vary from country to country and are summarized in Table B-8.

As the above data indicate, it should be noted that the level of bauxite cost greatly depends on the various factors, such as natural conditions (the condition of ore deposit, quality, quantity, general topography), access to and price of materials and fuel necessary for development and operation, availability of skilled labor and government policy towards the exploitation including fiscal regimes and accounting system, etc. Although

Table B-8 Bauxite Levies and Royalties in the Main Bauxite Producing Countries

Country	Levy	Royalty	Comments
Jamaica	6.8%-5.5% US ingot price	US$ 0.55/S. tonne	
Surinam	6.0% US ingot price	US$ 0.50/S. tonne	Levy based on ALCOA US ingot price; conversion ratio 4.3 s. tonne = 1 s. tonne metal as in the case of Jamaica; information as of mid-1977
Haiti	8.0%	US$ 0.50/S. tonne	Levy indexed to Reynold's ingot price; converson ratio 5.0 s. tonne = 1 s. tonne metal
Dominican Republic	7.7%	US$ 0.60/S. tonne	Agreement with ALCOA extending to 31 Dec., 1982 for minimum payment of US$17.00/tonne; ALCOA also to pay a royalty of US$ 0.60/S. tonne on exports, compared to previous charge of US$0.55/S. tonne (Reuters, 5 Dec., 1980).
Guyana	-	US$ 0.04-0.10/tonne	
Guinea	Variable	n.a.	
Sierra Leone	-	US$ 0.17/tonne	
Ghana	-	6% of realized value of ore plus mineral duty of 10% on realized ore selling price	
Indonesia	10% of f.o.b. export value	Mineral tax of US$ 0.06/tonne	Information as of mid-1977
Australia	-	Variable range from nil to US$ 1.00	Nil applies to ALCOA which pays alumina royalties instead

Source: AME

there are few data to fully clarify this point, the estimate of bauxite cost is shown in general form in Table B-9.

Table B-9 Estimated Total Bauxite Cost

(US$/T)

Cost Item	Jamaica	New Plant
Mining cost	6.07*	6.07
Depreciation	0.66	3.31
Infrastructure cost	0.28	0.55
Interest	1	1.38
(Sub Total)	(8.01)	(11.31)
Royalty & Taxes	17.04**	3.86
(Total)	(25.05)	(15.17)

* Jamaica's mining cost is estimated at $4.27 - $4.69 in Table B-7, but estimated at $6.07 in this Table, the same as new plant.

** In 1979

Source: JAF (Japan Aluminium Federation)

1.2 Shipping Cost

As described in Section II, the quantity of bauxite domestically consumed in the mining country is not generally large. Most of bauxite is transported to consumers by means of marine transportation from loading ports. Bauxite consumers such as alumina producers, therefore, are interested in the bauxite price including the shipping cost. Consequently, in addition to the production cost mentioned above, the cost of marine transportation should be also studied.

Since the shipping cost shows great variation according to the volume of goods shipped, the distance of vayage, the method of transportation, the availability of port facility and other factors, an overall description of this item is difficult. General trends, however, are indicated in Table B-10.

As shown in Table B-10, although the shipping costs differ considerably in respective shipping routes, most of them, roughly speaking, exceed the level of US$10/T. This indicates that the level of shipping cost is a very important factor, compared with the level of bauxite production cost (US$10 to 30/T). The ship-

Table B-10 Selected Bauxite Shipping Costs

Source of bauxite	Destination of shipment	Freight cost US$/tonne	Date of Freight cost
Australia:			
Gove, N.T.	Stade, Germany, FR	10.50-12.50	Feb.-June 1979
		20.00-21.50	Jan.-June 1980
		17.00	Nov. 1980
		18.75	Jan.-Apr. 1981
Weipa, Qld.	Gladstone, Qld.	8.00*	May 1981
	Porto Vesme, Italy	12.50-12.65	Jan.-May 1979
	Netherlands/Germany, FR	18.00	Nov. 1980
	Germany, FR	17.50	Mar. 1981
Weipa/Gove	Japan	15.00-20.00*	May 1981
Jamaica:			
Various ports	USA	4.40- 4.90**	Sept. 1980
Port Rhoades	Louisiana, USA	5.50	Dec. 1980
Dominican Republic:			
Cabo Rojo	Texas, USA	5.50	Apr. 1980
Brazil:			
Amazon	USA gulf	7.50	Nov. 1979
	USA	8.00-9.50**	Sept. 1980
Guinea:			
Port Kamsar	USA gulf	10.25*	May 1981
	Canada (Port Alfred, Quebec)	10.50*	May 1981
	W. Europe	10.50*	May 1981
	Yugoslavia	20.00	Aug. 1980
Greece:			
Itea	Taranto, Italy	5.50	Mar. 1980
Indonesia:			
Bintan Island	Rotterdam, Netherlands	14.00-14.50	Mid-1979

* Estimates by Sydney-based shipping consultants
** Estimates by Met. Bull. Month., Sept. 1980

Source: AME

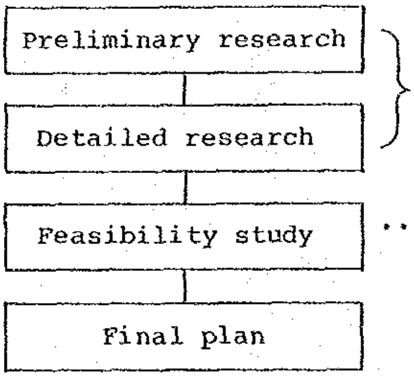
ping lot (the size of vessel) is also an element greatly affecting shipping cost. The unit shipping cost by a large-sized vessel proves more economical than that of small shipment.1)

As mentioned above, bauxite shipping cost is an element greatly affecting the cost of alumina production, and care should be always taken of the saving of shipping cost through the establishment of economical transportation system.

1.3 Bauxite Exploitation and Items for Investigation

In this section consideration is now given to the bauxite exploitation procedure and the main elements related to it.

The exploitation of bauxite deposits first requires the investigation of the physical and chemical properties of the ore to be mined, and confirmation of the quantity of the ore. Next, research and investigation are usually performed on the treatment processes suitable for ore quality and quantity, such as crushing, water-washing, and drying and, further, on loading and shipping conditions. Then, an overall feasibility including infrastructure, water resources, electric power, labor conditions, etc. is studied, and a final plan can be worked out. The summary of this procedures is as follows:



Research and investigation concerning ore quality and quantity, mining method, treatment, shipping, etc.

...Research and investigation concerning overall feasibility of exploitation including infrastructure, water resources, electric power, labor conditions, etc.

In order to study the feasibility of exploitation in the above procedure, the following are the main points to be investigated.

The first is the quality of the ore. For example, bauxite found in the Mitchell Plateau area in Australia with advantageous

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1) UNCTAD estimates that a large-sized vessel (60,000 DWT) proves more economical by 40 to 50% than a small-sized vessel (15,000T).

conditions for exploitation is evaluated to be less profitble, in spite of rich alumina content, than the low-grade ore at the Darling Ranges. As a further example, bauxite mined in Trombetas (Brazil) appears to have desirable quality for alumina production and reduce the cost of alumina [1].

Furthermore, it is also important to stably maintain the original quality for a long period of mining. In the case of domestic processing of bauxite (alumina refining) economics can be kept in spite of the reduction in quality to some extent. It should be, however, noted that certain high quality must be maintained by establishing higher cut-off grade for the purpose of export.

The second point is the cost of mining. Except in the case of Europe, bauxite is mined by the open-pit mining method. Since topsoil must be removed at the beginning of open-pit mining, the conditions of topsoil, such as quality, thickness and the vegetation are investigated. Bauxite is usually mined after blasting the ore by using dynamite. Some ore deposits in Soth-East Asia and Cape York in Australia, however, do not require such blasting. This difference in the method of mining affects the mining cost. Furthermore, post-mining rehabilitation and protection of the natural environment are very important factors to be considered.

The third point concerns the costs of shipping and loading. Bauxite is treated at the processes of crushing and water-washing and it is conveyed to the stockyard and loaded. This transportation process of bauxite also becomes an element greatly affecting the economics of exploitation. In particular, the cost of inland transportation is important for the economics of exploitation. In other words, a mine requiring long-distance inland transportation is placed in a highly disadvantageous position and the distance of inland transportation constitutes one of the most important factors determining economics of exploitation.

Fourth are the question of infrastructure, water resources, electric power, labor conditions, etc. Particularly, development of infrastructure has been the biggest problem in the developing

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1) Bauxite in the Kimberley area in Australia, which belongs to the gibbsite with 47 to 50% Al_2O_3 content, needs high-temperature digestion because of its content of several percent of boehmite. On the other hand, bauxite at Darling Ranges, which is a low-grade ore with 30 to 48% Al_2O_3, requires only low-temperature digestion since it is pure gibbsite. Bauxite in Trombetas is pure gibbsite with 47 to 50% Al_2O_3. The process of high-temperature digestion is disadvantageous in both the capital cost and the operating cost compared with low-temperature digestion.

countries. For examle, the proposed projects, such as West Kalimantan in Indonesia, Aye Koye in Guinea and Port Loko in Sierra Leone reportedly have to solve the problem of development of infrastructure as the top priority. In this regard, governmental assistance to solve this problem is required, since one private business cannot bear the burden of enormous funds required for the development of infrastructure.

The fifth point is the economy of scale. For the exploitation of the bauxite mining, the economy of scale plays a very important role. A large-scale mining is naturally more advantageous in unit cost of bauxite than a small-scale mining. On the other hand, the exploitation of a large-scale mine requires enormous investment and involves a big risk. It is also difficult to secure the markets in the case of the exploitation of a large-scale mine. Therefore, it is necessary to determine the optimum scale of the mining operation in consideration of these points.

In the exploitation of bauxite mines, overall consideration should be given to capital cost on the basis of investigation in the five points mentioned above, direct mining cost and levies and royalties which are drastically different from country to country. Needless to say, the cost of marine transportation from the loading port to the consumer is also an important factor for determining competitiveness.

2. Alumina

2.1 Production Cost

Alumina production facilities constitute a type of chemical plant. As described in Chapter A, the production process most widely adopted today is the Bayer process. Alumina production cost based on this process consists of the following elements.

- Direct costs
  - raw materials
    - bauxite
    - caustic soda
    - others
  - energy
  - labor
  - others (maintenance, administration etc.)
- Indirect costs
  - depreciation
  - interest

The main items in discussing alumina production cost are as follows: (1) capital cost, (2) bauxite price, (3) energy cost,