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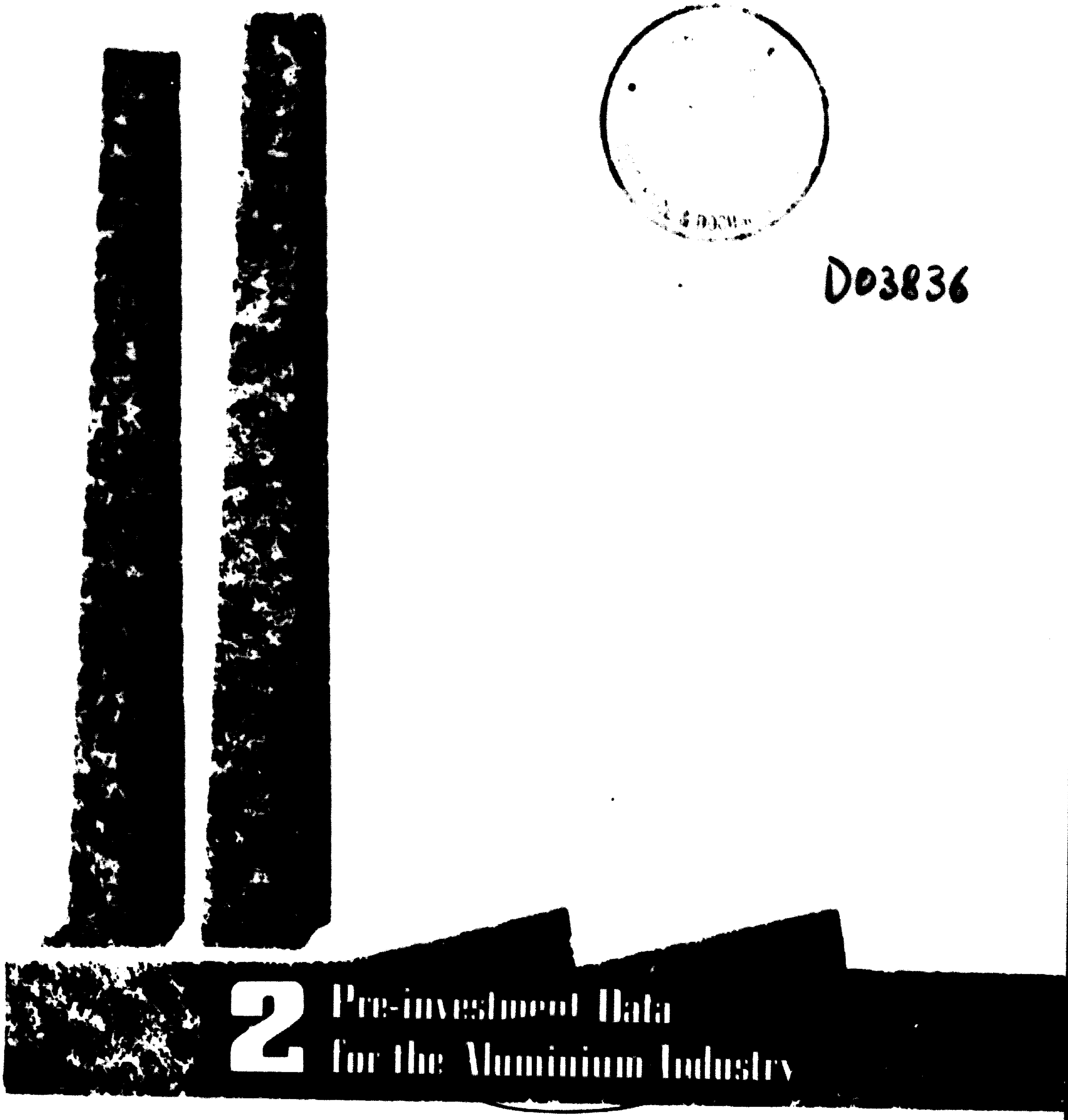
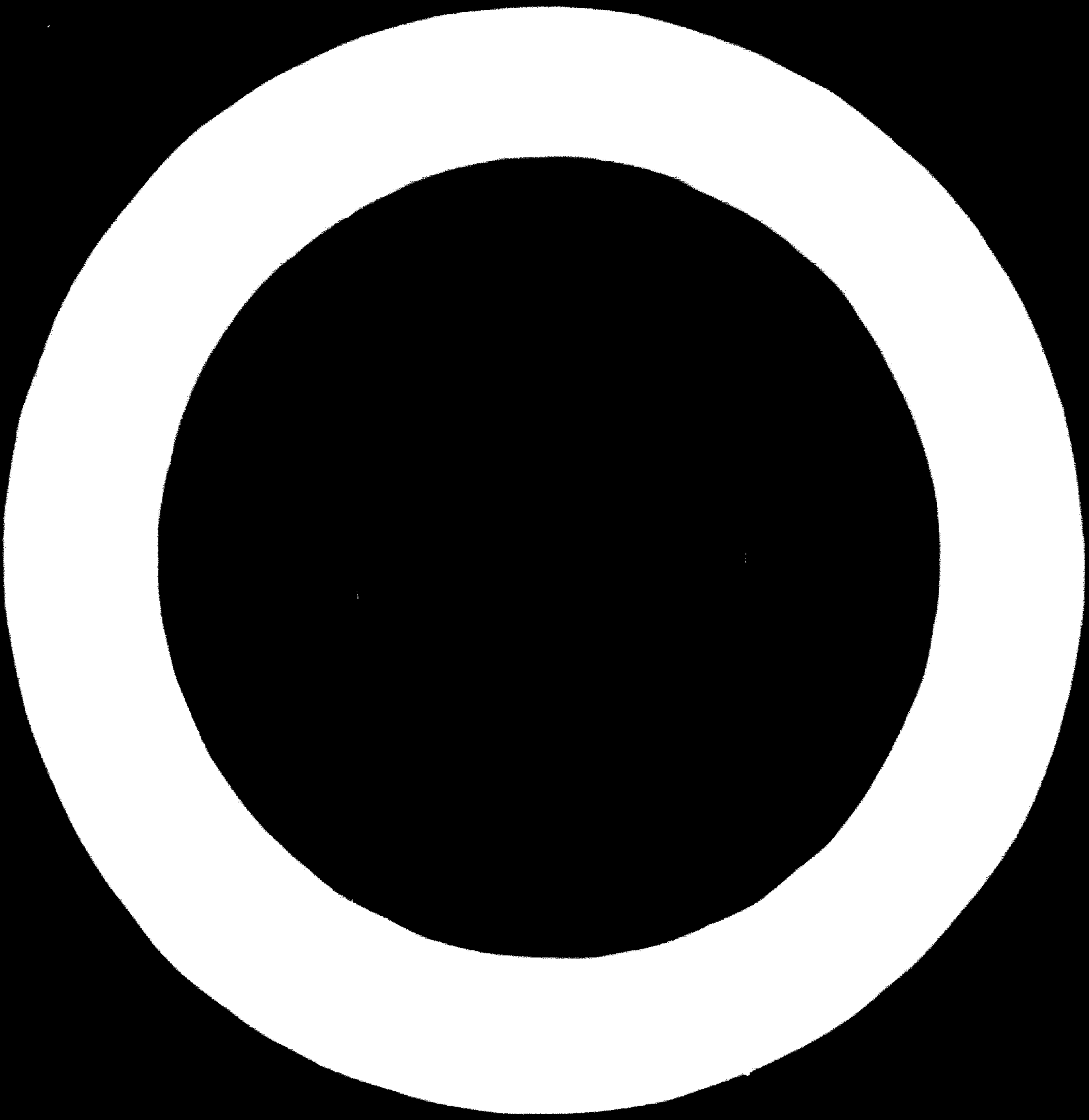
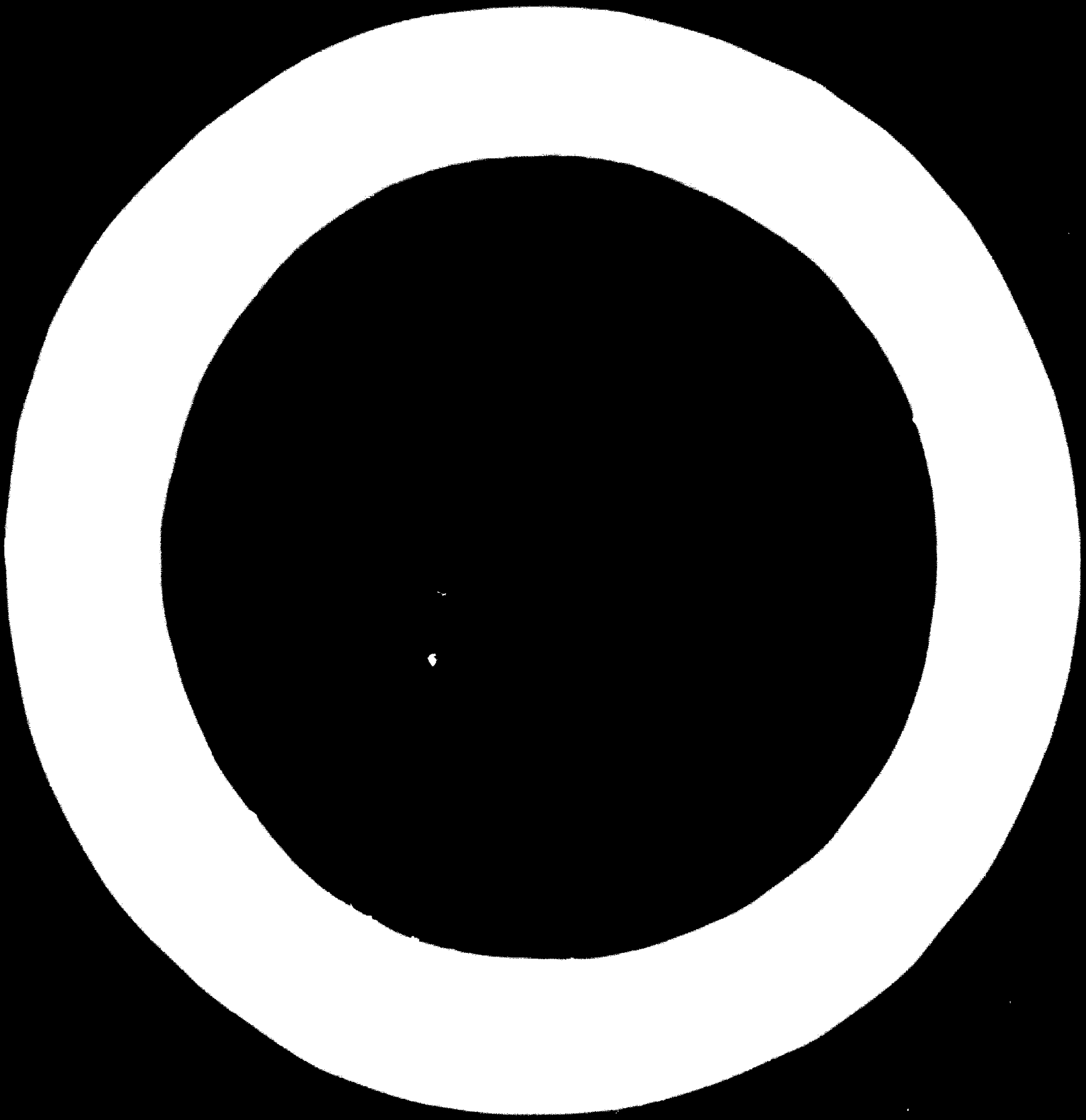


2 Pre-investment Data for the Aluminium Industry

UNITED NATIONS





DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS

Centre for Industrial Development

Studies in Economics of Industry

2

Pre-investment Data for the Aluminium Industry

UNITED NATIONS
New York, 1966

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FOREWORD

This report has been prepared by the Centre for Industrial Development of the Department of Economic and Social Affairs under the work programme formulated by the Committee for Industrial Development[1] and endorsed by the Economic and Social Council in resolution 872 (XXXIII). It has been prepared as part of a series, ***Studies in Economics of Industry***,[2] which is designed to develop basic programming data for a certain number of selected industries of interest to developing countries.

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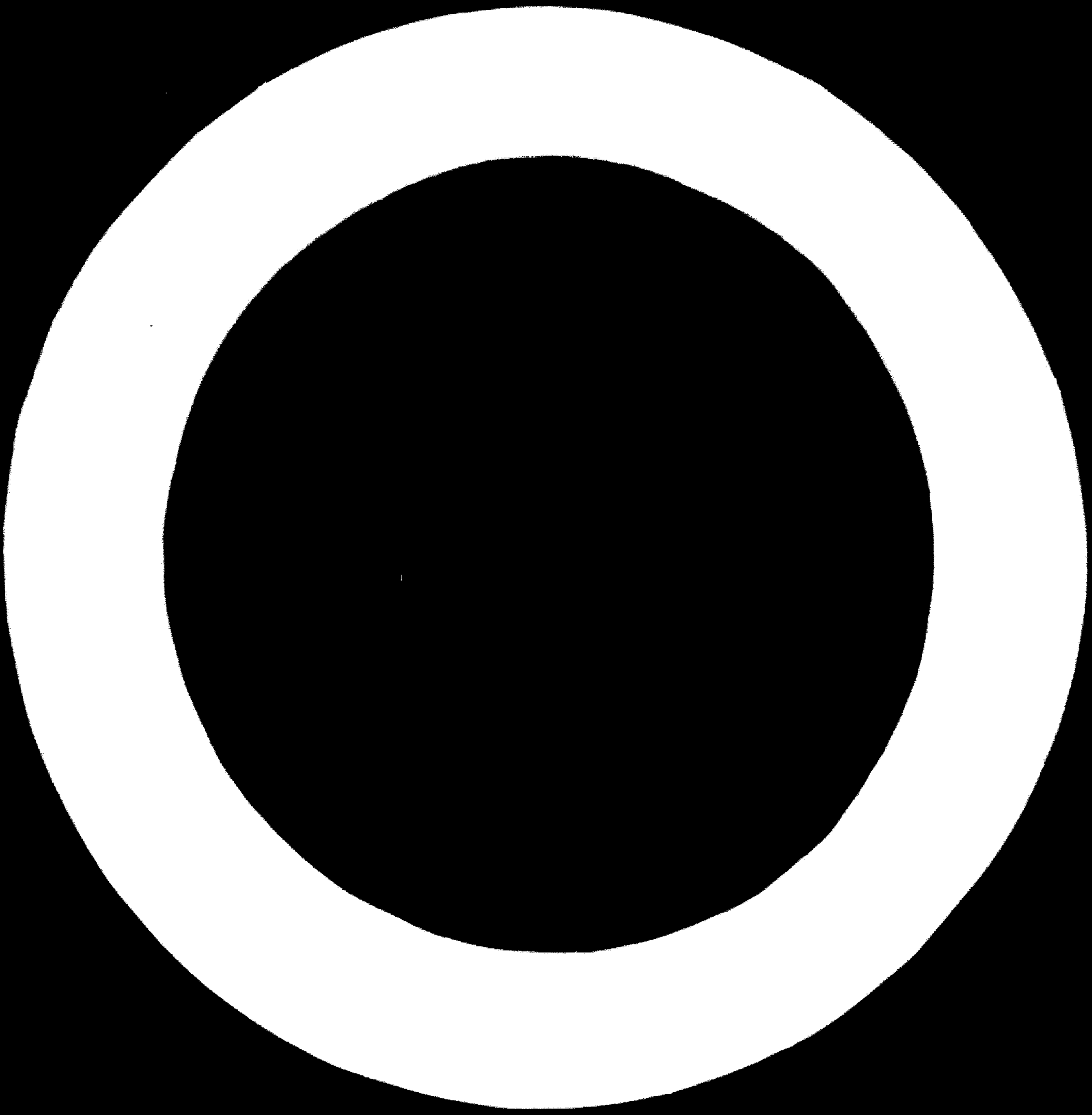
[1] *Official Records of the Economic and Social Council, Thirty-third Session, Supplement No. 2* (E/3600).

[2] The first report in this series was *Cement/Nitrogenous Fertilizers based on Natural Gas* (United Nations publication, Sales No.: 63.II.B.3).



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Explanatory notes

The following symbols have been used in the tables throughout the report:

Three dots (. . .) indicate that data are not available or are not separately reported

A dash (—) indicates that the amount is nil or neglible

A blank in a table indicates that the item is not applicable

A minus sign (-) indicates a deficit or decrease, unless otherwise stated

A plus sign (+) indicates a surplus or increase

A full stop (.) is used to indicate decimals

A comma (,) is used to distinguish thousands and millions

A slash (/) indicates a crop year or financial year, e.g., 1963/64

Use of a hyphen (-) between dates representing years, e.g., 1963-1965, signifies the full period involved, including the beginning and end years.

Reference to "tons" indicates metric tons, to "gallons", United States gallons, and to dollars, United States dollars, unless otherwise stated.

Annual rates of growth or change, unless otherwise stated, refer to annual compound rates.

Details and percentages in tables do not necessarily add to totals, because of rounding.

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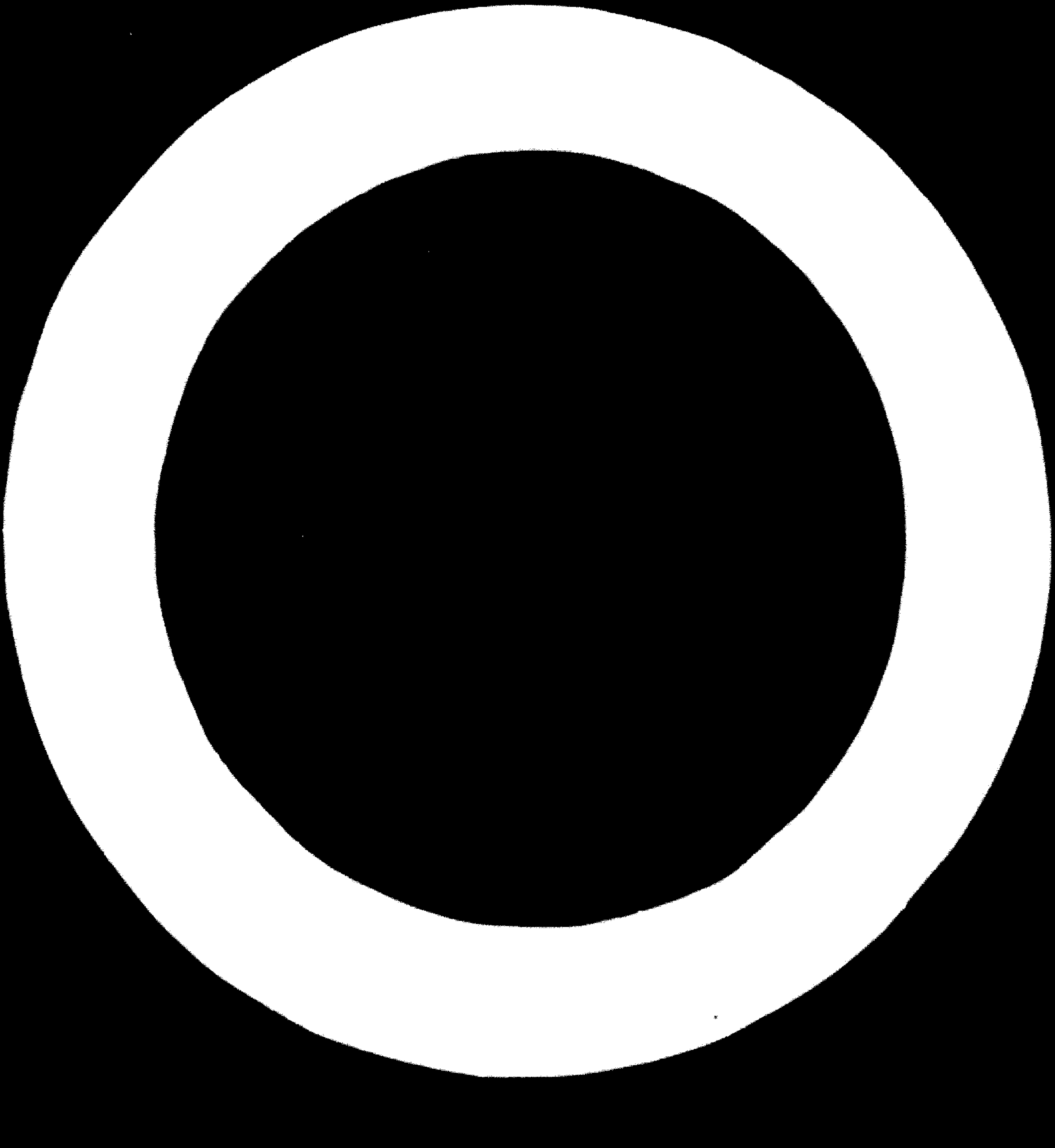

INTRODUCTION

1. Two main considerations have prompted the selection of the aluminium industry for inclusion in this series of studies on the economics of industry.

2. In several developing countries there exist large bauxite deposits and a great potential of low-cost and abundant power supply. Both factors are considered strategic for the development of aluminium metal production facilities. Furthermore, aluminium has proved to be a good substitute for several important products such as copper, zinc, steel, wood and plastics, a fact which makes this industry of particular interest to those countries that suffer from a lack or relative scarcity of these products.

3. The data used in this study are derived from engineering estimates prepared by consultants,[1] from plant data obtained from technical assistance reports, information made available to the United Nations Secretariat by several countries, and from published materials.

4. The method of analysis is similar to that followed in an earlier study on the economics of industry.[2] The aim is to present and analyse data on capital requirements and inputs that are based on the experience of several countries, both developed and under-developed, and to point out differences that may prove to be of use for those engaged in programming the development of this industry in developing countries. Aggregate data were used whenever available as a bench-mark for checking plant level data.

5. Aluminium production involves several stages: bauxite mining; production of alumina; manufacture of metallic aluminium, and fabrication of aluminium products. In this study, fabrication of aluminium products is confined mainly to "heavy fabrication", that is, rolling, drawing and extrusion. For each of the four stages capital and various input requirements as well as related programming data have been presented and analysed. A minimum of technical data have been used. However, more detailed technical data and descriptions of various processes are presented in annex I.

6. Additional data on capital and other inputs that may be of use in programming an aluminium industry are to be found in annex II, and statistical data pertaining to production, consumption, trade, prices and plant capacities are given in annex III. A selected bibliography is to be found in annex IV.

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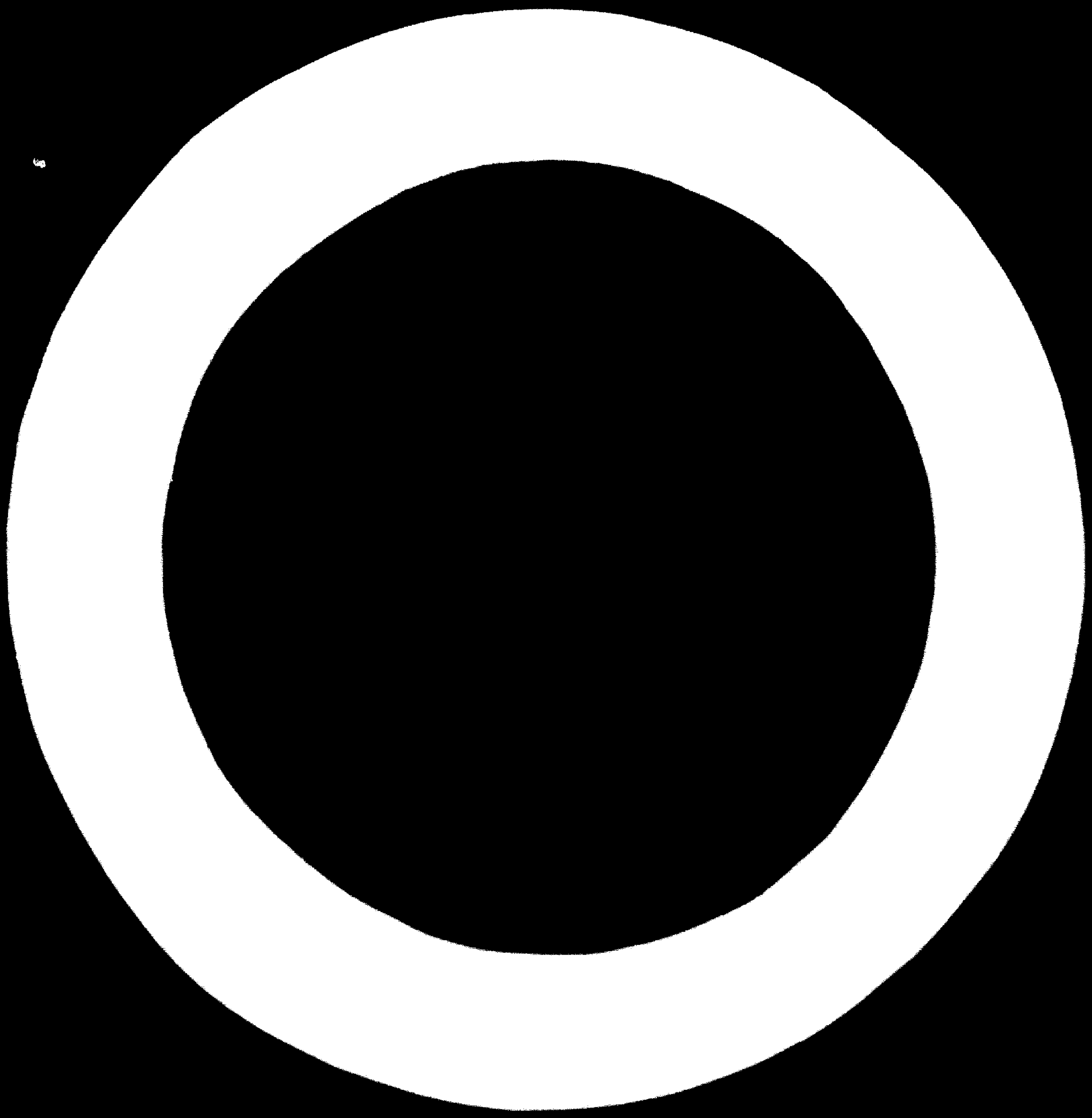
[1] Engineering data and technological information in this study have been drawn in large measure from a study prepared by Mr. Jan H. Reimer, an expert on the aluminium industry, which was submitted to the United Nations Industrial Development Programming Seminar held in São Paulo, Brazil, in March 1963.

[2] United Nations, *Studies in Economics of Industry, I. Cement/Nitrogenous Fertilizers based on Natural Gas* (Sales No.: 63.II.B.3).



Chapter I

BAUXITE

7. Bauxite is the predominant ore used in the production of aluminium. Experiments have been conducted in the use of raw materials other than bauxite, but their economic feasibility has yet to be proved. For example, andalusite was used in Sweden and aluminous clays in Germany and the United States on a trial basis during the Second World War. Nepheline is used in the Soviet Union where good-grade bauxite is not available. Leucite was used for some time in Italy. All these countries, however, reverted to bauxite, with the exception of the Soviet Union, in which country great expansion is planned for the extraction of alumina from nepheline ore.[1] Although most bauxite is used in the production of aluminium, a small percentage—about 10 per cent in the case of the United States—is used by the abrasive and other industries.

8. Bauxite consists of hydrated aluminium oxide, monohydrate ($Al_2O_3.H_2O$) and trihydrate ($Al_2O_3.3H_2O$), and occurs in nature mixed with impurities, principally oxides of silicone, iron and titanium. It is the content of impurities, particularly silica, that determines, among other things, the grade of the bauxite. A high-grade bauxite may contain less than one per cent of silica, and a content of 10 per cent is considered tolerable. As will be mentioned later, alumina is produced from bauxite having a higher silica content—of up to 15 per cent—by means of the combination process.[2]

9. Open-pit mining is usually used to extract the bauxite, although underground mining is practised in several countries, principally in Europe. In open-pit mining, stripping operations are undertaken by tractor-operated scrapers, power shovels, walking-type draglines, large-wheel excavators and by hydraulic mining. After stripping, the bauxite is usually loosened by blasting with low-strength dynamite. The ore is usually crushed and dried in order to reduce shipping costs. Beneficiation that involves mainly washing and classification with the main purpose of removing silica may also be undertaken.

INPUT REQUIREMENTS

10. Fixed investment includes the cost of stripping equipment, internal transport, drying kilns and crushers as well as the cost of buildings for providing storage facilities, workshops and office space. When beneficiation is called for, additional costs are incurred for a washing plant. Furthermore, the production of calcined bauxite for the abrasive industry requires additional investment in calcining kilns and related equipment and facilities. Since bauxite desposits usually occur in isolated locations, a relatively substantial amount of additional investment is needed to provide infra-structure, namely, external transportation, port facilities and townships (dwellings, schools, hospitals, community facilities and so forth). The location and nature of the bauxite deposits and the equipment required vary greatly, as do the mining and ancillary facilities, and the investment required varies accordingly.

11. The data available on large scale mining operations may indicate the order of magnitude for fixed investment. In a mining operation in Jamaica of 2 million-ton capacity, investment was estimated at $17.5 per ton of capacity,[3] and for the proposed Ghana operations with a 1 million-ton capacity it has been estimated at $10 per ton.[4] In the case of the former, investment included, in addition to investment in mining and drying equipment, the cost of pier, dock, storage and loading facilities as well as of transport facilities extending for six miles to the shipping point. Estimates for Ghana include, in addition to the cost of mining equipment and facilities, cost of a township and of a road from the mine to the nearest suitable existing road.

12. In this type of activity, substantial savings in unit investment and unit labour requirements are associated with increase in production capacity. Furthermore, open-pit mining offers possibilities for labour-capital substitution.

13. The order of magnitude of returns to scale of labour in bauxite mining may be illustrated by the Ghana project. Labour requirements are estimated to decrease by 50 per cent, from 3.1 to 1.6 man-hours per ton, with an increase in output of two and one-half times, from the intermediate stage (400,000-ton capacity) to the final stage (1 million tons).[5]

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[1] Technical data are discussed in annex I.

[2] Bauxite of yet higher silica content—up to 25 per cent—may be mined, and this is then combined with high-grade ore to give the accepted silica proportion.

[3] "Mining in Jamaica Means More and More Bauxite", *Engineering and Mining Journal* (New York), September 1957, pages 97 to 105.

[4] Governments of the United Kingdom and of the Gold Coast, *The Volta River Project, Volume I, Report of the Preparatory Commission* (London, 1956).

[5] Man-hour estimates are made on the assumption of an annual 2,000 hours of work per labourer. Labour requirements are estimated as follows:

Type of labour	*First stage (60,000-ton capacity)*	*Intermediate stage (400,000-ton capacity)*	*Final stage (1 million-ton capacity)*
	(Number of workers)		
Supervisory	20	30	40
Skilled and semi-skilled	290	410	560
Unskilled	160	180	220
TOTAL	470	620	820

SOURCE: *The Volta River Project*, v. *I*, page 28.

14. The technical characteristics of bauxite mining would allow wide latitude in the use of labour-saving techniques[6] were it not for the need for large-scale and efficient operations to maintain a regular flow of bauxite to aluminium plants, and the need to offer bauxite at competitive prices on the international market. Bauxite mines, particularly those catering to the international market, are in fact characterized by a high level of mechanization and a large scale of operation.

15. In the case of the proposed bauxite mining project in Ghana, a high level of mechanization has been planned and labour requirements are estimated, as mentioned above, at 1.6 man-hours per ton of output.[7] In British Guiana, the labour requirements of one mining concern with an output of 1.36 million tons of bauxite are estimated at 3.5 man-hours per ton of bauxite.[8] The low labour requirement of 0.54 man-hours per ton in the United States indicates in part the extent of possible mechanization in this type of operation.

16. The amount of fuel needed in the preparation of the bauxite depends on its "free moisture" content, that is, on the water present in addition to the chemically combined water. Crude bauxite may contain between 5 and 30 per cent of free moisture.[9] This may necessitate drying the ore, especially if it is to be shipped for processing. However, when bauxite is processed in an alumina plant at the mine site, it is often not necessary to dry it. Fuel requirements for drying the ore vary not only with its moisture content but with the size and design of the drying kiln. For drying bauxite with a high moisture content, between 0.8 and 1.1 million BTU per ton of ore may be required. Eight to ten times as much fuel as this is needed for calcining bauxite (removing chemically combined water) for use by the abrasive industry. Natural gas or heavy oil is used as fuel rather than coal, to avoid contaminating the bauxite with ash.

17. Other inputs are explosives and power. As stated above, after the stripping operations have been carried out, blasting with low-strength dynamite is generally done to loosen the bauxite. In some mines blasting is not required, but this is more the exception than the rule. Electric power is needed for grinding bauxite to a certain size, and this varies with the hardness of the ore: bauxite can range all the way from the earthy material found in Jamaica to the hard rock type found in Greece and India. Bauxite with a bond hardness index above 15 is expensive to grind.

18. Table 1 indicates average input requirements for bauxite mining in the United States.

PRODUCTION COST

19. Production cost varies greatly depending on several factors: economic, transport and location, technological, geological, etc. The following are the most important variables.

(1) The scale of operation is important in affecting production cost since substantial economies of scale are possible in bauxite mining.

(2) The amount and nature of the overburden affect production cost. Dry, sandy overburden is cheaper to remove than wet, earthy overburden covered by dense jungle. Furthermore, the amounts of overburden vary from one place to another; overburden up to 50 metres thick is removed in certain bauxite mining operations today. No definite figures can be given for the maximum amount of overburden which can be removed economically as this obviously depends on a number of factors such as the nature of the overburden, the quality of the bauxite and the size and location of the mining operation. In the case of large-scale operation and high-grade bauxite, the economic limit is usually five to eight times the amount of bauxite recovered.

TABLE 1. UNITED STATES: INPUT REQUIREMENTS FOR BAUXITE MINING, 1954 AND 1958

Input	*1954*	*1958*
Labour (man-hours/ton)	0.53	0.54
Fuel (millions BTU/ton)[a]	1.5–1.7	0.9–1.1
Electric power (kWh/ton)	3.8	5.5
Explosives (kg/ton)	0.135	0.127
Water intake (m^3/ton)	0.30	..

SOURCE: United States Department of Commerce, Bureau of the Census, *Census of Mineral Industries*, for the years 1954 and 1958 (Washington, D.C.).

[a] Fuel requirements were given as a combined figure for dried and calcined bauxite. Figures for drying were estimated on the basis of fuel requirements for calcining which are eight to ten times higher than those for drying.

(3) Replacing the overburden in order to re-surface the site of the deposit so that it may be used for forest or agricultural land may be required in some countries, and this may result in higher production cost. However, restoration of land may be economical for large bauxite mining operations under heavy overburden, even when re-establishment of the former surface is not important.

(4) The hardness of the bauxite, which affects the cost of grinding, and the moisture content, which affects the cost of drying, vary greatly with the type of ore. Furthermore, if beneficiation is applied, additional costs are involved.

20. An order of magnitude of the production cost of bauxite mined in the Caribbean islands may be estimated for major United States aluminium producers at between $7.00 and $8.00 per ton delivered at their alumina plants on the Mexican Gulf Coast.

21. The cost may be distributed as follows (in dollars):

Mining, including amortization of equipment, exploration, etc.	1.00–3.00
Beneficiation	Nil–1.00
Drying	0.75–1.50
Shipping	3.00–4.50
Local taxes, mining and (in some cases) shipping company profits	Balance

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[6] Bauxite mining is in many respects basically similar to earth moving, which also offers considerable opportunities for capital-labour substitution. In this connexion, see United Nations, "Capital Intensity and Costs of Earth-moving Operations", *Bulletin on Industrialization and Productivity*, No. 3 (Sales No.: 60.II.B.1).

[7] *The Volta River Project.*

[8] *Mining World* (San Francisco), May 1960, pages 54 to 58.

[9] See table 17 in annex I.

TRANSPORTATION COSTS

22. Transportation costs are very important for such a low-cost commodity as bauxite. Consequently, the accessibility of the deposit is of prime economic importance. It should preferably be located close to tide-water (sea coast or navigable river), as are the deposits in Australia, British Guiana, Greece, Jamaica and Surinam. In Europe, where distances are comparatively small, bauxite is shipped by railway from mines in southern France, Hungary and Yugoslavia. The economic exploitation of deposits located far inland usually calls for local processing of the bauxite in alumina plants close to the mine site, as in Arkansas (United States) and Guinea; this is particularly true when the bauxite is of low grade.

ECONOMIC SCALE OF OPERATION

23. Most bauxite mining operations in tropical underdeveloped countries are on a scale of at least 300,000 tons per year, and are highly mechanized; this scale is usually needed to achieve an economic mining operation in a remote location where all facilities, such as electric power, transportation, townships, etc. have to be provided and amortized by the mining operation. In locations where such facilities are readily available, mining can be carried out economically on a smaller scale; thus, bauxite mining is often on a much smaller scale in Europe where transport facilities, power supply and existing habitations are usually close at hand.

24. However, even in less developed countries, it may, under certain circumstances, be economical to mine bauxite on a smaller scale, say, 50,000 tons per year and over. Such conditions exist when there is little overburden and the bauxite is of high grade. But the best conditions for such small-scale mining exist when it can be integrated with alumina production at or close to the mine site; this has been done in Brazil and India.

25. The largest individual mining operations, each of the order of 1 to 2 millions tons of bauxite per year, are carried out in British Guiana, Guinea and Surinam, and there are several mining operations of this order of magnitude in Jamaica.

Chapter II

ALUMINA

26. Most of the output of alumina (over 90 per cent in the United States) is used in the production of metallic aluminium; the rest is used in the abrasive, chemical and other industries. The Bayer process, with some variations and improvements to take account of the differences in the quality of the bauxite, particularly the silica content, is still the only economically feasible process.[1] When high-grade bauxite containing less than 10 per cent of silica is used as raw material, the conventional Bayer process is applied. There are two principal variations to this process, each with major differences in equipment and procedures followed. The American Bayer process is used in treating trihydrate bauxite (gibbsite) in contrast to the European Bayer process which treats monohydrate bauxite (boehmite). The basic differences between the two are that the latter uses a greater concentration of caustic soda, a higher digestion temperature and a longer digestion period.

27. Low-grade bauxite containing up to 15 per cent silica is treated by the Combination process, which was developed in the United States during the Second World War. A modified Bayer process is first applied, then the red mud obtained as residue is treated further in a limestone-soda sinter plant (a unit additional to the Bayer plant) to recover a higher ratio of alumina and caustic. Investment and inputs for this process differ from those of the Bayer process proper.[2]

FIXED INVESTMENT

28. Fixed investment varies with the capacity of the plant. Significant economies of scale are realized with increasing capacity up to 330,000 tons per year, which is about the largest practical size of unit. A larger plant will consist of two or more parallel production units from which the economies obtained in fixed investment are less substantial.

29. Investment also varies with the process and with the modifications introduced to accommodate variations in the composition of the bauxite treated. It is estimated that the European Bayer process requires an investment between 10 and 15 per cent higher than the American Bayer process, while the Combination process requires additional investment of between 20 and 30 per cent, depending on the quality of the bauxite treated.

30. Investment data[3] based on engineering estimates and North American prices for alumina plants under typical conditions are shown in table 2 and figure 1. Elasticities of investment with respect to scale of output are estimated at 0.68 for a trihydrate plant and 0.75 for a monohydrate plant. This implies a constant ratio between the percentage increase in total investment and the percentage increase in the size of the plant; it also reveals that total investment increases less than proportionately to increase in plant capacity.

TABLE 2. ESTIMATE OF PLANT INVESTMENT[a] FOR AMERICAN AND EUROPEAN BAYER PROCESSES

(Dollars per ton annual Al_2O_3 capacity)

Plant capacity (tons per year)	*American Bayer process (trihydrate bauxite)*	*European Bayer process (monohydrate bauxite)*
100,000	170–210	190–230
165,000	140–180	160–200
330,000	110–150	140–180

[a] Plant investment includes the cost of the following: equipment, buildings, foundations, steam plant, direct plant services (power and steam distribution and materials handling within the plant area, plant office, laboratory, change house, maintenance workshops), storage and handling facilities for bauxite, fuel oil and alumina, and operating and maintenance supplies.

Excluded are: bauxite mining, beneficiation and drying plant, town site (dwellings, schools, hospital, community facilities, etc.), power generation and transmission to plant site, wharf, railway, roads and other transport facilities outside of plant area, caustic soda or soda ash production facilities, and limestone mining, crushing and burning facilities.

31. The capital cost figures include the complete plant but no outside facilities, which depend on local conditions. Additional investment would be required if caustic soda or soda ash production facilities were included.[4]

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[1] Various alumina processes are referred to in more detail in annex I.

[2] See annex I.

[3] These data are based on treating a typical trihydrate bauxite from British Guiana or Surinam (extensively used for alumina production in North America) and a typical monohydrate bauxite from southern France (extensively used in Europe), of the following approximate compositions:

	Trihydrate bauxite	*Monohydrate bauxite*
	(percentage)	
Alumina (Al_2O_3)	57	53
Silica (SiO_2)	4	7
Iron oxide (Fe_2O_3)	5.5	25
Titanium dioxide (TiO_2)	1.5	33
Water (H_2O)	32	12

[4] Caustic can be supplied to the Bayer process either as caustic soda or as soda ash in combination with burnt lime. In cases where caustic is expensive and electric power comparatively cheap, it may be justified to install an electrolytic caustic-chlorine plant locally. The raw material is sodium chloride (common salt), which can be obtained at low cost in many locations. The economy of the caustic-chlorine plant depends, however, on a market being available for the chlorine; such a market exists in countries with a well-developed chemical or petrochemical industry, but it may not be available in an industrially under-developed country.

In certain cases it may be more attractive to build a soda ash

(continued on page 8)

32. Higher plant investment is required in developing countries than in advanced countries because of the added transport, distribution and other costs, and possibly higher construction and installation costs. Further, in these countries, it is often necessary to incur additional costs in providing infra-structure.

LABOUR REQUIREMENTS

33. Labour requirements per ton of alumina vary with the size of the plant and with the particular process adopted. Plants treating monohydrate bauxite and those treating low-grade bauxite (the Combination process) require between 20 and 40 per cent more labour than do comparable plants using trihydrate as raw material.

34. Assuming a well-managed plant, direct and indirect labour requirements for a plant with a capacity of about 1,000 tons of alumina per day may be estimated at 3 man-hours per ton capacity for a trihydrate plant and 4 man-hours for a monohydrate plant. If an alumina plant is integrated with a bauxite mining operation or an aluminium reduction plant, labour requirements may be reduced, mainly as a result of sharing the maintenance and other indirect labour. Under such conditions, it is possible to get down to 2 to 3 man-hours per ton of alumina.

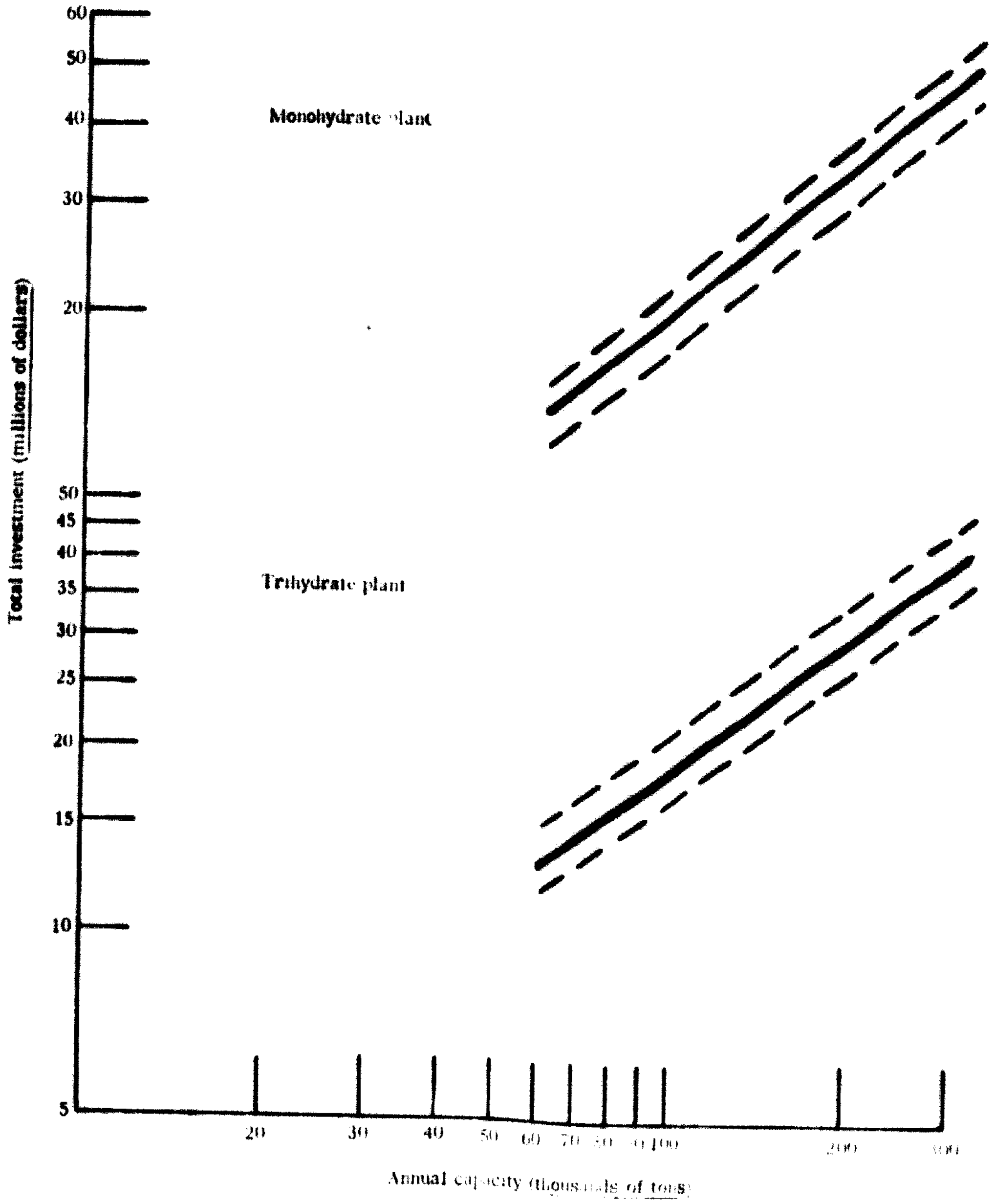

Figure 1. Plant investment for American and European Bayer processes

35. On the other hand, a self-contained alumina plant (with its own complete maintenance facilities) in an isolated location usually requires considerably more labour, even if the plant is of modern design. Under such circumstances, it is prudent to reckon on 5 to 8 man-hours per ton of alumina for a good-sized plant (500 to 1,000 tons Al_2O_3 per day), and even more for a smaller plant.

36. The above figures are based on engineering estimates reflecting the experience and practice in advanced countries, and assume a fairly mechanized plant. In developing countries, higher labour inputs than those suggested earlier may result from lower factor performance. Moreover, the relatively low wages paid in these countries may induce the substitution of labour for capital (within the limits possible in a modern plant), particularly in materials handling and other ancillary facilities.

37. Data from actual experience are available for Japan which indicate higher labour requirements (see table 4).[5] The reduction of labour requirements in that country through the introduction of labour-saving devices in alumina plants in recent years is further indication of the possible capital-labour substitution in this field. Thus, labour input (both direct and indirect labour) has decreased from 28.8 man-hours per ton of output in 1955 to 10.6 man-hours in 1960.[6] The decrease in labour input has also been brought about in part by the increase in the scale of operations during this period.

OTHER INPUTS

38. Other important inputs in alumina production include bauxite, caustics, fuel, power and water.

Bauxite

39. The amount of bauxite required does not vary significantly with the size of the operation. However, it does depend on the quality of the bauxite, and the amount of extractable alumina may be estimated from the alumina and silica content of the ore. The silica causes alumina to be lost as part of the insoluble residue; the amount lost is approximately equal to the silica content of the bauxite. In addition, a reasonable allowance must be made for miscellaneous plant losses, of 3 to 4 per cent.[7]

40. In the Combination process, a higher proportion of alumina is recovered. The red mud containing alumina and caustic soda, which would otherwise be discarded as residue, is further treated and partial recovery of the alumina made.

Caustic

41. Certain amounts of caustic are needed to replace that lost as insoluble residue in the process of producing alumina.[8]

42. As stated above, caustic may be supplied to the Bayer process either as caustic soda or as soda ash in combination with burnt lime. Consumption of the caustic or its soda ash equivalent varies widely, depending primarily on the silica content of the bauxite and to a less extent on the amount of residue washing. Caustic soda losses are equivalent to approximately 90 per cent of the silica content of the bauxite used in the production of alumina. A small allowance must be added for washing losses. Further recovery of caustic from the red mud is possible in the Bayer process but this would require additional investment and is economical only in large-size plants.

43. In the Combination process, part of the soda in the red mud is recovered by further treatment, and the caustic consumption is lower per unit of silica content than is the case in the Bayer process, although the requirement per unit of alumina may be as great.

Fuel

44. This input is used mainly for the production of steam and for calcination of the alumina. There is a wide variation in the consumption of steam since this is primarily a function of heat exchanger efficiency. A heat exchanger with high efficiency requires additional investment, which has to be weighed against the lower cost of the fuel. Steam consumption per ton of output also decreases with the increase in size of plant and with the higher grades of bauxite. Higher steam consumption is required for treating monohydrate as compared with trihydrate bauxite owing to the higher digestion temperature and pressure needed for the former. Engineering estimates for steam requirements range between 1.5 and 4 tons per ton of calcined alumina for trihydrate bauxite and between 2.2 and 7 tons for monohydrate bauxite. The lowest figures are for large plants (1,000 tons of Al_2O_3 per day) using high-grade bauxite and high-efficiency heat exchanger systems; the highest are for small plants (150 tons of Al_2O_3 per day) using low-grade bauxite and with poor heat exchanger efficiency. A greater amount of steam (one and one-half times to twice as much) is also required in the Combination process as compared with the American Bayer process.

45. It may be feasible to combine steam production with electric power generation and this, of course, would affect the over-all consumption of steam. Power generation is economically attractive in isolated locations where electric power is not available from established grid systems, and also often in connexion with monohydrate

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(*continued from page 6*)

plant, which can use ammonia from a fertilizer plant. The minimum economic size of a Solvay (ammonia) process soda ash plant is, however, considerably larger than that of an electrolytic caustic-chlorine plant.

No definite figure can be given for the maximum price that can be paid for caustic to be used in alumina production. The consumption of caustic varies greatly with the quality of the bauxite, as has already been pointed out; for this and other reasons, the maximum economic cost of caustic must be determined for each individual case.

[5] Average labour requirements in the United States for the year 1951 amounted to 2.7 man-hours per ton, lower than those in Japan. They have probably been reduced since then in the former country as a result of increased scale of operations and further mechanization in alumina plants.

[6] See, in this connexion, annex II, table 20.

[7] For more details, see annex I.

[8] Caustic is continuously recycled, and its consumption represents the replacement of that lost, largely as an insoluble sodium aluminium silica in the Bayer process and as insoluble dicalcium silicate in the Combination process.

bauxite treatment because of the high available steam pressure.

46. With respect to fuel for calcination, the requirement does not vary with plant size. Some saving is, however, obtained by the use of large-capacity kilns.

Electric power

47. Power consumption per unit of output increases somewhat with reduction of plant size. Small plants may require up to 300 kWh per ton for a trihydrate plant and up to 420 kWh for a monohydrate plant, as compared with about 200 kWh and 275 kWh, respectively, for large plants of 1,000 tons of alumina per day. Power consumption also depends on the hardness of the bauxite used, high energy being required to grind hard bauxite prior to digestion.

48. Engineering estimates for input requirements of typical good operating practice in modern large plants (1,000 tons of alumina per day) are given in table 3. These figures are given on the same basis as the capital cost figures and raw materials assumed for table 2.

TABLE 3. INPUT REQUIREMENTS PER TON OF CALCINED ALUMINA FOR A MODERN ALUMINA PLANT

Item	*Trihydrate bauxite*	*Monohydrate bauxite*
Bauxite (tons)	2.1	2.5
Caustic soda (NaOH) (kg)	80	170
Steam (tons)	2.0	2.4
Electric power (kWh)	200	275
Fuel for calcination (litres of fuel oil)	130	130
Labour, operating, maintenance and indirect (man-hours)	3	4
Maintenance, materials and equipment (dollars)	3.00	4.00

49. Data depicting actual performance for Japan are given, as an industrial average, in table 4. Alumina plants in Japan range between 100,000 and 200,000 tons annual capacity. Japan has no domestic bauxite resources and all of its requirements are imported. Consumption of power and fuel for calcination is roughly comparable to the suggested engineering estimates discussed above.
With respect to steam consumption, the figures are within the lower range suggested, reflecting fuel conservation practices by the Japanese industry, which is faced with a relatively high fuel cost. Caustic soda consumption is lower than the suggested engineering estimate because the industry in Japan recovers some from the red mud.

TABLE 4. JAPAN: INPUT REQUIREMENTS PER TON OF ALUMINA, INDUSTRIAL AVERAGE, 1960

Item	
Bauxite[a] (tons)	2.1
Caustic soda (kg)	63
Steam (tons)	1.58
Electric power (kWh)	222
Fuel for calcination (litres of fuel oil)	168
Labour (man-hours)	10.6

SOURCE: Japan Development Bank, Research Division, "Units of Input Consumption by Alumina and Aluminium, Refining Capacity and Import of Bauxite" (in Japanese) (Tokyo, 1961).

[a] The average composition of bauxite used by the industry in Japan is as follows:

	Bintan	*Rumania*
	(percentage)	
Alumina (Al_2O_3)	54.39	53.95
Silica (SiO_2)	4.24	5.91
Iron oxide (Fe_2O_3)	11.11	10.42
Titanium dioxide (TiO_2)	0.92	0.85
Water (H_2O)	10.44	10.70

SCALE OF OPERATION

50. Returns to scale are obtained in alumina production. Labour requirements per unit of output decrease as the scale of operation increases. As was mentioned in an earlier section, substantial economies are obtained in fixed investment in plants up to a maximum capacity of about 330,000 tons. Beyond this capacity, saving in investment associated with increasing size of plant is less marked since a larger plant will consist of two or more production units. Some economies in production cost are realized at such capacities, mainly as a result of the sharing of common ancillary facilities, such as maintenance, materials handling and storage facilities. Table 5 indicates economies of scale for plants ranging from a yearly capacity of 60,000 tons to 330,000 tons. These estimates, which are presented for purposes of illustration, are based on engineering approximations using United States prices.

51. In the United States most plants have capacities larger than the maximum referred to above and about half have capacities ranging from 730,000 to about 1 million tons per year.[*] Aside from economies obtained in production costs, large external economies are realized, particularly in the cost of transporting and handling the bauxite, as is evident by the proximity of alumina plants in the United States to bauxite mines or tide-water outlets close to the major suppliers of imported bauxite.

52. As for minimum-size plants, these vary greatly, depending on the economic circumstances of each individual case. Small plants may be found economical when combined with reduction plants catering to the local market. However, plants catering to the international market would probably have to operate at a higher scale, say, 100,000 to 165,000 tons per year.

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[*] *See* annex III.

TABLE 5. UNITED STATES: AVERAGE PRODUCTION COSTS FOR HYPOTHETICAL ALUMINA PLANTS OF VARIOUS CAPACITIES[a]

(Dollars per ton of calcined alumina)

Item	Yearly capacity (tons)			
	60,000	100,000	165,000	330,000
Bauxite	16.80	16.80	16.80	16.80
Caustic soda	5.10	5.10	5.10	5.10
Steam	3.30	3.30	3.30	3.30
Electric power	1.20	1.05	0.96	0.80
Fuel for calcination	2.60	2.60	2.60	2.60
Labour, operating, maintenance and indirect	15.00	12.50	10.00	7.50
Maintenance, materials and equipment	3.00	3.00	3.00	3.00
Capital cost:				
Depreciation on fixed capital	15.00	11.80	11.20	9.00
Interest on fixed capital	12.00	10.30	9.00	7.20
Miscellaneous supplies and general expenses	8.30	7.00	5.50	3.70
TOTAL PRODUCTION COST	82.30	73.45	67.46	59.00

SOURCE: Calculated on the basis of data in tables 2 and 3 and in the text.

[a] Plants are assumed to use trihydrate bauxite as raw material and to operate three shifts at 90 per cent of total capacity. The following data have been used:

(1) Bauxite consumption: 2.1 tons at $8.00 per ton;

(2) Caustic consumption: 80 kg NaOH at $0.064 per kg;

(3) Steam consumption: 2 tons at $1.65 per ton;

(4) Electric power consumption as follows:

Capacity of plant (tons)	kWh
60,000	300
100,000	265
165,000	240
330,000	200

Price of power: 4 mills per kWh;

(5) Fuel for calcination: 130 litres of fuel oil at $0.02 per litre;

(6) Labour requirements assumed as follows:

Capacity of plant (tons)	Man-hours per ton
60,000	6
100,000	5
165,000	4
330,000	3

Wages: $2.50 per hour;

(7) Maintenance: $3.00 per ton;

(8) Fixed investment assumed as follows:

Capacity of plant (tons)	Millions of dollars
60,000	13.0
100,000	18.5
165,000	26.4
330,000	43.0

(9) Depreciation for equipment: 12.5 years, and for buildings, 20 years. Interest on fixed investment at 5 per cent;

(10) Miscellaneous supplies and general expenses, including insurance, property tax, supervisory and technical personnel cost, office supplies and contingencies, assumed at 3 per cent of fixed investment plus 50 per cent of labour cost.

Chapter III

ALUMINIUM REDUCTION

53. Metallic aluminium is produced exclusively by the Hall-Héroult process. Alumina is dissolved in a fused cryolite bath and metallic aluminium is deposited electrolytically. Two types of reduction plants are in commercial operation today, using the prebaked or Soderberg anode system. In the prebaked anode plants, the anode consists of hard blocks of carbon that are inserted on top of the electrolytic cell by means of a steel stub or rods. In the Soderberg plant (self-baking anode), carbon-mix is added periodically to a steel shell (anode casing) placed on the reduction cell. Investment and other input requirements may differ for these two systems.

54. Two new processes, the Quebec and the Péchiney, have reached the pilot-plant stage. Their main feature is that they reduce aluminium directly from bauxite; it is expected that these processes will substantially reduce the requirement for capital. The idea of producing aluminium by direct reduction of aluminium compound is not new. However, this development has gained impetus in the past fifteen years, and technically feasible solutions have been found. A semi-commerical pilot plant has been built in France jointly by Péchiney and Ugine with a planned capacity of 4,000 to 6,000 tons a year, and is now in operation. Aluminium Laboratories, Limited, are building a large pilot plant in Canada with a planned capacity of 6,000 to 8,000 tons per year. Until the economic feasibility of these processes has been demonstrated, however, aluminium plants will continue to rely on conventional methods.

INVESTMENT REQUIREMENTS

55. Fixed investment comprises the cost of equipment and electricals, including furnaces, materials handling equipment, casting, rectifiers, transformers, bus-bars, the cost of buildings including pot-rooms, workshops, paste plants, laboratories and offices, and the cost of land, land improvement and the erection of equipment, as well as of construction and engineering fees.

56. Economies of scale are obtained in fixed investment. This is because the cost of several important items of equipment increases less than proportionately with increase in capacity. Among such items are rectifiers, transformers, bus-bars, materials handling equipment, paste plants, and casting and ancillary facilities; the cost of erection is similarly affected.

57. With respect to furnace size, unit investment requirements for a reduction plant decrease as capacity increases up to a certain point. The lowest investment per unit or output is probably achieved with a furnace size of approximately 70,000 to 80,000 amperes. A further increase in furnace size requires an increase in unit plant investment because of the more than proportionate increase in the size of the furnace associated with a given increase in amperage; moreover, greater ventilation is required and more complex bus-bar systems are needed to counteract the increasingly serious magnetic disturbance.[1]

58. Engineering estimates for typical order of magnitude investment figures for aluminium reduction plants today are given in table 6 and figure II. The figures are based on experience in North America. The capital cost figures include the complete plant but no outside facilities.

TABLE 6. AVERAGE PLANT INVESTMENT FOR PREBAKED AND SODERBERG REDUCTION PLANTS[a]

(Dollars per ton annual aluminium capacity)

Annual plant capacity (tons)	*Prebaked plant*	*Soderberg plant*
20,000	1,000 1,300	900 1,200
50,000	750 1,050	700 1,000
100,000	650 850	650 850
200,000	500 700	550 750

[a] Investment includes the cost of the following: power supply and distribution (sub-station with transformers, rectifiers, DC bus bar system and AC power distribution within the plant area), aluminium reduction plant (pot-rooms), carbon plant (prebaked anodes or Soderberg paste plant), cast house (for refining, alloying and casting produced metal into ingots and shapes for shipping), gas removal and cleaning facilities, direct plant services (i.e. materials handling within the plant area, plant office, laboratory, charge house, maintenance workshops), storage and handling facilities (alumina, fluorides, carbon-plant raw materials, aluminium ingots and shapes, operating and maintenance supplies), and buildings and foundations for all the above items.

Excluded are: power generation and transmission to plant site, town site (dwellings, schools, hospital, community facilities, etc.), wharf, railway, roads and other transport facilities outside the plant area, synthetic cryolite and aluminium fluoride production and regeneration facilities.

The data indicate that investment for a prebaked plant is higher than that for a Soderberg plant. The difference, however, narrows down as the size of plant approaches 100,000 tons per year, beyond which the investment in prebaked plants becomes lower than that for a Soderberg plant. Elasticities of investment with respect to plant capacity are: prebaked, 0.72; Soderberg, 0.80.

59. Additional investment may be required for an elaborate gas and pot-room air cleaning installation, depending on the location of the plant, the prevailing winds and topography.[2]

60. Capital requirements for identical plants vary from region to region. In western Europe the investment is generally lower than in North America. This may be

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[1] *See* annex I.

[2] The anode gas from the cells and the pot-room air contain dust (alumina, fluoride and carbon particles) and, in the case of a Soderberg plant, also tarry fumes. Both the anode gas and the pot-room air can be more or less cleaned before being released to the atmosphere, depending on the surroundings.

illustrated by the data available for recently built plants shown in annex II.

61. It may be further observed that in the Scandinavian countries fixed investment is expected to be relatively higher because of modifications required in building construction on account of rugged weather conditions. Additional investment may also be required in a tropical climate. In cold and temperate climates it is customary to install two parallel rows of cells arranged end to end, or a single row of cells arranged side by side, in each pot-room building; these arrangements normally provide sufficient ventilation to ensure adequate working conditions in the pot-rooms. In a tropical climate, however, it is advisable to install only one line of cells arranged end to end in each pot-room building, particularly if high-amperage cells are chosen. This increases the building area, the number of cranes, etc., resulting in a higher capital cost.

62. In developing countries higher fixed investments are expected because the cost of transport, distribution and insurance would be added to the cost of imported equipment. Furthermore, the cost of erection of the plant is likely to be higher also. The data in table 7 are based on detailed cost estimates for two Soderberg plants proposed for two developing countries.

63. For plant 1 it was estimated that the investment

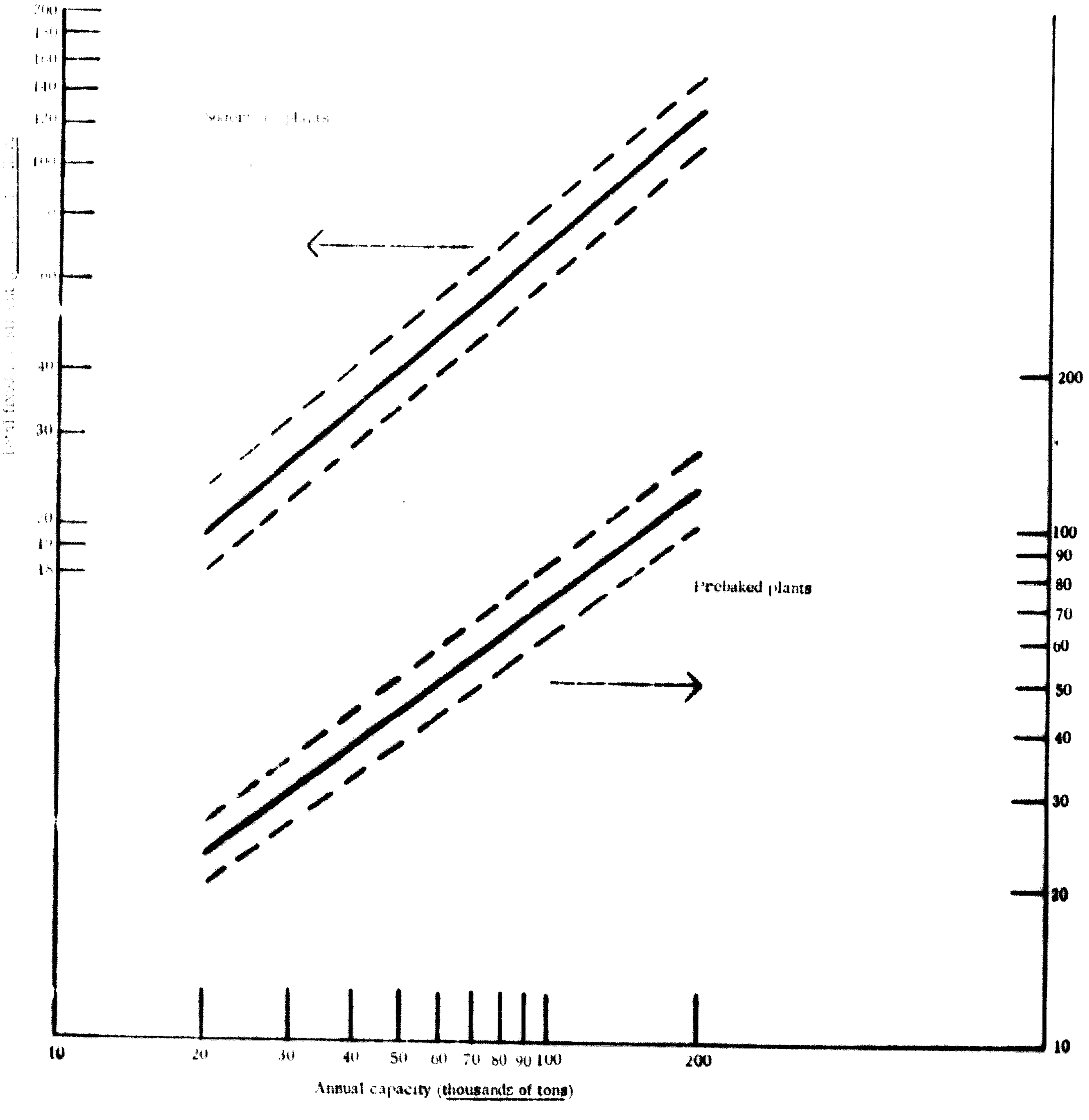

Figure II. Total fixed investment for prebaked and Soderberg reduction plants

TABLE 7. ESTIMATES OF INVESTMENT FOR TWO PROPOSED ALUMINIUM PLANTS IN DEVELOPING COUNTRIES

(Dollars)

Item	*Plant I (22,700 tons annual capacity)*	*Plant II (20,000 tons annual capacity)*
Investment per ton capacity	1,260	1,050
Composition of fixed investment:		
Buildings and land	7,760,000	6,000,000
Equipment installed	16,680,000	12,300,000
Other	3,560,000	2,700,000
TOTAL	28,000,000	21,000,000

requirement was about 20 per cent higher than that of a comparable plant in the advanced country from which equipment was to be imported. The additional cost reflects the additional cost of transportation and delivery of equipment as well as higher costs of erection of equipment and of construction.

64. As far as possible investment figures in table 7 have been made comparable with those in table 6, and are of an order of magnitude similar to the figures in the upper range given in that table.

65. Substitution of labour for capital in developing countries is possible, particularly in materials handling and ancillary activities, as will be discussed later. The small share of materials handling facilities in total investment, however, limits the effect of capital savings in this area.

Cost of expanding existing plants

66. The cost of expanding existing plants is usually considerably less, per ton annual aluminium capacity, than that of new plants. It is particularly cheap to add new electrolytic cells to a potline where the voltage capacity of the rectifiers has not yet been fully utilized. But it is also economical to add new potlines to existing reduction plants; for example, a new 23,000-ton per year potline, including auxiliary installations such as rectifiers, carbon plant, cast house and gas cleaning and maintenance workshops extensions, was recently added to an existing European plant at a cost of about $550 per annual ton. In general, the cost of additional potlines is from two-thirds to three-quarters of the cost of a new plant, and the addition of new cells to an existing potline provides capacity at even lower cost.

Power facilities

67. Investment in electric power facilities associated with aluminium reduction is high. Investments in hydropower facilities are estimated at $310 per kW for the proposed reduction plant in Ghana[3] and between $135 and $200 per kW for a Norwegian plant.[4] An appreciation of the magnitude of such investment may be illustrated for these two plants by an estimated additional investment for power facilities equal to 100 per cent and 32 65 per cent of the total plant investment, excluding power, respectively.

68. Thermal power facilities have been used in recent years for aluminium reduction, although on a much smaller scale than hydro-power. Two reduction plants utilizing thermal power required an added investment of $133 per kW for a coal-powered plant in the United States[5] and $120 per kW for a gas-powered plant in France.[6] Further discussion of these matters will be found below in the section on power.

LABOUR REQUIREMENTS

69. Labour requirements vary with the type of reduction plant, the scale of operation, the size of the electrolytic cells and the degree of mechanization adopted as well as with the differences in factor performance.

70. More labour is needed in a prebaked plant than in a Soderberg plant (*see* table 8) mainly because of the additional labour required to manufacture and handle individual anode carbons.

TABLE 8. ENGINEERING ESTIMATES OF INPUT REQUIREMENTS IN ALUMINIUM REDUCTION, PER TON OF OUTPUT

Item	*Prebaked plant*	*Soderberg plant*
Electric power (kWh)	17,000	17,500
Alumina (tons)	2	2
Fluorides (fluorine content) (kg)	25	15
Anode carbon, net (kg)	500[a]	560[b]
Total labour (man-hours):		
Total plant[c]	18	15
Pot-rooms only	8	7
Operating and maintenance supplies (dollars)[d]	20	18

[a] Prebaked carbon anodes.

[b] Soderberg paste.

[c] Including carbon plant maintenance, supervision and indirect labour.

[d] Including cathode replacement.

71. Unit labour requirements in aluminium reduction decline as plant capacity increases, although the extent of this is limited because a large part of the labour force is engaged in operations that require repetitive service at the unit level, such as stirring alumina in cryolite and furnace reconstruction.

72. It was reported that a sixfold increase in the capacity of the Canadian plant at Kitimat[7] would decrease labour requirements from 26 man-hours per ton to 22, or about 17 per cent; a similar increase of two and one-half times in the Ghanaian plant[8] would result in a decrease of 10 per cent, from 120 man-hours per ton to 110.

73. Aside from the savings obtained as a result of enlarging the capacity of a plant of given furnace size, large savings in labour may be obtained by increasing

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[3] Governments of the United Kingdom and of the Gold Coast, *The Volta River Project, Volume I, Report of the Preparatory Commission* (London, 1956).

[4] "Aluminium in Norway", *Metal Industry* (London), 29 July 1960.

[5] "Three Companies Plan Fully Integrated Aluminum Project", *Electrical World* (New York), 30 January 1956.

[6] United States Department of the Interior, Bureau of Mines, *Minerals Yearbook* (Washington, D.C.), v. I, 1957.

[7] "Kitimat Workers will have a Planned Town", *Engineering News-Record* (New York), 19 August 1954.

[8] *The Volta River Project.*

the size of the furnace. It may be observed, however, that experienced personnel are required to obtain good results with very high-amperage cells, and this may be a limiting factor, *inter alia*, in their use in developing countries.[9]

74. Capital-labour substitution is achieved principally in the area of materials handling and ancillary facilities. Operations involving the distribution of alumina into electrolytic cells, stirring alumina in cryolite (an operation repeated every two to four hours) and collection of the metallic aluminium can be performed with simple tools and equipment. On the other hand, because of their repetitive nature and the large amount of labour involved, such activities are amenable to mechanization and possible automation.[10] The extent of possible capital-labour substitution may be roughly illustrated from a United Nations technical assistance report in which it was suggested that through mechanization of materials handling activities and by enlarging the capacity of the cells, the over-all labour requirement could be reduced from the existing level of 132 man-hours per ton to 29–38 depending on the size of the cells adopted. The extent of possible further mechanization may be illustrated by the low figures for total labour requirements of 11 and 14 man-hours attained in a few recently built, highly mechanized plants in the United States and France.

75. It is difficult to assess the differences that may be attributed to factor performance since this varies from one country to another. In the technical assistance report referred to above it was indicated that the labour figures had been adjusted upwards by 25 per cent to take into account the differences in factor performance as compared with established European standards. Industrial averages of labour input for several countries are given in table 9.

76. The low labour requirements in the United States reflect in part the relatively high degree of mechanization and the higher scale of operation as well as the relatively larger size of the electrolytic cells in the plants.

TABLE 9. INDUSTRIAL AVERAGES OF LABOUR REQUIREMENTS IN ALUMINIUM REDUCTION

Country	*Man-hours per ton of output*
Japan (1960)	69.0
Norway (1958)	55.5
United States (1958)	19.5

SOURCE: For Japan, Japan Development Bank, Research Division, "Units of Input Consumption by Alumina and Aluminium, Refining Capacity and Import of Bauxite" (Tokyo, 1961); for Norway, Norway Central Statistical Bureau, *Annual Survey of Industrial Production Statistics, 1958* (Oslo, 1960); for United States, United States Department of Commerce, Bureau of the Census, *Census of Manufactures, 1958* (Washington, D.C.).

77. Table 10 gives data on the actual labour required in three selected plants. All of these plants have Soderberg-type cells. Plant I is in Japan, plant II in an advanced European country; both have cells of about 33 KA and 50 KA current. Plant III is in a developing country, and has cells of 26 KA current; the data under heading IV are for the same plant, taking into account the effect of proposed expansion and mechanization.

TABLE 10. LABOUR REQUIREMENTS IN SELECTED REDUCTION PLANTS

(Number of workers, unless otherwise indicated)

Item	*Plant I*	*Plant II*	*Plant III*	*Plant IV*
Capacity (tons/year)	30,000	14,000	10,000	20,000
Operating labour:				
Pot-room	300	115	400	140
(Potmen)	(221)	(...)	(294)	(88)
Casting	54	25	115	49
Carbon plant	...	14	...	...
Maintenance[a]	96	43	73	53
Other	63	25	50	29
TOTAL OPERATING LABOUR	513	222	638	271
Man-hours per ton capacity[b]	41	32	165	35

[a] Including electrical, mechanical and other maintenance as well as furnace reconstruction.

[b] Figure for plant II has been estimated on the basis of 2,000 hours per year per worker. The remaining figures presumably depict actual performance reflecting local employment conditions.

78. Labour requirements in aluminium reduction involve a relatively high proportion of skilled and semi-skilled labour, as a result mainly of the high proportion of furnace attendants and other workers needing advanced skills for pot reconstruction, maintenance and the like.

79. In programming the establishment of aluminium plants in developing countries, capital-saving techniques should be considered whenever possible on account of the relatively low level of wages. Moreover, maintenance of mechanized equipment presents a problem in reduction plants owing to the highly abrasive nature of the alumina which is present everywhere in such plants. Consequently, it is not advisable to push mechanization in developing countries where skilled labour is relatively scarce. On the other hand, there are limits to the utilization of manual labour for materials handling operations owing to the high unit weights of the materials to be handled. Further, experience indicates that hard and hot work, such as crust breaking, metal tapping and anode and pin changing in the pot-rooms, is more reliably and efficiently carried out with machines than with hand labour, particularly in tropical climates.

80. In the light of available data for moderately mechanized plants in developing countries, operating labour requirements may be estimated at 40 to 50 man-hours per ton capacity for a plant of 20,000 tons of yearly capacity and 30 to 40 man-hours for a 60,000-ton plant. To arrive at total labour requirements, allowance must be made for administrative, managerial and clerical personnel, involving an additional 10–15 per cent.

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[9] See annex I.

[10] In this connexion it should be pointed out that there are two ways of organizing the pot-room work. The traditional system is to assign a certain number of cells to one or two workmen who carry out most of the operations on them. The other method, which lends itself to mechanization and which has been used in North America for a considerable time, consists in assigning each operation (such as crust breaking, alumina charging, metal tapping, anode changing or paste changing) to a crew equipped with specialized instruments; each crew performs its particular operation throughout the entire pot-room. This organization of the work has been adopted, at least in part, in the newest reduction plants in western Europe. It results in considerable labour saving but does not always give as good operating results since no one workman is responsible for a particular cell.

POWER

81. Electric power used in a reduction plant includes the direct current consumed in the electrolytic cells and losses in transformer and rectifier as well as miscellaneous power for cranes, conveyors, compressed-air and vacuum systems, gas removal and purification systems and the like.

82. High electric consumption has stimulated efforts to reduce power requirements. Since as much as 60 per cent and even more of current is lost in transmission and through exposure in the electrolytic cells, efforts have been focused on reducing these losses. Such efforts have met with success through the development of large-capacity cells (where less exposed areas per unit of output are obtained) and improved bus-bar design.

83. To illustrate the magnitude of the savings obtained in power consumption one may refer to the technical assistance report mentioned earlier. It was stated that the expansion of cells in the plant from a capacity of 26,000 amperes to 42,000 or 52,000 amperes could be expected to reduce direct current consumption from 20,000 kWh to 18,000 or 17,500 kWh per ton of aluminium, respectively. Lower direct current consumption figures of 14,500 kWh per ton have been reported for a recently built French plant using 100,000-ampere cells and an elaborate bus-bar design.[11]

84. As mentioned in the section on investment, cells beyond a certain size would require additional investment. Hence, the saving in power consumption associated with larger cells would have to be weighed against the additional investment. In countries with cheap power, such as Canada and Norway, it is more economical to use relatively small-size cells and low-cost bus-bars and have a relatively high power consumption—from 16,500 to 19,500 kWh per ton in modern plants. Power consumption in the United States lies between these two figures.

85. Table 11 indicates *actual* power consumption for plants operating in several countries and illustrates, albeit roughly, the variation in power consumption with size of cells. Industrial averages for consumption of power are given in table 12.

86. As indicated in table 8, power consumption in Soderberg plants is higher than that in prebaked plants.

87. Aside from the aspect of physical inputs discussed earlier, reduction plant capacity may be related to the optimum size of electric power plant. The high share of electricity in total cost makes it important to take advantage of the increasing returns to scale existing in electric power generation. To illustrate, the target capacities for the Canadian plant at Kitimat (550,000 tons) and for the Ghanaian plant (210,000 tons) were planned to take maximum advantage of the optimum scale of the hydroelectric facilities.

88. Power from coal and lignite, natural gas and, in particular, hydro-electricity is used variously in aluminium production. Hydro-power offers the cheapest source of energy. The lower boundaries for power cost may be found in some old plants with fully amortized hydroelectric power plants. In such cases, power costs may be as low as one mill per kWh, and this is probably the case for certain plants in Canada and Norway. As table 13 indicates, in Norway the industrial average cost for power obtained from own plants is 1.33 mills per kWh and 1.82 mills for purchased power. For recently built plants the cost is rising, ranging between 2.1 and 2.8 mills per kWh. The range for Canada is 1.5 to 3.5 mills and for the United States, 2 to 4 mills. In western Europe, 4 to 6 mills may be paid and in Japan, 2.7 to 8.0 mills. Table 14 shows power costs for proposed plants in developing countries and indicates rather low-cost hydro-power. It is difficult to determine the maximum economic power cost for aluminium production catering to export markets and it must, of course, be decided upon for each plant individually. It may be stated as a rough approximation, however, that costs lower than 4 mills per kWh would probably provide a favourable environment for the development of aluminium smelting.

89. Reduction plants are tied to sources of power. They may be located close to hydroelectric power, in which case raw materials in the form of dried bauxite or, more frequently, alumina must be conveyed to them, or,

TABLE 11. ELECTRIC POWER CONSUMPTION FOR A NUMBER OF REDUCTION PLANTS

(Kilowatt-hours per ton, except as indicated)

Plant[a]	Size of cell KA	*Power in cells direct current*	*Power loss in conversion*	*Other uses*	*Total power consumption*
VII	18	19,800	1,800		21,500
VIII	26	20,000	3,800		23,800
VI	42	17,000	1,800		18,800
	33	18,800	1,700		20,500
I	52 (17)[b] 45 (75) 38 (8)	16,887	987	1,166	19,000
V	54 (57) 33 (43)	17,238	1,077	640	18,955
IV	55	16,344	1,816	48	18,612
IX	66	15,000	920	880	16,800
II	89	16,806	1,301	908	19,015
III	100 (42) 40 (58)	17,228	1,362	782	19,372

[a] All plants use the Soderberg anode system.

[b] Figures in parentheses indicate the percentage share of the size of cell in the total number of cells.

TABLE 12. POWER CONSUMPTION, INDUSTRIAL AVERAGES FOR SELECTED COUNTRIES

Country	*Kilowatt-hours per ton*
China (mainland)	20,000–22,000
China (Taiwan)	19,000[a]
India	25,000
Japan	19,700
Norway	21,800
United States	17,700

SOURCE: For China, India and Japan, United Nations, *Bauxite Ore Resources and Aluminium Industry of Asia and the Far East*, Mineral Resources Development Series, No. 17 (Sales No.: 63.II.F.2); for Norway, Norway Central Statistical Bureau, *Annual Survey of Industrial Production Statistics, 1958*; for United States, United States Department of Commerce, Bureau of the Census, *Census of Manufactures, 1958*.

[a] Direct current, 17,000 kWh.

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[11] G. A. Baudart, "Le rôle du gaz de Lacq dans les récents développements de l'industrie de l'aluminium en France", *Revue de l'aluminium* (Paris), January 1961.

TABLE 13. COSTS OF HYDRO-POWER FOR ALUMINIUM REDUCTION IN SELECTED COUNTRIES

Country	*Mills per kWh*
Cameroon (Edea)	
1957	1.7
Norway	
Recent trend	2.1–2.8
Average 1958 trend	1.82[a] 1.33[b]
Sweden	
Recent trend	4.8
United States	
Pacific North-west, 1959[c]	2.0
TVA	4.25
Average, 1958	3.48[a]

SOURCE: For Norway and Sweden, recent trends, "Prospects of the Scandinavian Chemical Industry in the 1960's", *Tekniskt Tidskrift* (Stockholm), 1961, No. 28, page 781; "Hydro-electric power and costs", *ibid.*, 1961, No. 38, page 1,073 (in Swedish); industry averages, Norway Central Statistical Bureau, *Industrial Production Statistics*; for United States industry average, United States Department of Commerce, Bureau of the Census, *Census of Manufactures, 1958*; for others, United States Department of the Interior, Bureau of Mines, *Minerals Yearbook* (Washington, D.C.), v. I, for the years 1959 and 1960.

[a] Purchased power.

[b] Power from own plant.

[c] Base rate.

TABLE 14. COST OF POWER TO PROPOSED PLANTS

Project and installed power (megawatts)	*Mills per kWh*
Volta (Ghana)	
360	4.40
540	2.85
720	2.32
INGA (Democratic Republic of the Congo)	
1,570	2.50
25,000	1.25
Kouilou (Congo (Brazzaville))	
800	1.67
Kariba (Rhodesia)	
500	10.2
1,200	3.5
Saudi Arabia	
(plant powered by natural gas)	
25	9.65
70	7.00
132	6.00

SOURCE: For Ghana, *The Volta River Project*; for Saudi Arabia, *Report on the Utilization of Natural Gas in Saudi Arabia*, Deutsche Projekt Union GmbH (Frankfurt, 1959); for others, E. and M. R. Marcus (ed.), *Investment and Development Possibilities in Tropical Africa* (New York, Bookman Associates, 1960).

where thermal power is used, they are usually located in areas possessing abundant supplies of natural gas or coal. The latter are usually less remote from industrial centres than are the hydro-power facilities.

90. The new processes referred to earlier—the Quebec and Péchiney—do not offer any savings in power consumption. With lower capital charges, however, they would, if feasible, tend to increase the relative importance of power costs in aluminium production. These and other new processes are discussed in the technical annex to this report.

OTHER INPUTS

91. Other inputs include alumina, fluorides and carbon, requirements for which may not change significantly, if at all, with changes in scale of operation. Table 8 provides engineering estimates, and in table 15 industrial averages for important input items are given for several countries.

92. Alumina consumption per ton of output does not vary with the scale of operation. Of course, good housekeeping must be enforced in order to avoid spillage losses when handling the alumina. Floor sweepings are always re-used in cells producing lower-purity metal.

93. Fluorides are used in the form of cryolite and aluminium fluoride and small amounts of fluorspar. Cryolite and aluminium fluoride can be substituted for one another, subject to technical and operational restrictions. Fluoride consumption depends primarily on operational practices: it increases with cell operating temperatures and with the acidity of the electrolyte bath, that is, the AlF_3:NAF ratio. However, it may still be advantageous to operate with an acid bath because of better current efficiency.

94. Fluorides are mostly lost in the anode gas and the cathodes. Because they are expensive they are recovered in some plants from the gases and from used cathode linings. This, however, requires additional investment for fluoride recovery facilities, and may be economic in a relatively large-sized plant.

TABLE 15. INPUT REQUIREMENTS FOR PRIMARY ALUMINIUM, INDUSTRIAL AVERAGES FOR SELECTED COUNTRIES

(Kilogrammes per ton of output, except as indicated)

Input	*Hungary*	*Japan*	*Norway*	*United States*
Alumina (tons)	1.91	1.95	...	1.93
Fluorides (fluorine content)	39	45	44	38
Cryolite	30	56	40	24
Aluminium fluoride	9	23	34	29
Carbon, total	555	646	...	700

SOURCE: For Hungary, data obtained through correspondence with the Ministry of Heavy Industry; for Japan, Japan Development Bank, Research Division, "Units of Input Consumption by Alumina and Aluminium, Refining Capacity and Import of Bauxite"; for Norway, Norway Central Statistical Bureau, *Annual Survey of Industrial Production Statistics, 1958*; for United States, alumina, United States Department of Commerce, Bureau of the Census, *Census of Manufactures, 1958*. Other items represent the industrial practice in 1951 as published in United States Department of the Interior, Bureau of Mines, *Mineral Facts and Problems*, Bulletin No. 556 (Washington, D.C., 1956).

95. Engineering estimates for fluoride consumption are given at 25 kg and 35 kg per ton of output for prebaked and Soderberg plants respectively, but the industrial averages for several countries given in table 15, which reflect recent trends, indicate generally higher consumption figures than those suggested above. The relatively lower figures for Hungary and the United States are influenced in part by their fluoride recovery practices.

96. Carbon, in the form of petrol coke, pitch coke and pitch, is consumed mainly as anode. In addition, a small amount of carbon is consumed as cathode paste. Consumption of anode carbon depends mainly on the quality of the raw material and the manufacture of the carbon paste and prebaked carbon anodes as well as on pot-room operating practice. Poor-quality carbon paste and poor cell operation result in considerable carbon losses from the burning of the anode sides and the disintegration of the anode.

97. The lowest carbon consumption figures obtained today are approximately as follows:

Prebaked carbon anodes: 450–480 kg per ton of output;
Soderberg anode paste: 520–530 kg per ton of output.

However, consumption is considerably higher in many plants, often in the 600 to 700-kg range, as may be seen from the industrial averages for Japan and the United States in table 15. Close co-operation between the pot-room and the carbon plant is an aid towards obtaining the best results, and it is therefore an advantage for a reduction plant to have its own carbon plant rather than to purchase anode carbon from outside.

SCALE OF OPERATION

98. Table 16 illustrates costs of production at several capacities, using United States prices and engineering estimates for a well-managed and operated plant. These data indicate moderate economies of scale in production cost.

99. It is difficult to determine the optimum size of a plant, and each case needs to be assessed individually. However, certain general observations may be made, differentiating between operations catering to local markets and those catering to the international market.

100. As indicated earlier, capital requirements are higher in developing countries than in advanced countries, so that higher capital costs are to be expected. Inputs that have to be imported are also likely to be more costly. Moreover, since the domestic demand for aluminium in developing countries is limited, the scale of operation may be small unless export markets are available, though small plants would have difficulty in meeting competition from large-scale plants in advanced countries. Offsetting factors are lower wages and, in some cases, lower costs of electricity and raw materials. Transport costs may also be low in catering to the local market. Thus, a country that has access to low-cost bauxite or alumina, has electricity available at moderate cost and is located far from the main aluminium producing centres may very well be in a position to establish an economical reduction plant of relatively low capacity.

101. In India, for example, aluminium plants have capacities ranging between 2,500 and 10,000 tons *per annum*, and the industry is protected. Production costs have recently been estimated for a 10,000-ton plant at 20 per cent higher than c.i.f. prices for imported aluminium. However, it was further indicated that production costs may be sufficiently reduced at a capacity of 20,000 tons to withstand competition without any protection.[12]

102. Since reduction plant capacity is characterized by relative divisibility, a small plant may be established at first and gradual expansion of capacity may be phased over a period of time, responding to growth in demand.

103. In plants producing for the international market, however, economies of scale in the production of aluminium favour large-scale operation, and, because aluminium production requires very low-cost power, an even more important factor favouring large-scale operation may be the economies of scale to be obtained in the generation of hydro-power. This consideration is of particular importance when there are no alternative uses for a large power supply.

COMPARISON OF PREBAKED AND SODERBERG SYSTEMS

104. Both the prebaked carbon and the Soderberg anode systems are widely used today and both have their advantages and disadvantages. The question as to which system to adopt comes up in the early planning stage of any aluminium reduction project as this decision affects all phases of the project. The main points to consider when comparing the systems are the following.

Advantages of the prebaked system

(1) Lower power consumption, other factors being equal. The main reason for this is the higher conductivity of baked carbon as compared with carbon paste.

(2) Easier to operate. Particularly with an inexperienced crew, it is easier to obtain good operating results with prebaked cells.

(3) The gas is less obnoxious and easier to clean. Consequently, the prebaked system is often preferred in cases where air pollution is an important factor.

Advantages of the Soderberg system

(1) Simpler and cheaper carbon plant. In both systems it is necessary first to produce carbon paste, and considerable additional baking and rodding facilities are required to produce prebaked carbons from the paste.

(2) Lower operating labour requirements. The Soderberg system avoids the handling and manufacture of individual anode carbons and is in general more suitable for mechanization.

105. The two systems are closely competitive with respect to metal quality and carbon consumption, taking into account the baking loss when producing prebaked anodes. There is, therefore, no general answer to the question as to whether the prebaked or the Soderberg

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[12] United Nations, *Bauxite Ore Resources and Aluminium Industry of Asia and the Far East.*

TABLE 16. AVERAGE PRODUCTION COSTS OF ALUMINIUM INGOTS, HYPOTHETICAL UNITED STATES PLANTS[a]

(Dollars per ton of output)

Item	*Capacity (tons per year)* *20,000*	*30,000*	*60,000*	*100,000*
Alumina	150	150	150	150
Fluorides	25	25	25	25
Carbon	25	25	25	25
Operating and maintenance supplies	18	18	18	18
Power	61	61	61	61
Labour	54	51	45	42
Miscellaneous and general expenses	50	48	40	38
Capital charges:				
Depreciation	72	66	58	53
Interest on fixed capital	53	48	41	38
TOTAL	502	492	463	450

SOURCE: Calculated on the basis of data given in tables 6 and 8 and in the text.

[a] Plants are assumed to be using Soderberg anode systems and operating three shifts at 95 per cent of rated capacity. The following additional data are used in the estimates:

(1) Alumina consumption: 2 tons per ton of output at $75 per ton;
(2) Fluoride consumption: cryolite, 35 kg at $0.32 per kg; aluminium fluorides, 35 kg at $0.40 per kg;
(3) Carbon consumption: 560 kg at $45 per ton;
(4) Operating and maintenance supplies at $18 per ton of output;
(5) Power: 17,500 kWh per ton of output at 3.5 mills per kWh;
(6) Labour per ton of output assumed as follows:

Capacity (tons)	*Man-hours*
20,000	18
30,000	17
60,000	15
100,000	14

Wages assumed at $3 per hour;

(7) Miscellaneous and general expenses include insurance, property tax, supervisory, technical and clerical personnel, office supplies and contingencies. Assumed at 2.5 per cent of fixed capital plus 45 per cent of labour cost;

(8) Fixed investment assumed as follows:

Capacity (tons)	*Millions of dollars*
20,000	19.6
30,000	26.6
60,000	47.0
100,000	72.0

Life of equipment assumed at 12.5 years; of buildings, 20 years.
Interest at 5 per cent.

system is the better one. This question must be studied carefully in each case.

106. Plant size has a bearing on the selection of the anode system. A minimum plant size of 60,000–100,000 tons is required to justify the additional facilities required for a prebaked plant. Investment data given in figure II indicate lower costs for Soderberg plants at capacities below 100,000 tons, and lower costs for prebaked plants above this capacity. It may still be justified to build a smaller prebaked plant if future expansions are planned or in cases where air pollution restrictions make this advisable regardless of economic considerations.

Chapter II

ALUMINIUM FABRICATION

107. The most important conventional fabrication methods for aluminium, the starting materials and products obtained are indicated below.

Fabrication process	*Starting material*	*Products*
Flat rolling	Rolling ingots (slabs)	Sheet, plate, strip, foil
Rod rolling	Wire bars	Rod for wire and cable
Extrusion	Round ingots (billets)	Structural shapes, tubing, also rod for wire and cable (on a small scale)
Forging.	Extruded bar stock	Products requiring high strength, such as engine parts
Spinning and deep drawing	Circles made from rolled sheet	Hollow ware, such as kitchen utensils, containers and the like
Impact extrusion.	Slugs made from rolled strip or extruded bar	Small containers
Casting (sand, permanent mould and die casting) .	Molten metal	Engine blocks and pistons, and all kinds of cast shapes

108. In the conventional processes, the trend in the past has been towards more capital-intensive high-capacity plants. This has resulted in a keen interest in processes for direct casting of aluminium. These methods directly produce shapes close to the final shapes desired, such as rods, strips and continuous sheets. The fact that direct casting methods are less capital-intensive and more amenable to small-scale operation makes them of interest for developing countries.[1]

109. The following section reviews factors affecting capital cost for several types of fabricating plant.[2]

CAPITAL REQUIREMENTS

Rolling mills

110. Modern continuous hot mills for aluminium sheet cost $30 to $50 million for hot-rolling capacities ranging from 100,000 to 200,000 tons per year in widths of up to 100–120 inches (2.0–2.5 m). These investment figures include cast house and soaking pits for producing and preheating aluminium rolling ingots weighing up to 6–10 tons. However, these figures do not include cold-rolling, heat treatment and finishing facilities (corrugating, flattening, slitting, embossing, printing, square-cutting, circle-cutting, etc.). When such facilities are added, full utilization of hot-rolling capacities of this magnitude may increase the cost of the total project from $60 million to more than $100 million. However, a proportion of the hot-rolled production from a continuous hot mill is usually sold as reroll stock to other fabricating plants for cold rolling and finishing.

111. Rolling mills of this kind are not usually a priority requirement in under-developed countries; the investment, production capacity, maximum width and unit weight of rolling ingot and hot-sheet coil are all relatively high for such countries. A conventional arrangement of one or two reversing hot mills and hand-fed cold and finishing mills is suitable for outputs ranging from 2,000 to 10,000 tons per year. The same hot mill arrangement, but with at least part of the cold rolling being carried out in reel-fed mills, is suitable for outputs ranging from 5,000 to 30,000 tons per year. Approximate investment figures for complete rolling mills of this type, including all auxiliary installations, range from $1,500 down to $500 per annual ton of aluminium products, depending on plant size and the variety of finishing equipment included. A 10,000-tons per year plant of this type, capable of producing a maximum finished sheet width of 48 inches (1.2 m), with finishing equipment, would cost from $8 to $12 million.

112. The new direct sheet casting processes are suit-

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[1] Aluminium is processed into many different metal products and consequently there exist many types of aluminium fabricating plants. The most important fabricating processes are described in annex I as are also new fabricating methods of interest to under-developed countries. For data on aluminium fabricating facilities in Asia, *see* United Nations, ***Bauxite Ore Resources and Aluminium Industry of Asia and the Far East*** (Sales No.: 63.II.F.2).

[2] Additional data on capital, labour and other input requirements as well as production costs are given in annex II. These data include industrial averages for the United States as given in United States Department of Commerce, Bureau of the Census, *Census of Manufactures* (Washington, D.C.) for the years 1954 and 1958 as well as data taken from feasibility reports on establishing fabricating facilities in developing countries.

able for outputs ranging from 5,000 to 30,000 tons per year. Complete plants of this type, including intermediary rolling and finishing facilities, cost from $800 down to $400 per annual ton capacity, depending on plant size and the variety of finishing equipment.

Rod, wire and cable plants

113. Similarly, the capacity and capital costs of a conventional rod rolling mill are high; rod rolling mills are therefore only justified when a large output (say, more than 15,000 tons per year) is being considered. The production of rod, wire and cable can be achieved on a smaller scale at much lower investment by using Properzi machines. This has already been done successfully in several under-developed countries.

Extrusion plants

114. The extrusion processes lend themselves to small operations as extrusion presses, draw benches, straightening benches, etc. can be added gradually. A small extrusion plant (say, 2,500–5,000-ton annual capacity) can be built for $1.5 to $3.0 million and later expanded as required. Such plant would produce only light profiles and tubes; the large extrusion presses required for heavier products would call for more expensive plant.

Kitchen utensils and hollow ware

115. Plants for the production of kitchen utensils and other hollow ware from aluminium circles require comparatively low investment. A small plant can be built for $400,000–$800,000 and expanded gradually as required by the addition of deep drawing presses, spinning benches and the like.

Use of fabricating facilities for other non-ferrous metals

116. Much of the fabricating equipment used for other non-ferrous metals, such as copper, brass, zinc and nickel alloys, is also suitable for aluminium. This applies, for example, to rolling mills, extrusion presses and draw benches. On the other hand, aluminium and aluminium alloys require heat treatment temperatures and conditions which differ considerably from those used for other non-ferrous metals; consequently, new furnace equipment is usually required for aluminium.

117. While it is possible to use for aluminium fabrication equipment which has previously been used for other non-ferrous metals, it is not advisable to use the same equipment alternately for aluminium and other non-ferrous metals. The reason for this is that particles of the heavier metals adhering to the equipment (rolls of rolling mills, containers of extrusion presses and so forth) are pressed into the aluminium surface, resulting later in corrosion due to aluminium-heavy metal electrochemical couples. In the case of rolling mills, this can be avoided by changing roll pairs whenever a change is made from aluminium to another metal, or *vice versa*; however, this is not usually economical because of the production time lost in the roll changing.

ANNEXES

Annex I

TECHNICAL DATA

RAW MATERIALS

1. Aluminium metal is produced from alumina-rich raw materials, such as bauxite, by a two-stage process consisting of an extraction of pure alumina from the raw material followed by an electrolytic reduction of the pure alumina to metallic aluminium. This electrolytic reduction process was developed simultaneously in 1886 by Hall in the United States and Héroult in France and, although many improvements have been introduced since then, it remains the only commercial process for the production of aluminium in the world.

2. Aluminium is the metal occurring in the largest quantity in the earth's crust; it is an important component of practically all common rocks. The aluminium silicates present in primary rocks have been broken down by weathering processes during which the alumina has become enriched in clays and bauxite.

3. Under normal economic conditions the only commercial raw material for aluminium production is bauxite. Bauxite is basically hydrated aluminium oxide, with varying contents of impurities. Two types may be identified, monohydrate and trihydrate bauxites. The degree of hydration and the nature and quantity of the impurities are important economic factors in the processing of bauxite to pure alumina. Table 17 gives analyses of typical bauxites from different countries.

4. Alumina monohydrate, $Al_2O_3 \cdot H_2O$, occurs in two mineralogically different forms, boehmite and diaspore. Boehmite is soluble in caustic solutions, but it needs much higher temperature and pressure than does gibbsite, the typical trihydrate bauxite mineral. Diaspore, on the other hand, is very refractory to caustic leaching.

5. The European Bayer process to be discussed later is applicable to monohydrate bauxites in which boehmite is the main constituent. Most bauxites mined in Europe are of this type and the Bayer process for monohydrate bauxites is therefore primarily a European development. Monohydrate bauxites with high diaspore content are mined in Greece and the Soviet Union. These bauxites are not suitable for the Bayer process and an important proportion of the Greek bauxite production therefore goes to Norwegian and Soviet alumina plants which use another process, namely, the Pedersen process.

6. Alumina trihydrate, $Al_2O_3 \cdot 3H_2O$, in the form of the mineral gibbsite is the main constituent of most of the bauxites found in British Guiana, Indonesia, Malaysia, Surinam, the United States, West Africa and Western Australia. These bauxites are the cheapest to treat by the Bayer process practice for trihydrate bauxites developed in North America, and this type of bauxite is therefore the most desirable. Until recently, only trihydrate bauxite was used for alumina production in Canada, Japan and the United States.

7. In recent years mixed bauxites in which the alumina is present partly as monohydrate and partly as trihydrate have grown in importance as raw materials for the aluminium industry. Thus, the large bauxite deposits which have been developed in the Caribbean area, particularly in Haiti, Jamaica and Puerto Rico, are to a considerable extent mixed bauxites with one to 25 per cent monohydrate. Most bauxites found in India and northern Australia are also mixed, with trihydrate as the predominant constituent. To treat these mixed bauxites successfully it has been necessary to make an adjustment in the conventional trihydrate Bayer process as the presence of even small amounts of monohydrate alters the digestion conditions.

Mining methods

8. Practically all the bauxite produced in the western hemisphere, Africa and Australia is mined by open-pit methods. In Europe some bauxite is produced by underground mining, but there, too, most of the production comes from open-pit operations.

9. Open-pit mining of bauxite, when carried out on a comparatively large scale, usually consists of the following operations:

Removal of overburden. Sandy and earth overburden is usually removed by bulldozers, bucket excavators and draglines, by hydraulic mining and, most recently, by large-wheel excavators. The latter have capacities of up to 1,200 tons per hour;

Removal of bauxite. Similar methods are used for removing the bauxite itself. Usually, the bauxite must first be loosened by blasting;

Replacing of overburden. In some countries it is desirable to restore the surface of the mines for re-use as forest or agricultural land. In that case, the overburden is continuously stripped ahead of the advancing bauxite mining operation, and dumped behind it. Drag-lines or belt conveyors take the overburden directly from the stripping zone to the replacement zone.

Beneficiation of bauxite

10. In the commercial beneficiation of bauxite the main purpose is usually to remove silica. Reactive silica in the form of clay and other loose impurities is removed by washing and classification. This is not always possible, however, as in some cases the alumina hydrate is almost as fine and soft as the clay minerals.

11. Raw bauxite from the mines is usually crushed, washed and dried to lower the tonnage to be shipped. Drying is carried out in rotating kilns at moderate temperature to remove the free moisture without affecting the hydration. Natural gas or heavy oil is used as fuel in preference to coal, in order to avoid contamination with ash. The largest drying kilns in operation handle about 70 tons of bauxite an hour. Fuel consumption varies considerably, depending on the moisture in the bauxite and the design and size of the drying kiln.

Other aluminous raw materials

12. Since aluminium is more widely distributed in rocks and clays than any other metal, many minerals exist which appear to have an attractive content of alumina. In the course of the past half-century, therefore, many other minerals have been proposed for processing into alumina. These have included aluminous clays such as kaolin, alumina-rich coal ashes, leucite, nepheline, andalusite, labradorite and alunite.

TABLE 17. TYPICAL ANALYSES OF BAUXITE (percentage)

Types of Bauxite: B-Boehmite (monohydrate); D-Diaspore (monohydrate); G-Gibbsite (trihydrate); C-Corundum (anhydrous)

Location	*Type of bauxite*	Al_2O_3	SiO_2	TiO_2	Fe_2O_3	H_2O
AFRICA						
Ghana						
Nyinahin	G	46–51	1	—	17–25	26–29
Mt. Ejuanema	G	57–61	1	1–2	10–12	27–29
Guinea						
Kassa Island	G	54	7	1–2	11–12	28–29
Kindia (Fria)	G	40–42	2–3	—	20–30	25–28
ASIA						
India						
Madras, Orissa	G and D	52–58	2–4	6–11	7–14	25–28
Indonesia						
Bintan	G	54–58	2–4	1	4–10	28–30
Malayasia						
Johore	G	55–60	2–7	1	4–6	27–29
AUSTRALIA						
Western Australia						
Darling Range	G	48–52	8	4	12–18	27–29
EUROPE						
France						
Bouches-du-Rhône: Var, Ariège, Hérault	B	54–58	1–6	2–3	23–26	10–13
Greece						
Mt. Parnassus	B	57	4	2–3	23	11–13
Other	D and C	58–67	1–2	2–5	15–31	5–12
Hungary						
Bakony Mountains	B and G	50–52	5–6	2–3	17–19	17–20
Vértes Mountains	B	53–55	7	2–3	20	14
Italy						
Abruzzi, Campania	B	54–58	1–3	3	23–27	11–13
Romania						
Bihar Mountains	D	57	2–4	3	24	12
USSR						
Northern Ural Mountains	D	49–59	3–7	2	21–24	11
Yugoslavia						
Istria	B	54–59	2–5	3–4	20–24	12–15
Drniš	B and G	51–53	1–3	2–4	20–23	20–22
Mostar	B	56–62	1–4	3–4	20–25	12–15
NORTH AMERICA						
Dominican Republic	G	46–49	1–5	...	19–21	...
Jamaica	G and B	50–53	1–3	2–3	17–20	26–27
Haiti	G	47	3	...	22	...
United States						
Arkansas	G	52–58	6–10	2–3	6–14	28–30
SOUTH AMERICA						
British Guiana	G	50–61	2–9	1–2	3–10	26–32
Brazil						
Poços de Caldas	G	54–58	3–7	1–2	6–10	28–29
Surinam	G	57–59	2–4	1–3	5–6	31–32

Bauxite, however, is the only economical raw material for alumina production under competitive conditions, although other raw materials have been used in war-time and in countries following a policy of self-sufficiency.

13. The only non-bauxite raw material which is used today on a large scale is nepheline, a sodium-potassium-aluminium silicate ($Na_2O \cdot Al_2O_3 \cdot 2SiO_2$) with approximately 34 per cent Al_2O_3. This is obtained as a by-product from the beneficiation of apatite, which is mined on a large scale in the Kola Peninsula. Nepheline is used for the production of alumina in the Soviet Union, potash being obtained as a by-product. It has recently been reported that a similar process is to be used for producing alumina on a large scale in Siberia.

ALUMINA

The Bayer process

14. Practically all the world's alumina production is still made by the Bayer process. A multitude of other alumina processes have been proposed and some are still being in-

vestigated, but the Bayer process has proved to be a very flexible process capable of treating a wide range of bauxite qualities and also capable of producing a wide variety of alumina qualities, both with respect to chemical analysis and grain structure. From its beginning as a batch process with small units, the Bayer process has been developed into a continuous process with large units and highly efficient heat recovery systems. Trihydrate bauxite has been treated continuously for a number of years, and now the more refractory monohydrate and mixed bauxites can also be treated continuously. (*See* Bayer process flowsheet, figure III.)

15. The only other processes used on a commercial scale today are the Pedersen process, used in Norway and in at least one plant in the Soviet Union, and a Russian process using nepheline as raw material. This latter process has already been used by the Russians for producing alumina from the Kola nepheline.

16. In the Bayer process, finely ground bauxite is digested at elevated temperature under pressure with a caustic solution, whereby the alumina hydrate present in the bauxite is dissolved as sodium aluminate. The pressure and temperature required for the extraction depend primarily on the form in which the alumina is present in the bauxite, alumina trihydrate being more easily soluble at low temperature and pressure than alumina monohydrate. The necessary caustic is supplied as sodium hydroxide or as soda ash causticized with lime.

17. After digestion is completed, the insoluble components of the bauxite—primarily iron oxide, silica and titania—remain as a residue known as red mud (its colour being derived from a usually high content of iron oxide). At the same time, a certain amount of alumina and caustic is lost in the red mud; this amount is primarily a function of the reactive silica content of the bauxite, which forms an insoluble sodium-aluminium-silicate compound. The red mud is separated from the sodium aluminate solution by thickening and filtering. After filtering and washing, the red mud is usually discarded by pumping the slurry to disposal areas known as "red mud lakes".

18. The sodium aluminate solution is cooled and pumped to precipitators where the precipitation of alumina hydrate is induced by the addition of "seed alumina", which is previously precipitated alumina hydrate. The particle size and shape of the precipitated alumina hydrate and the proportion of the alumina precipitated are controlled by the time, temperature and agitation as well as by the alumina and caustic concentration of the pregnant solution.

19. The alumina hydrate is separated and washed by thickening and filtering. The alumina hydrate is separated in wet classifiers into a coarse fraction and a fine fraction, the latter being returned to the precipitators to serve as seed alumina. The coarse alumina hydrate is calcined at 1,150–1,250° C in oil fired or gas-fired rotary kilns. The calcined alumina is then cooled and stockpiled for shipment to aluminium reduction plants.

20. The spent caustic solution from the precipitators, which still contains an appreciable amount of dissolved alumina, is returned, with makeup caustic, to the bauxite digesters. A considerable amount of water is required to wash the red mud and alumina hydrate. In order to maintain the water balance in the system it is necessary to remove a corresponding amount of water by evaporation. This is usually done in multiple-effect evaporators. The amount of heat required for evaporation depends on the heat exchanging efficiency of the system; considerable advances have been made in this field in recent years, resulting in fuel economies in Bayer alumina plants.

21. In European Bayer practice, digestion temperatures of 180° to 250° C and pressures of 280 to 700 psi (20 to 50 kg/cm²) are used. Under these high-temperature and pressure conditions the handling of slurries presents many technical problems, and conventional monohydrate Bayer practice has therefore been based on batch operation. However, these difficulties have gradually been overcome and it is expected that continuous processing will gradually become standard also for monohydrate bauxites.

22. Until recently, the North American industry has relied almost exclusively on trihydrate bauxites, mostly from British Guiana and Surinam. These bauxites are economically treated by the low-temperature (130 to 150° C), low-pressure (50 to 100 psi or 3.5 to 7 kg/cm²) Bayer process.

23. In recent years new bauxite sources had to be developed to satisfy the increasing bauxite requirements of the North American aluminium industry. Thus, large new bauxite deposits have been developed in the Caribbean area, particularly in Jamaica, Haiti and Puerto Rico. Some of these bauxites contain substantial amounts (up to 25 per cent) of monohydrate alumina in addition to the trihydrate and this has resulted in unsatisfactory yields in conventional North American Bayer practice. Since retreatment of the leach residue complicates the flowsheet and is usually not economically attractive it has become necessary to adjust the North American continuous Bayer process to the new raw materials by increasing the temperature and the pressure. This has resulted in operating conditions which are a compromise between conventional North American trihydrate and European monohydrate practices.

24. Since 1950 the North American aluminium industry has been working on this problem. A high-temperature (230° C) and high-pressure (400 to 560 psi or 28 to 40 kg/cm²) continuous practice has been developed which, however, differs from European practice in equipment design. North American high-pressure practice uses much lower caustic concentration than does European practice, and this results in less solution volume to be evaporated and, consequently, lower steam consumption. On the other hand, the North American high-pressure technique requires a more complicated flowsheet, primarily because more flashing stages (6 to 10, as compared with 2 to 4 in conventional low-pressure North American Bayer plant design) are necessary in order to achieve optimum heat economy in spite of the temperature and pressure drop after digestion. This is to some extent balanced by more rapid digestion—of the trihydrate part of the bauxite as well—at the elevated temperature and pressure. Because of its flexibility, which permits almost any bauxite to be processed, the high-temperature and pressure practice will probably be adopted for most new alumina plants in North America.

25. The large trihydrate plant recently built by FRIA, Compagnie internationale pour la production d'aluminium, in Guinea, which was designed by Pechiney, uses leaching at atmospheric pressure. This results in a considerable simplification of design and maintenance. On the other hand, the consumption of caustic and the Na_2O content of the alumina are somewhat higher because it is necessary to operate at a higher NaOH level to stabilize the sodium aluminate solution. This is, however, an interesting development which could result in lower alumina plant cost and production cost, particularly where cheap caustic is available.

Effect of bauxite impurities

26. The most objectionable impurity is silica. Silica occurs in bauxite in two forms:

(1) Reactive silica, which is chemically combined as clay or other silicates;

(2) Non-reactive silica, such as quartz, sand, chalcedony, etc.

The reactive silica causes losses of alumina and caustic in the red mud. The losses are of the following order:

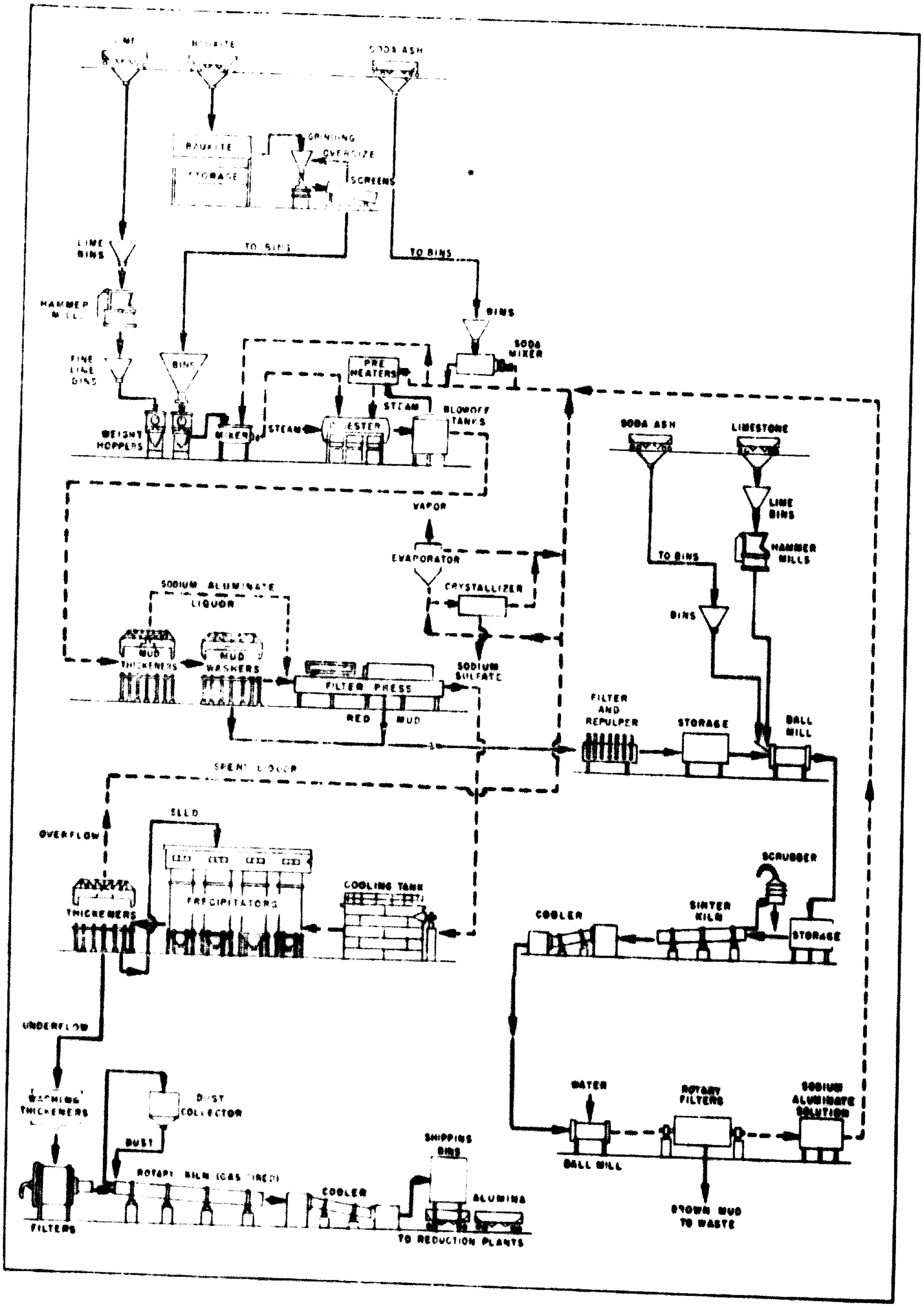

Figure III. Bayer process flowsheet

TABLE 18. REQUIREMENTS PER NET TON OF ALUMINA: BAYER PROCESS v. COMBINATION PROCESS

Item	*Bayer (A)*	*Bayer (B)*	*Combination (C)*
Raw material			
Bauxite (net tons dry)	2.0	3.0	2.2
Soda ash (net tons)	0.08	0.40	0.12
Lime (net tons)	0.06	0.30	0.10
Limestone (net tons)			0.70
Natural gas (thousands of cu.ft.)	0.9	10.0	23.0
Bauxite quality (percentage)			
SiO_2	3	13	13
Al_2O_3	55	50	50
Expected recovery (percentage)			
Bauxite	50	33	45
Al_2O_3	91	66	90

SOURCE: United States Department of Commerce, *Materials Survey—Aluminum* (Washington, D.C.), November 1956.

Alumina loss: 1.0 × reactive silica;
Caustic loss (as NaOH): 0.9 × reactive silica;
Caustic loss (as Na_2CO_3): 1.2 × reactive silica.

27. Only the reactive silica causes losses of alumina and caustic when trihydrate bauxites are digested at low temperature and pressure, as quartz is not attacked under those conditions. When monohydrate bauxites are digested at high temperature and pressure, however, silica in all its forms is attacked, and the total silica content of the bauxite results in losses of the order shown above; in these bauxites, therefore, the total silica content can be considered as "reactive".

28. Iron oxide is normally not harmful except in so far as it increases the bulk of the red mud thus causing additional washing and handling problems when present in large amounts. Bauxites with up to 25–30 per cent of Fe_2O_3 are successfully treated by the Bayer process. In certain bauxites some of the alumina seems to be combined with insoluble hydrated iron oxide minerals and in these cases the iron oxide does cause an alumina loss.

29. Titania is not soluble and therefore is generally harmless in the Bayer process. In India, bauxites with up to 11 per cent TiO_2 are successfully treated by the Bayer process. Other minor impurities, such as vanadium and phosphorus, can also cause problems.

Extractable alumina

30. The proportion of alumina which is theoretically extractable by the Bayer process can be estimated approximately by the following formula:

$$\text{Percentage of extractable } Al_2O_3 = 100 - 2 \times \% \, SiO_2 - \% Fe_2O_3 - \% \, TiO_2 - \% \, H_2O.$$

31. If the low-temperature and pressure Bayer practice is to be used for a trihydrate bauxite, the percentage of monohydrate Al_2O_3 must also be subtracted.

32. However, while the above formula will give a rough indication, to determine more accurately the available Al_2O_3 it is necessary to carry out laboratory digestion tests using standard temperatures, pressures and digestion times. The amount of alumina which is extractable under industrial conditions is actually somewhat less, because of unavoidable losses due to incomplete washing of the red mud, etc.

Caustic losses, red mud characteristics, etc.

33. It is usual to follow up the above tests with further digestion tests simulating the proposed Bayer practice. Practical values for extractable alumina, caustic losses, mud quantities, and mud settling and filtration characteristics, all of which are important for the economics of processing the bauxite, are obtained from this test work.

Lime-soda-sinter and Combination processes

34. When high-silica bauxites (more than 10–15 per cent SiO_2) are treated by the standard Bayer process, serious alumina and caustic losses occur in the red mud owing to the formation of an insoluble sodium-aluminium silicate compound. In such cases, it is possible to recover a substantial proportion of these alumina and caustic values from the red mud by the lime-soda-sinter process, which was developed as an industrial process in the United States during the Second World War, and which is still used in Arkansas for the treatment of high-silica bauxites. In this process, the red mud is mixed with limestone and soda ash, the mixture is sintered in a kiln at approximately 1,260° C, and the sinter is cooled, ground and leached with water. The resulting brown mud is separated and discarded to waste, while the leach solution containing sodium aluminate is returned to the Bayer plant digesters. The combination of the Bayer and lime-soda-sinter processes is generally known as the "Combination process". (*See* Combination process flowsheet, figure IV.)

Consumption of alumina and caustic

35. The additional investment required in the Combination process is justified because of additional recovery of alumina and caustic. Data in table 18 illustrate raw material and input required for the two processes. The bauxite under (A) is good-quality ore typical of that imported by the United States from South America, whereas bauxite under (B) and (C) represents an average-quality ore used by the Arkansas Combination plants.

Other processes

Acid processes[a]

36. Since the infancy of the aluminium industry a large number of processes have been proposed for recovering alumina based on extraction with acids or with solutions of strong acid salts (such as ammonium sulphate). Such processes have particularly been suggested for the treatment of raw materials other than bauxite which are not suitable for the Bayer process, such as various clays, alumina-rich coal ashes, leucite, nepheline, andalusite, labradorite and alunite.

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[a] For additional data on new processes, see United Nations, *Bauxite Ore Resources and Aluminium Industry of Asia and the Far East*, Mineral Resources Development Series, No. 17 (Sales No.: 63. II. F. 2), chapter III.

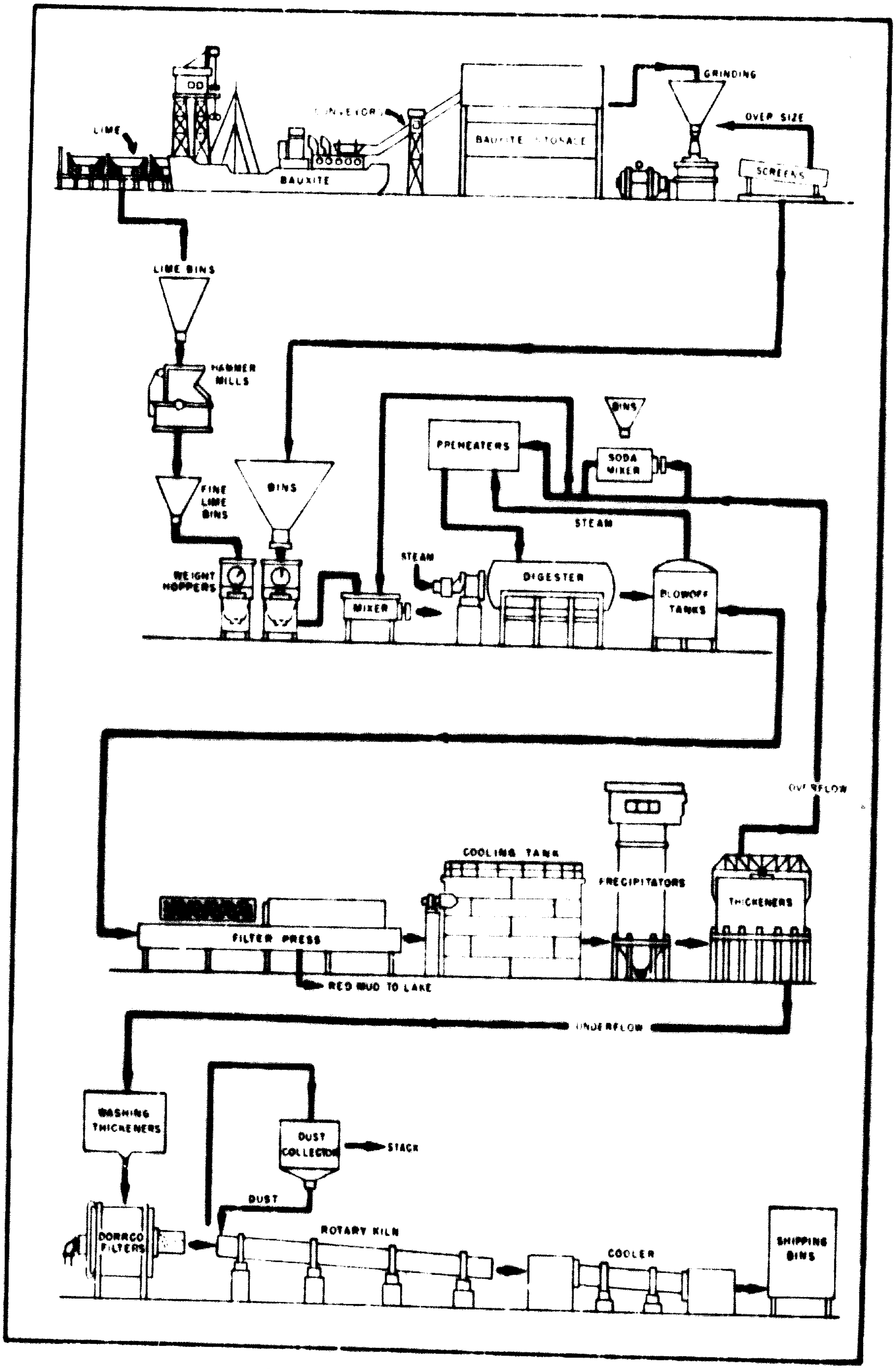


Figure IV. Combination process flowsheet

37. In general, the acid processes suffer from a number of technical and economic disadvantages, including the following:

(1) Iron being soluble in acids, it is difficult and expensive to remove it completely and produce an alumina with a low iron content comparable to that obtained by the Bayer process;

(2) Highly corrosive conditions necessitate the use of expensive construction materials, such as stainless steel, and rubber-lined equipment. In the Bayer process, common carbon steel is suitable for most of the equipment.

(3) Some of the processes are economically dependent on by-products, such as potash.

(4) In some acid processes the last step consists in recovering alumina from a salt, such as aluminium sulphate, by calcination. On a commercial scale this is a difficult operation, and it is also difficult to produce an alumina with low sulphur content.

38. Efforts to produce alumina from non-bauxite raw materials by acid processes will undoubtedly continue in various quarters, but it is improbable that these attempts will result in processes which are truly competitive with the Bayer process, which is a highly efficient process in its present form and which will undoubtedly be further improved in the years to come.

Pedersen process

39. In this process bauxite, limestone and coke are smelted together in an electric furnace. A calcium aluminate slag is formed and pig iron is recovered as a by-product. The slag is leached with sodium carbonate solution; calcium carbonate is precipitated and a sodium aluminate solution is obtained from which alumina hydrate is precipitated with carbon dioxide gas. The hydrate is calcined to alumina. The Pedersen process is the only furnace process which has found commercial application; it is used in Norway where electric power is very cheap, and a similar process is reportedly used in the Soviet Union.

ALUMINIUM REDUCTION

Electrolytic reduction

40. In the electrolytic reduction process, the alumina is dissolved in molten cryolite and dissociated into aluminium and oxygen. The oxygen combines with the carbon at the anode to form a mixture of carbon dioxide and carbon monoxide, whereas the aluminium is deposited at the cathode in the form of a molten metal layer underneath the cryolite. (*See* aluminium reduction flowsheet, figure V.)

41. Cryolite is a double fluoride of sodium and aluminium, represented by the formula Na_3AlF_6, which melts at 1,000 C. Alumina is soluble in molten cryolite and the melting temperature decreases with increasing alumina content until a minimum is reached at 935 C with 16 per cent Al_2O_3. Under practical conditions, the addition of alumina is limited to 5–10 per cent Al_2O_3, and the electrolytic cells operate in the temperature range of 950 to 1,000 C.

42. The gas liberated at the anode consists primarily of CO and CO_2, as already mentioned, and the carbon monoxide burns when reaching the surface of the cryolite bath. Thus there is no hazard from carbon monoxide, but the gas contains other impurities which can be objectionable, particularly if the plant is located in an agricultural area. These undesirable impurities are primarily fluorine compounds resulting from the breakdown of fluorides in the cellbath, entrained cryolite and alumina dust, and tarry constituents from the anode. In modern aluminium plants, therefore, the gas is cleaned before being released to the atmosphere. In this way not only are valuable alumina and cryolite recovered but the gas cleaning ensures better working conditions for the workmen and protects the vegetation of the surrounding district. The gas can be collected and cleaned by several methods, of which the more elaborate are quite expensive and only required when the plant is surrounded by valuable agricultural land.

43. The aluminium cells consist of an outer iron shell, lined with prebaked carbon blocks or rammed carbon paste; the iron shell is separated from the carbon lining by a layer of insulation. The cells are of rectangular shape, the size depending on the amperage used. The carbon-lined shell serves as cathode, and the cathodic current connexion is provided by iron bars projecting into the carbon lining. The carbon-lined pot also serves as container for the cryolite bath and the deposited molten aluminium.

Anode systems (prebaked and Soderberg)

44. The anode consists of carbon and is suspended from above into the molten cryolite bath. Two anode systems are in use: prebaked electrodes, and the continuous Soderberg electrode.

45. The oldest system uses a number of prebaked carbon blocks in each cell. These blocks are individually suspended by iron rods hanging from the anode bus-bars above the cell. This system suffers from several disadvantages, such as the manufacture of the carbon blocks and the necessity of removing the blocks before they are fully used up in order to avoid contamination of the bath with iron from the suspending rods. Also, the efficient collection of the anode gas is complicated by the multitude of anodes.

46. The principal feature of the Soderberg system is that the anode is baked by the reaction heat from the pot as it is being continuously lowered into the bath. Green carbon paste is used as anode material and fed into the top of the anode casing. This system makes it possible to equip each cell with only one large anode. The main advantages of the system are the elimination of separate carbon forming and baking facilities, the avoidance of return materials, and the easy collection of gas along the rim of the single anode. On the other hand, the gas from Soderberg electrodes is more obnoxious because of its content of tarry components and organic fluorine compounds, and the cleaning of this gas is therefore more complicated.

47. In the older type of Soderberg cell, the anodic current was introduced by a number of horizontal steel studs rammed into the sides of the anode. In the more modern version of the Soderberg system, the anodic current is transmitted to the carbon paste by vertical steel studs suspended from the anode bus-bars and projecting into the top of the anode. The gas which is generated at the juncture of the anode and the bath is collected in a small cast-iron hood attached to the anode steel casing. In this way the amount of gas is reduced by avoiding dilution with tramp air

48. All Canadian, Japanese and Soviet post-war plants are based on the Soderberg system; this has also been used in most of the new reduction plants in Europe and in those built by the Reynolds Metal Company in the United States. The other main producers in the United States, such as Alcoa, Kaiser and Ormet, have preferred the prebaked system. The newest reduction plant now being built by AIAG (Aluminium Industrie Aktien-Gesellschaft) in Switzerland is also based on the prebaked system.

Electrolytic cells

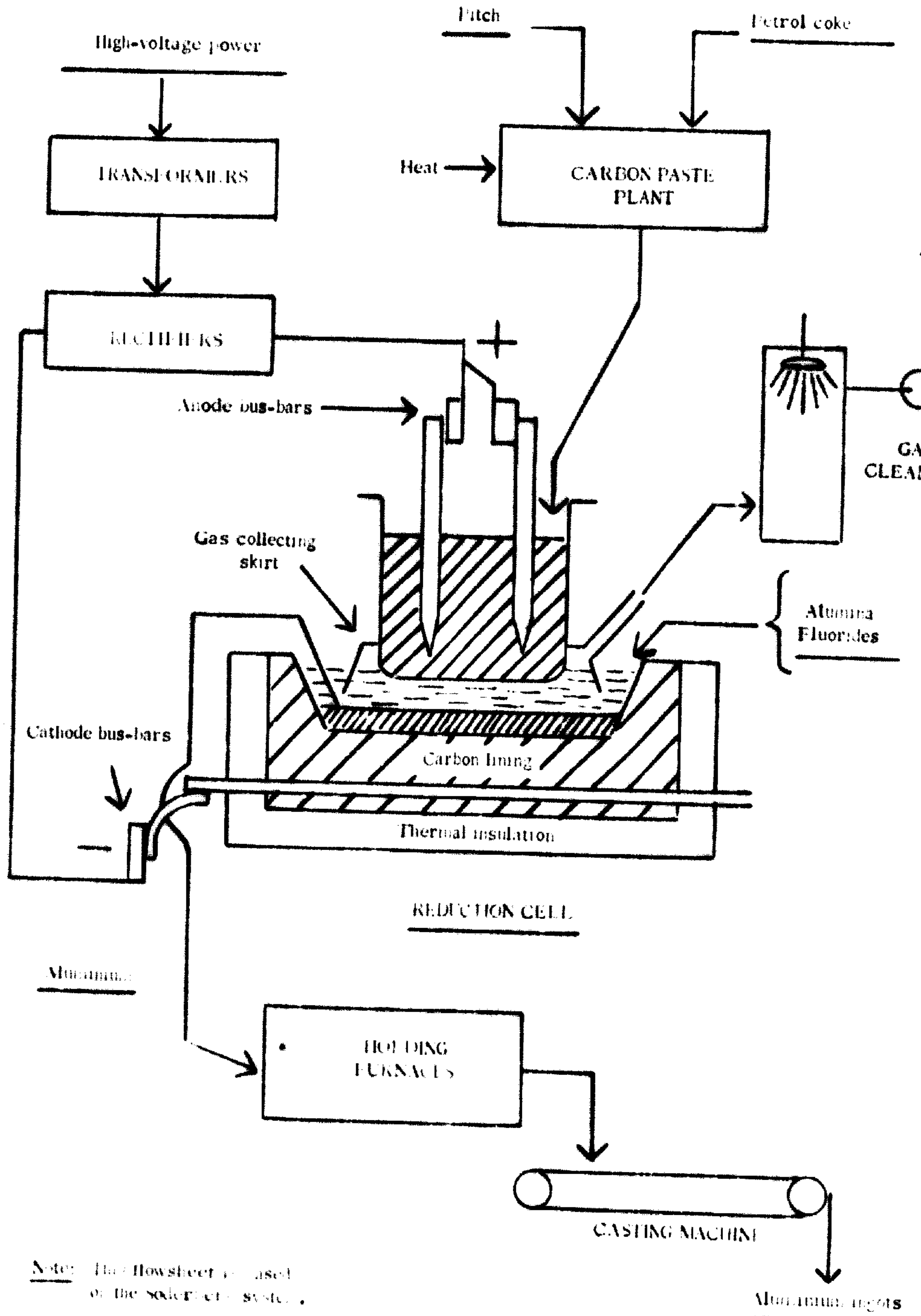
49. In a reduction plant the electrolytic cells are arranged in series, known as potlines, the anode of one cell being connected to the cathode of the next cell, and so on. Each potline forms a loop with the positive and negative ends connected with the rectifier groups feeding the potline with direct current. The maximum rectifier voltage is 850 volts and the average

voltage per cell is about 5 volts, when all voltage drops in the system are included. In practice, this means that a maximum number of about 160 cells, with an average of 150 cells in operation, can be accommodated in one potline. The maximum annual production of such a potline is shown here for cells of various amperages (assuming 87 per cent current efficiency). *(See table opposite.)*

50. The lowest capital cost per ton of aluminium capacity is achieved by building one or several complete potlines, that is, with the maximum number of cells for the chosen amperage. In this way the maximum number of production units (cells) are serviced by the same rectifier group, cranes, etc.

Direct current (amperes)	*Tons Al per cell per day*	***Tons Al per year (150 cells)***
32,000	0.22	12,000
40,000	0.28	15,000
60,000	0.42	22,500
80,000	0.56	30,000
100,000	0.70	37,500
120,000	0.84	45,000
150,000	1.03	55,000

51. The advantages to be derived from large units are obvious. When a large cell is chosen, the desired production can be attained with fewer units, requiring less operating labour and the production value of each unit justifies a higher degree of mechanization than is possible with smaller units.



Note: The flowsheet is based on the Soderberg system.

Figure V. Electrolytic aluminium reduction process flowsheet

52. The largest cells in commercial operation today are of the following sizes:

	Amperes
North America	
Prebaked	85,000
Soderberg	130,000
Europe	
Prebaked:	
Conventional (many small anodes)	90,000
Continuous (new system with large anode blocks)	128,000
Soderberg:	
In commercial operation	128,000
Large-scale testing	150,000

53. Experience has shown, however, that the application of large currents results in considerable operating difficulties primarily owing to concentrated heat formation and strong magnetic fields. These effects can be counteracted by reducing insulation and increasing ventilation to protect the cell lining from overheating, and by careful design of the bus-bar arrangement so that a uniform magnetic field is created throughout the cross-section of the cell.

54. Cells for 100,000 amperes and above have been adopted for a number of aluminium reduction plants built in the past few years in Europe as well as in Canada, Japan and the United States. The design of these cells, however, is quite complicated, and experienced personnel is required to obtain good results. Somewhat smaller pots are much easier to operate and in developing countries, therefore, it may often be preferable to base aluminium projects on a cell size of 50,000 to 80,000 amperes, which is still large enough to be economical with respect to power consumption and maintenance. Cells of this size require, of course, some additional labour as compared with the 100,000-ampere cells, but this is not believed to be a serious handicap where labour is available at reasonable cost.

55. In this connexion it should be mentioned that it is often advisable to start up a plant at a comparatively low amperage, as large cells in particular are easier to operate with good results at a lower current density. After experience has been gained, the amperage could be increased with additional rectifier capacity, which would result in a larger and more economical future aluminium production. For example, cells could be designed for initial operation at 65,000 amperes and future increase to 80,000 amperes.

Recent developments in cell composition

56. Although various electrolytic bath compositions have been tried out in the past, the industry still predominantly uses cryolite with small additions of aluminium fluoride and, sometimes, calcium fluoride. However, much research is being directed towards reducing the bath temperature and increasing the electrical conductivity of the bath by adding other salts. Of particular interest in this connexion is the proposed addition of lithium fluoride, which considerably increases the conductivity and decreases the bath solidification temperature. With this addition it would seem possible to operate a cell at higher current density without increased anode carbon consumption, because of the lower operating temperature. Problems are the high cost of the lithium compounds and their low specific gravity, which may affect cell operation.

57. The British Aluminium Company and the Kaiser Aluminum and Chemical Corporation have for some years been jointly investigating the uses of refractory metal conductors, such as titanium dibaride, particularly in the cathode construction. These materials have the following advantages:

Good electrical conductivity;

High density;

High resistance to molten aluminium and cryolite.

58. It is reasonable to expect that a substantial power reduction and a longer cathode life can be achieved with these cathode conductors. It will take considerable time to evaluate the durability of the special refractories, although the results obtained to date in full-sized cells in Scotland and the United States seem to be encouraging. However, the advantages would have to be quite significant to justify the high cost of these new refractory materials.

New processes[b]

59. Promising technological developments are being pursued which would serve to produce aluminium by direct reduction. Two processes are being developed, one the carbothermic process jointly by Péchiney and Ugine in France, the other the subchloride process by Aluminium Laboratories, Limited, in Canada. The developers of these new processes claim the possibility of substantial reduction in capital cost (50 per cent decrease) and no reduction in power consumption.

Subchloride process

60. This process is based on the existence of aluminium subchloride which, under certain temperature and pressure conditions, decomposes into aluminium trichloride and aluminium metal according to the following reaction:

$$2\,AlCl \quad AlCl_3 + 2\,Al.$$

In practice, bauxite is reduced with carbon in an electric smelting furnace to an alloy of aluminium and the reduction products of the other constituents of the bauxite, such as iron, silicon and titanium. This alloy is treated at elevated temperature with aluminium trichloride gas, whereby the aluminium content of the alloy is volatilized as aluminium subchloride. The gaseous aluminium subchloride is then decomposed by altering the temperature and pressure conditions; the decomposition products are pure aluminium metal and aluminium trichloride gas, which is recycled to the volatilization or distillation step.

Carbothermic process

61. Bauxite is partially reduced in an electric furnace to yield a comparatively pure fused alumina (corundum), while the impurities are discarded as an alloy consisting mainly of iron, silicon and titanium with some aluminium. The fused alumina is transferred to another electric furnace where it is reduced with pure carbon to a mixture of metallic aluminium and aluminium carbide. The metal-carbide mixture is separated. The aluminium carbide is returned to the process.

Electric power

62. Power consumption depends mainly on the following factors.

(1) ***Cell design.*** Power consumption can be reduced by decreasing current density, using low-resistance cathode constructions, and by other design changes. All these measures increase the capital cost, however, and the extent to which such technical improvements are economically justified depends on the availability and cost of the power.

(2) ***Bus-bar design.*** Power consumption can be decreased by increasing the bus-bar cross-sections to lower bus-bar resistance. The undesirable effects of electromagnetic fields can be countered with more complicated bus-bar layout. Both methods result in more aluminium and, in some cases, copper invested in the bus-bars. In this case, too, the availability and cost of power determines whether such technical improvements are economically justified.

(3) ***Good operating practice.*** This is, of course, most important. Accurate control and supervision as well as well-

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[b] *See* foot-note *a*.

trained and efficient labour are required to obtain the best results. Even with an experienced crew it may take considerable time to achieve good results with a type of cell they are not accustomed to; this is particularly true of the large (high-amperage) cells that have been introduced in recent years.

63. High power supply is required in aluminium production. Electric power capacities required for given reduction plants at various capacities are computed below. These computations are based on an assumed 20,000 kWh per ton and 8,000 hours per year.

Annual capacity of plant (tons)	*Electric power capacity (kW)*
10,000	25
20,000	50
30,000	75
50,000	125
80,000	200
100,000	250
200,000	300

FABRICATION

64. This section discusses briefly recent trends in the conventional methods of aluminium fabrication (confined to rolling and extrusion) as well as new fabrication processes. (*See* aluminium fabrication flowsheets, figure VI.)

65. In conventional fabrication the trend is towards heavier unit weights (of ingots, billets and coils) and towards higher-speed machinery, as illustrated by the following figures for some of the heaviest and fastest equipment in use today:

Rolling ingot weight	Up to 10 tons
Hot-rolled sheet coil weight	Up to 8 tons
Continuous hot sheet mill delivery speed	1,250 feet (380 metres) per minute
Cold sheet mill delivery speed	3,000 feet (910 metres) per minute
Foil mill delivery speed	4,000 feet (1,220 metres) per minute
Extrusion press capacity	15,000 tons

66. This trend has resulted in increasingly heavy and expensive equipment and this is particularly evident in flat rolling, which is the most important fabrication process for aluminium.

Continuous rolling mills

67. Prior to the Second World War aluminium fabrication methods, including flat rolling, followed the conventional pattern of non-ferrous metals fabrication, such as is still used for copper, brass, zinc and nickel alloys. The enormous growth of the market for aluminium sheet products in the industrially advanced countries in recent years has resulted in the adoption of equipment similar to that used for steel. Thus, continuous hot rolling mills capable of reducing a twenty-inch-thick (500-mm) ingot directly to one-tenth-inch-gauge (2.5-mm) sheet in widths up to 100 inches (2.5 metres) are now in operation, with production capacities ranging up to 200,000 tons per year. There are now about ten such continuous aluminium mills in the United States and two in western Europe.

68. Most of the rod required for aluminium wire and cable is now produced in continuous and highly automatic rod mills where 6" × 6" (150 mm × 150 mm) wire bars are reduced to three-eighths-inch-diameter (9.5-mm) rod in approximately twenty-two passes.

New fabrication processes

69. The very high capital cost of the heavy equipment needed for handling large unit weights at high speeds has resulted in a keen interest in processes for the direct casting of aluminium sheet and rod.

70. Direct casting processes are defined here as casting methods which directly produce shapes close to the final shapes desired, such as rod, strip and continuous sheet. This is pointed out to avoid misunderstanding, because the expression "DC casting" is widely used in the United States in connexion with the now generally used semi-continuous vertical casting of rolling ingots, extrusion billets and wire bars.

71. The production of metal shapes having cross-sections which do not differ appreciably from those of the finished product is now being carried out on an increasing scale. The development of a number of continuous casting processes, some of which operate in tandem with rolling mills, has shown that savings in production costs are possible by manufacturing in this way. This is particularly true when such a continuous casting process can be tailor-made for producing directly the intermediate product for mass-produced special products, such as aluminium rod for cable manufacture, narrow aluminium strip for venetian blinds, and impact extrusion slugs for low-cost production of aluminium cans.

72. Ideas of this kind were put forward long ago, but it is only since the Second World War that a large amount of practical work has been carried out both in Europe and North America on such processes, and that some processes have become commercially successful. A large number of methods have been proposed but only the most successful ones will be mentioned here.

73. In some cases, continuous casting is followed by immediate continuous hot rolling to make use of the residual heat in the cast metal. In other cases, the metal is cast in such thin cross-sections that the cast product is suitable for direct cold rolling, thereby by-passing the hot-rolling operation altogether. It should be mentioned, however, that it is not necessarily more economical to produce a thin cross-section suitable for direct cold rolling since this considerably lowers the output of the casting machine; on the other hand, a direct-cast one-inch-thick (25-mm) slab, for example, can be immediately hot rolled (using the remaining heat present in the slab) in a simple and cheap hot-rolling mill, thus taking advantage of the higher output of the casting machine producing such a comparatively thick slab.

74. The most succesful direct casting processes to date are the ones which utilise the following machines

Wheel-and-belt-type casting machines

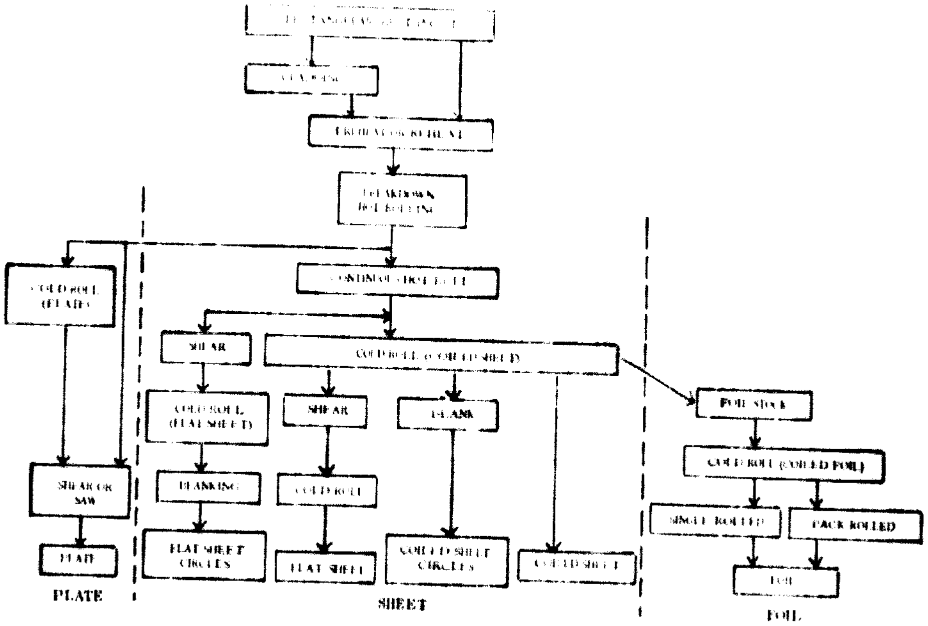
75. In these machines the liquid metal is poured into a groove on the outer edge of a wheel, and the groove is closed by a steel strip. Cooling is applied as the wheel and the strip turn, and the cast shape emerges after the metal has solidified.

76. The Properzi machine, developed in Italy, has found wide use throughout the world for the casting of a triangular-shaped bar which is directly converted into three-eighths-inch-diameter (9.5-mm) rod by continuous rolling on a special tandem mill installed next to the casting machine.

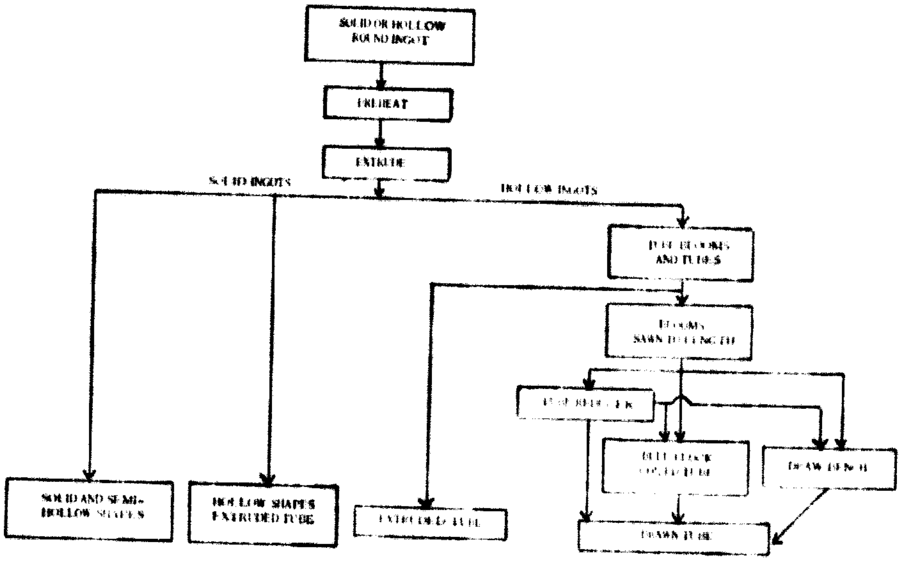
77. The Rigamonti and Coors machines use the same principle for the manufacture of strip for impact extrusion of cans.

Twin-belt-type casting machines

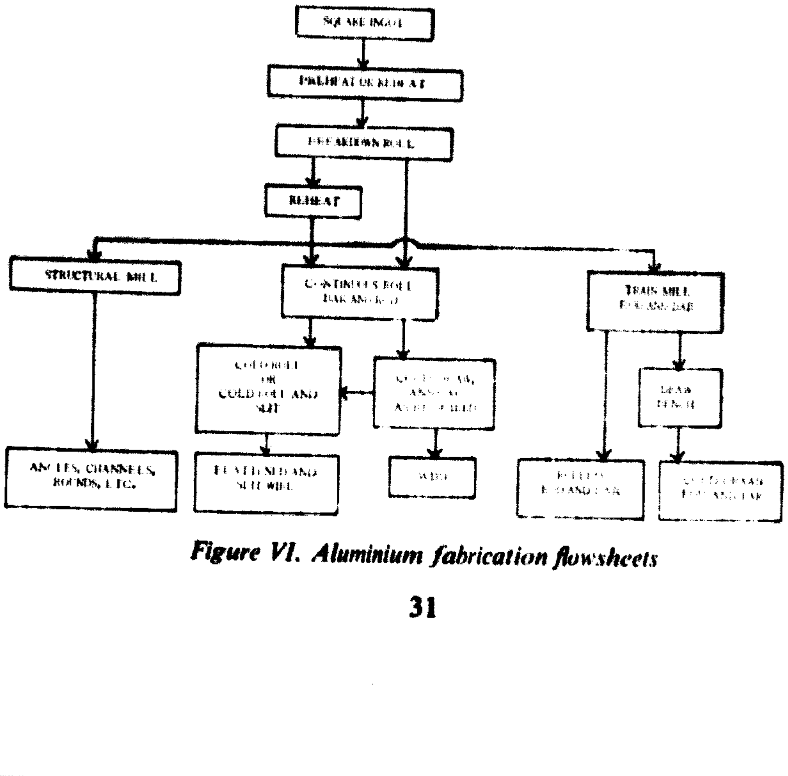
78. In this type of machine the molten metal is fed between two moving steel belts, which are water cooled on their outer surfaces. The solidified aluminium strip or sheet emerges



SHEET, PLATE AND FOIL



EXTRUDED SHAPES AND TUBES AND DRAWN TUBE



ROLLED ROD, BAR, STRUCTURAL SHAPES AND WIRE

Figure VI. Aluminium fabrication flowsheets from the other end of the parallel travel length of the belts.

79. Two machines of this type are in successful commercial operation today: the Hunter-Douglas machine which produces a narrow slab for the continuous production of venetian blinds, and the Hazelett machine which produces an approximately one-inch-thick (25-mm) slab in widths up to forty inches (one metre). The Hazelett slab can be directly hot rolled in a comparatively cheap hot mill. The Hazelett machine has been installed during the past few years in the United States and Canada.

Twin-roll-type casting machines

80. Actually, the idea of casting metal continuously between two chilled rolls is a very old one but it is only in recent years that a practical method based on this principle has been developed, by the Hunter Engineering Company in the United States. In the Hunter machine, the molten metal is fed from below through a distributor between two revolving water-cooled cylinders. The cast strip, approximately one-quarter-inch thick (6 mm), emerges vertically upwards between the cylinders and is coiled as cast, for further reduction by cold rolling. Hunter machines are now installed in several aluminium mills in the United States and Australia. To date, the greatest cast width is approximately sixty inches (1.5 metres).

Oscillating-mould machines

81. It has long been known that shapes can be cast at greater speed when the mould follows the shape for a limited distance and then jumps back to its starting position, and so on. These so-called oscillating-mould processes have been used for a number of years for the casting of large rolling ingots and the like, but it is only quite recently that a horizontal oscillating-mould casting machine was developed by Tessmann for the production of thin bar suitable for direct rolling to rod. Several of these machines are now in operation in the United States.

82. It is reasonable to expect a continued trend towards the use of direct casting processes, particularly by small and medium-sized fabricators where the quantities of metal required do not justify the installation of major fabricating facilities. These processes should therefore be of considerable interest to developing countries wishing to establish an aluminium fabricating industry on a moderate scale.

Annex II

CAPITAL AND OTHER INPUTS

BAUXITE AND ALUMINA

1. Table 19 indicates capital and labour requirements for proposed or already operating bauxite mines and alumina plants in several countries. These data have been collected mainly from current technical literature, and are not strictly comparable.

2. Table 20 presents the trends in input requirements in the Japanese industry during the past decade; the data indicate that the trends in consumption of most inputs are downward. Several observations may be made with respect to these data:

(1) Consumption of bauxite per unit of output has been decreasing over the years mainly owing to the improved quality of the imported ore;

(2) The high recovery ratio of caustic soda has resulted in decreasing consumption per unit of output;

(3) Increased consumption of heavy oil for boiler use reflects the trend towards substitution of this item for coal and electric power;

(4) With respect to labour requirements, the downward trend mainly reflects the shift towards labour-saving techniques in alumina production, and an increased scale of operations.

ALUMINIUM REDUCTION

Capital requirements

3. A detailed breakdown of the investment for the two proposed plants in developing countries mentioned in the text[a] are given in tables 21 and 22. Both estimates are based on the Soderberg anode system. Plant A has an estimated annual capacity of 22,700 tons; plant B a 20,000-ton capacity. The latter will have 160 cells of 60,000 amperes current, arranged in two potlines. Total building area for this plant is 40,000 m²; 22,000 are for pot-rooms, 6,000 for silos and storage, and the remaining 12,000 for other buildings and structures.

4. Table 23 contains data on investment and labour requirements for plants recently built or in the planning stage in various countries. These data have also been obtained mainly from current literature, and are not strictly comparable.

Labour requirements

5. The number of employees in plant A, referred to above, was estimated at 297; table 24 gives the breakdown.

6. Tables 25 and 26 give detailed labour requirements for a plant in a developing country with an actual capacity of 10,000 tons per year and a proposed additional annual capacity of 10,000 tons.

ALUMINIUM FABRICATION

Investment and other data for proposed plant in a developing country[b]

Investment

7. Total investment is estimated at $24.5 million for a rolling and extrusion plant with an annual capacity of 20,000 tons of fabricated product. Table 27 gives a breakdown for this investment.

Labour requirements

8. The total number of employees is estimated at 526, and a breakdown of this figure is given in table 28.

Other inputs

9. Consumption of metal, power and fuel per ton of output is assumed as follows:

Power	1,900 kWh
Fuel	11 million BTU
Metal	1.02 tons

Production costs

10. Average costs for fabrication are estimated in table 29.

Other data

11. Table 30 gives investment estimates for several fabrication plants in various countries, as reported in current literature. These data are not comparable.

12. Table 31 indicates input requirements in the United States as reported in *Census of Manufactures* for the years 1954 and 1958.

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[a] *See* chapter III, "Aluminium reduction".

[b] These data are obtained from a feasibility study.

TABLE 19. INVESTMENT AND LABOUR REQUIREMENTS FOR BAUXITE MINING OPERATIONS AND ALUMINA PLANTS

Item, country and year	*Capacity (thousands of tons)*	*Investment (dollars per ton of capacity)*	*Labour (man-hours per ton of capacity)*
Bauxite mining			
Ghana:			
1955	1,000	10.0	2.0
Jamaica:			
1952–1957	2,000	17.5	...
1953	1,000	12.0	...
Alumina plants			
Caribbean islands:			
1961	150	230	...
Guinea:			
1960	500	310[a,b]	3.4[a]
Jamaica:			
1950–1957	500	120[a]	4.9[a]
1957	245	140[a]	...
United States:			
1956	750	90	1.4
1952	900	90–120[c]	1.8

SOURCE: For Ghana, Governments of the United Kingdom and of the Gold Coast, *The Volta River Project, Volume I, Report of the Preparatory Commission* (London, 1956); for others, United States Department of the Interior, Bureau of Mines, *Minerals Yearbook*, v. I (Washington D.C.), for the years 1950 to 1960, and current technical periodicals (*see* bibliography, annex IV).

[a] Including bauxite facilities.

[b] Including railroad, harbour and township.

[c] Estimated from combined total for alumina and reduction plants.

TABLE 20. JAPAN: INPUT REQUIREMENTS PER TON OF ALUMINA, 1951–1960

Item	*1951*	*1953*	*1955*	*1957*	*1958*	*1959*	*1960*
Production of alumina (tons)	78,431	91,306	138,201	153,566	221,794	298,428	374,543
Consumed materials:							
Bauxite (tons)	2.22	2.09	2.10	2.13	2.11	2.10	2.08
Caustic soda (kilogrammes)	103	85	74	68	66	66	63
Coal (kilogrammes)	595	272	164	127	77	70	93
Heavy oil (litres):							
For boilers	...	104	100	111	100	126	142
For burning	224	199	190	191	184	178	165
Steam (tons)	4.20	3.02	2.32	2.16	1.70	1.74	1.58
Consumed electric power (kWh):							
Motor power	443	342	298	282	249	230	220
Power for boilers	1,153	474	288	104	42	31	2
TOTAL	1,596	816	586	386	291	261	222
Labour (man-hours):							
Direct	21.8	19.8	11.5	9.0	6.4	5.0	4.1
Indirect	27.7	30.4	17.3	14.2	9.7	7.6	6.5
TOTAL	49.5	49.2	28.8	23.2	16.1	12.6	10.6

SOURCE: Japan Development Bank, Research Division, "Units of input consumption by alumina and aluminium, refining capacity and import of bauxite" (Tokyo, 1961).

TABLE 21. ESTIMATED FIXED INVESTMENT FOR ALUMINIUM REDUCTION PLANT A

Item	*Thousands of dollars*
Machinery	11,300
Buildings	7,000
Land	800
Land improvement	2,000
Design, construction and administration	5,400
Crane for unloading, and warehouse	500
Temporary housing	500
Interest on capital, construction period	1,150
Working capital	5,750
TOTAL	34,400

TABLE 22. ESTIMATED FIXED INVESTMENT FOR ALUMINIUM REDUCTION PLANT B

Item	*Thousands of dollars*
Machinery:	
Furnaces	6,842
Electrical and bars	...
Materials handling	200
Transportation costs	115
Erection costs	1,500
Other	1,600
Buildings	6,000
Power plants:	
Rectifier station	1,875
Inter-power substations	154
Fixtures and others	...
Workshops	185
Laboratory	34
Sub-total	18,505
Contingencies and missing items	2,495
TOTAL	21,000

TABLE 23. INVESTMENT AND LABOUR REQUIREMENTS FOR RECENTLY BUILT OR PROPOSED ALUMINIUM REDUCTION PLANTS, SELECTED COUNTRIES

Country or area and year	*Capacity (thousands of tons)*	*Investment (dollars per ton of capacity)*	*Labour (man-hours per ton of capacity)*
Cameroon:			
1957	45	820	...
Canada			
1951	550	1,100	22
France:			
1957	27	630-700	31
1957	60		14
Germany (Federal Republic):			
1960	44	750	...
Ghana:			
1954	210	950[a]	110[a]
India:			
1958	11	910	...
Latin America:			
1961	20	1,250	...
1962	20	1,430	...
1961	25	1,200	28
Middle East:			
1962	20	1,100	84
Norway:			
1960	30	1,330	...
1961	30	950	...
Surinam:			
1957	66	690	...
United States:			
1954	54	1,200[b]	...
1961	56	900	...
1955	60	1,000	15
1952	95	700-1,000[c]	...
1956	112.5	665-710	...
1957	145	700	...
1956	150	540	...
1958	180	610	...

SOURCE: As for table 19.

[a] Including alumina.

[b] Including cost of electricity transmission.

[c] Estimated from combined total for alumina and reduction plants.

TABLE 24. NUMBER OF EMPLOYEES IN ALUMINIUM REDUCTION PLANT A

Category	
Manufacturing, sub-total	266
Unskilled	151
Skilled	58
Supervisory, non-technical	34
Supervisory, technical	23
Administrative and sales, sub-total	31
Clerical	16
Salesmen	2
Managers and other professionals	13
TOTAL	297

TABLE 25. ALUMINIUM REDUCTION: COMPARATIVE LABOUR REQUIREMENTS PER TON OF METAL OUTPUT IN A DEVELOPING COUNTRY

Type of labour and category of workers	*26-KA furnaces as existing without mechanization*		*42-KA furnaces with mechanization*		*52-KA furnaces with mechanization*	
	Number of workers	*Man-hours per ton*	*Number of workers*	*Man-hours per ton*	*Number of workers*	*Man-hours per ton*
Potroom:						
Shift workers	294	69.50	88	14.30	88	11.41
Supervisory staff	16	4.40	16	2.60	16	2.40
Anode work:						
Stub pullers	24	6.65	19	3.09	12	1.54
Frame and flex raisers	20	5.55			4	0.52
Frame and stub straighteners	6	1.65	6	0.98		
General workers	4	1.10	4	0.65		
Supervisory staff	2	0.55	2	0.33	2	0.26
Metal tapping:						
Tappers	28	7.75	15	2.44	15	1.95
Casters	12	3.30		liquid transfer		
General workers	8	2.20				
Supervisory staff	3	0.83	3	0.49	3	0.39
Materials distribution:						
Alumina and flux handlers	13	3.58	9	1.46	9	1.17
Waste handlers and cleaners	5	1.38	5	0.82	5	0.65
Electrical maintenance:						
Inspection staff	14	3.85	4	0.65	4	0.52
Supervisory staff and record-keepers	8	2.20	5	0.82	5	0.65
Services:						
Crane operators	10	2.75	10	1.64	10	1.30
Ventilation and compressed air operators	5	1.38	5	0.82	5	0.65
Furnace reconstruction:						
Furnace repairers	31	8.58	24	3.90	24	3.12
General workers	8	2.20	10	1.64	10	1.30
Miscellaneous workers	12	3.30	10	1.64	10	1.30
TOTAL WORKERS IN ALL CATEGORIES	478	132.70	235	38.27	222	29.13
Man-hours saved per metric ton			*94*		*103*	

TABLE 26. LABOUR IN CASTING SHOP, ACTUAL AND PROPOSED CHANGES WITH MECHANIZATION

Category	*Present requirement*	*Proposed requirement*
Supervisory	3	3
Casting	72	26
Runner cutting	10	Operation omitted
Transport	6	6
Sawing		2
Weighing	3	3
Furnace maintenance	8	2
Inspection and records	3	3
Miscellaneous	10	4
TOTAL	115	49

TABLE 27. CAPITAL REQUIREMENTS FOR A FABRICATION PLANT IN A DEVELOPING COUNTRY

(Thousands of dollars)

Item	
Equipment and machinery	13,586
Principal machinery	10,530
Auxiliary machinery	174
Transport and materials handling equipment	500
Maintenance equipment	772
Administration and engineering fees	1,610
Buildings	3,092
Cost of land	675
Principal buildings	1,505
Secondary buildings	268
Land improvement	644
Other	825
Administration and engineering fees	325
Design and technical assistance	500
Total, above fixed investment	17,503
Working capital	7,000
GRAND TOTAL	24,503

TABLE 28. NUMBER OF EMPLOYEES IN A FABRICATION PLANT IN A DEVELOPING COUNTRY

Category	
Manufacturing	421
Skilled labour	171
Unskilled labour	159
Supervisors, non-technical	32
Supervisors, technical	26
General clerical	33
Administration and sales	105
Clerical	59
Sales	6
Managers and other professionals	40
TOTAL	526

TABLE 29. PRODUCTION COST ESTIMATES FOR A ROLLING AND EXTRUSION PLANT IN A DEVELOPING COUNTRY

(Dollars per ton)

Item	
Production costs:	
Labour	111
Materials:	
Metal	778
Other	61
Power and fuel	27
Other	21
Capital charges:[a]	
Depreciation	64
Insurance, local taxes, interest	82
Sub-total, production costs and capital charges	1,144
Administration and sales costs:	
Wages and salaries	46
Other	23
TOTAL, AVERAGE COSTS	1,213

[a] Depreciation assumed at 5 per cent for buildings, 8 per cent for machinery and equipment, and at 10 per cent for others. Interest rate assumed at 6 per cent.

TABLE 30. INVESTMENT REQUIREMENTS FOR RECENTLY BUILT OR PROPOSED FABRICATION PLANTS IN SEVERAL COUNTRIES

Country or area and type of plant	*Year of proposed investment*	*Capacity (tons per year)*	*Investment (dollars per ton)*
Middle East:			
Extrusion plant	1960	7,000	570
Nigeria:			
Rolling mill	1961	5,000	850
United States:			
Rolling mill	1955-1957	17,000	600
Extrusion plant	1957	9,000	610

TABLE 31. UNITED STATES: INDUSTRIAL AVERAGES OF INPUT REQUIREMENTS FOR ALUMINIUM ROLLING, DRAWING AND EXTRUSION, 1954 AND 1958

(Per ton)

Input	*1954*	*1958*
Production workers (man-hours)	77	60
Aluminium and alloys (tons)	1.15	1.00
Electric power (kWh)	1,770	1,580
Fuel (millions of BTU)	22	20

SOURCE: United States Department of Commerce, Bureau of the Census, *Census of Manufactures* (Washington, D.C.), for the years 1954 and 1958.

Annex III

DATA ON PRODUCTION, CONSUMPTION, TRADE, PRICES AND PLANT CAPACITIES

PRODUCTION, CONSUMPTION AND TRADE

1. This section presents statistical data covering the past decade;[a] in some cases figures for the year 1938 are given for reference purposes. The following is a summary of recent trends as indicated by these data.

2. World production figures for bauxite, alumina and aluminium metal as given in tables 32 to 34 and figures VII and VIII indicate an upward trend. Between 1950 and 1955 production of primary aluminium grew at an average annual rate of 11.4 per cent, and since then at a slower rate—5.2 per cent. The average for the past decade as a whole is recorded at 9.2 per cent. Similarly, bauxite output recorded a growth rate of 11.4 per cent and 6.8 per cent for the 1950-1956 and 1957-1961 periods, respectively, and an average of 10.1 per cent for the decade as a whole.

3. During the decade the rate of growth of primary aluminium by region varied, the highest rates being recorded by Asia, 14.7 per cent, and the centrally planned economies, 13.0 per cent, with lower rates for western Europe, 11.0 per cent, and the United States, 7.0 per cent.

4. Canada and the United States have the highest share in world production of primary aluminium, followed by western Europe and the centrally planned economies, which share between them most of the remaining production. Although western Europe has roughly maintained its share of world production, the share of Canada and the United States has decreased in the past decade, from 67.1 per cent in 1950 to 50 per cent in 1961, while the centrally planned economies have increased their share from 14.7 per cent to 23.7 per cent. Similarly, China (Taiwan), India and Japan increased their share from 2.1 per cent to 4.0 per cent in the same period.

5. With respect to bauxite, the countries of Central and South America had the highest share—46.6 per cent of world production in 1961—followed by the centrally planned economies, which recorded an increase in their share from 18.3 per cent in 1950 to 25.0 per cent in 1961, and by western Europe which maintained its share of about 13 per cent. In the same period, the share of domestic production in the United States decreased from 16.1 per cent to 4.3 per cent.

6. Tables 35 and 36 indicate, respectively, total consumption and *per capita* consumption for selected countries. The *per capita* figures show the correlation between a high level of income and high consumption.

7. As table 37 shows, most bauxite is used in the production of alumina; in 1960 the share was 87-92 per cent in France and the United States. However, bauxite is used in other industries, including the abrasives, chemical, refractory and high-alumina cement industries.

8. With respect to the final uses of aluminium, this varies from one country to another, as indicated in table 38, depending on the degree of industrialization of the country as well as on the industrial practices followed there.

9. About 25 per cent of world aluminium enters the international market. Data on trade in aluminium for the period 1951-1961 are given in table 39 for the major producers and users of aluminium. Austria, Canada, France and Norway are the major net exporting countries. The major net importers are the Federal Republic of Germany, the United Kingdom and the United States. The data show an upward trend in net imports of all net importing countries, with the exception of the United States where a downward trend is recorded.

10. Table 40 gives data for the major exporters of aluminium and principal destinations for the years 1958-1960.

11. With respect to bauxite, about 60 per cent of world production enters the international market. Table 41 summarizes data on exports by major exporting countries and principal destinations.

PRICES OF RAW MATERIALS AND PRODUCTS

Bauxite

12. In the United States there is no open-market price for bauxite since the producers are also the main consumers of the ore. The average value of bauxite as calculated by the United States Bureau of Mines on the basis of producers' reports is given below (in dollars per ton):

	1960	*1961*
Crude (undried)	9.30	9.60
Dried	11.84	12.50
Activated	62.90	67.40

13. The price of French monohydrate bauxite in September 1962 was F fr 17.68 ($3.60) per ton, f.o.b. mine in southern France, basis 54-55 per cent Al_2O_3, 5 per cent SiO_2. Premium for better grades amounted to F fr 0.68 ($0.14) for each percentage point of Al_2O_3 above 55 and F fr 2.04 ($0.41) for each percentage point of SiO_2 below 5. The price for average-grade bauxite delivered by French mines is about F fr 21.00 ($4.25), f.o.b. mine.

Fluorides

14. Natural cryolite occurs in commercial quantities only in Greenland and is refined in Denmark. Natural cryolite is not available in sufficient quantity to meet the growing requirements of the aluminium industry, and a considerable proportion of the cryolite used today is synthetic. Synthetic cryolite is usually made from fluorspar, sulphuric acid and sodium aluminate solution. The present price of cryolite is approximately as follows:

United States (natural)	approximately $320 per ton
France (synthetic)	F fr 1,500 ($300) per ton

15. Aluminium fluoride is always produced synthetically from fluorspar, sulphuric acid and alumina hydrate. The price in the United States is approximately $400 per ton.

Carbon

16. Anode carbon costs depend on many factors, such as types and costs of raw materials used, proportion of carbon recycled as butts in the case of prebaked anodes and so forth. The following figures show the order of magnitude of anode carbon costs:

Prebaked carbon anodes	$55-70 per ton
Soderberg paste	$40-50 per ton

Alumina

17. There are no open-market prices either for alumina in the United States. The average value of calcined alumina as reported by the United States Bureau of Mines in 1961 was

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[a] For projections of future demand for aluminium, *see* United Nations, "Prospective Demand for Non-agricultural Commodities: Problems of Definition and Projection Methodology" (mimeographed document E/3629), and K. A. Bohr, *The Prospects for Aluminium*, Report No. EC-786 published by the International Bank for Reconstruction and Development (Washington, D.C., 1959).

$75.60 per ton. For the same year, lower values were reported for imported calcined alumina at the port of shipment, namely, $63.40 per ton.

18. In France, the average value of calcined alumina was reported in 1960 at F fr 360–370 ($75–76) per ton.

Aluminium ingot

19. The prices of aluminium for several countries are given below. These are for mid-January 1960 and represent the average f.o.b. prices of domestically produced aluminium ingot.

	Dollars per ton
Canada	546
France	462
Germany (Federal Republic)	524
Italy	608
Japan	722
United States	582

Source: United Kingdom, Overseas Geological Surveys, *Bauxite, Alumina and Aluminium* (London, 1962), page 72.

Fabricated products

20. In table 42 the value of various fabricated aluminium products is given for the United States.

Plant capacities

21. Tables 43 and 44 give recently reported capacities for alumina and aluminium plants in the world.

Annex IV

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TABLE 32. WORLD PRODUCTION OF BAUXITE, 1950-1963

(Thousands of tons, except as indicated)

Country	1950	1952	1954	1956	1958	1959	1960	1961	1962	1963
Africa										
Ghana	116.8	75.6	166.1	140.1	210.4	150.2	228.1	199.2	291.4	210.8
Guinea	13.9	109.8	433.5	451.5	330.0	302.0	1,378.0	1,766.7	1,450.0	1,664.0
Mozambique	4.3	2.5	2.4	3.8	4.7	4.3	4.5	4.7	6.2	6.6
Total, Africa	135.0	187.9	602.0	595.4	545.1	456.5	1,610.9	1,970.6	1,747.6	1,891.4
Percentage of total world production	1.6	1.5	3.7	3.2	2.5	2.0	5.9	6.7	5.6	6.1
Latin America										
Brazil	18.6	14.3	27.6	69.8	69.9	97.0	120.8	97.9	190.7	200.0
British Guiana	1,668.4	2,426.3	2,341.4	2,520.8	1,611.3	1,701.3	2,630.0	2,412.0	2,762.2	2,500.0
Dominican Republic	—	—	—	—	—	771.2	688.6	711.8	717.1	773.1
Haiti	—	—	—	—	334.2	302.4	346.5	267.2	458.6	527.7
Jamaica	—	345.9	2,066.4	3,134.1	5,813.8	5,207.9	5,596.0	6,770.0	7,615.4	7,078.2
Surinam	2,045.4	3,223.7	3,425.8	3,482.6	2,988.0	3,430.0	3,455.0	3,453.0	3,297.0	3,508.0
Total, Latin America	3,732.4	6,010.2	7,861.2	9,207.3	10,817.2	11,509.8	12,814.1	13,711.9	15,041.4	14,586.9
Percentage of total world production	44.3	47.1	48.4	48.9	50.6	50.0	46.9	46.6	48.4	47.1
United States	1,355.9	1,693.8	2,026.9	1,771.3	1,331.7	1,727.3	2,004.7	1,247.7	1,391.0	1,571.0
Percentage of total world production	16.1	13.3	12.5	9.4	6.2	7.5	7.3	4.9	4.5	5.1
Asia										
China (Taiwan)	0.1	7.6	—	—	—	—	—	—	—	—
India	65.4	64.5	75.9	92.7	169.5	218.0	383.5	475.9	573.0	565.1
Indonesia	531.1	343.8	173.2	303.3	343.9	387.2	366.8	419.9	461.2	439.1
Malaysia	—	22.1	168.4	268.7	266.6	387.9	459.2	416.5	355.0	451.2
Pakistan	—	—	—	3.0	2.0	2.2	0.6	0.4	—	—
Sarawak	—	—	—	—	138.5	210.2	264.3	257.5	201.9	157.7
Total, Asia	596.6	438.0	417.5	667.7	920.5	1,205.5	1,474.4	1,573.3	1,591.1	1,613.1
Percentage of total world production	7.1	3.4	2.6	3.5	4.3	5.2	5.4	5.4	5.1	5.2
Western Europe										
Austria	0.6	15.2	17.3	22.1	23.6	24.0	26.0	18.0	17.0	17.8
France	807.8	1,119.0	1,287.3	1,461.9	1,817.2	1,745.0	2,038.8	2,224.5	2,194.3	2,002.6
Germany (Federal Republic)	4.2	7.2	4.2	4.9	3.8	4.5	3.8	4.2	4.7	4.3
Greece	77.4	284.9	353.5	698.0	856.2	900.2	905.7	1,708.0	1,321.0	1,300.0
Italy	153.4	265.5	294.1	275.8	299.0	294.2	315.5	321.9	309.3	268.6
Spain	12.2	11.7	5.7	7.0	8.3	8.7	4.4	5.6	6.0	6.0
Total, western Europe	1,055.6	1,703.5	1,962.1	2,469.7	3,008.1	2,976.6	3,294.2	3,581.8	3,852.3	3,599.3
Percentage of total world production	12.5	13.3	12.1	13.1	14.1	12.9	12.1	12.6	12.4	11.6
Centrally planned economies										
China (mainland)	...	...	...	50.0	150.0	300.0	350.0	350.0	400.0	400.0
Hungary	578.0	1,207.0	1,260.0	893.0	1,049.0	937.8	1,190.0	1,366.0	1,473.0	362.0
Romania	5.0	8.0	31.0	52.0	73.0	71.0	88.0	69.0	31.0	70.0
USSR	750.0	900.0	1,400.0	2,225.0	2,750.0	3,000.0	3,500.0	4,000.0	4,200.0	4,230.0
Yugoslavia	206.1	613.4	686.7	881.4	732.6	815.5	1,025.0	1,232.0	1,332.0	1,255.0
Total, centrally planned economies	1,539.1	2,728.4	3,377.7	4,101.4	4,754.6	5,124.3	6,099.0	7,017.0	7,436.0	7,377.0
Percentage of total world production	18.3	21.4	20.8	21.8	22.2	22.3	22.3	24.0	23.9	23.8
Australia	3.5	7.3	5.6	10.5	7.0	15.4	70.5	26.4	30.0	335.0
Percentage of total world production	0.04	0.06	0.03	0.06	0.03	0.07	0.1	0.2	0.1	1.1
WORLD TOTAL	8,418.1	12,769.1	16,253.0	18,823.3	21,384.2	23,015.4	27,330.4	29,226.4	31,089.4	30,973.7

SOURCE: Metallgesellschaft AG, *Metal Statistics* (Frankfurt am Main, 1964).

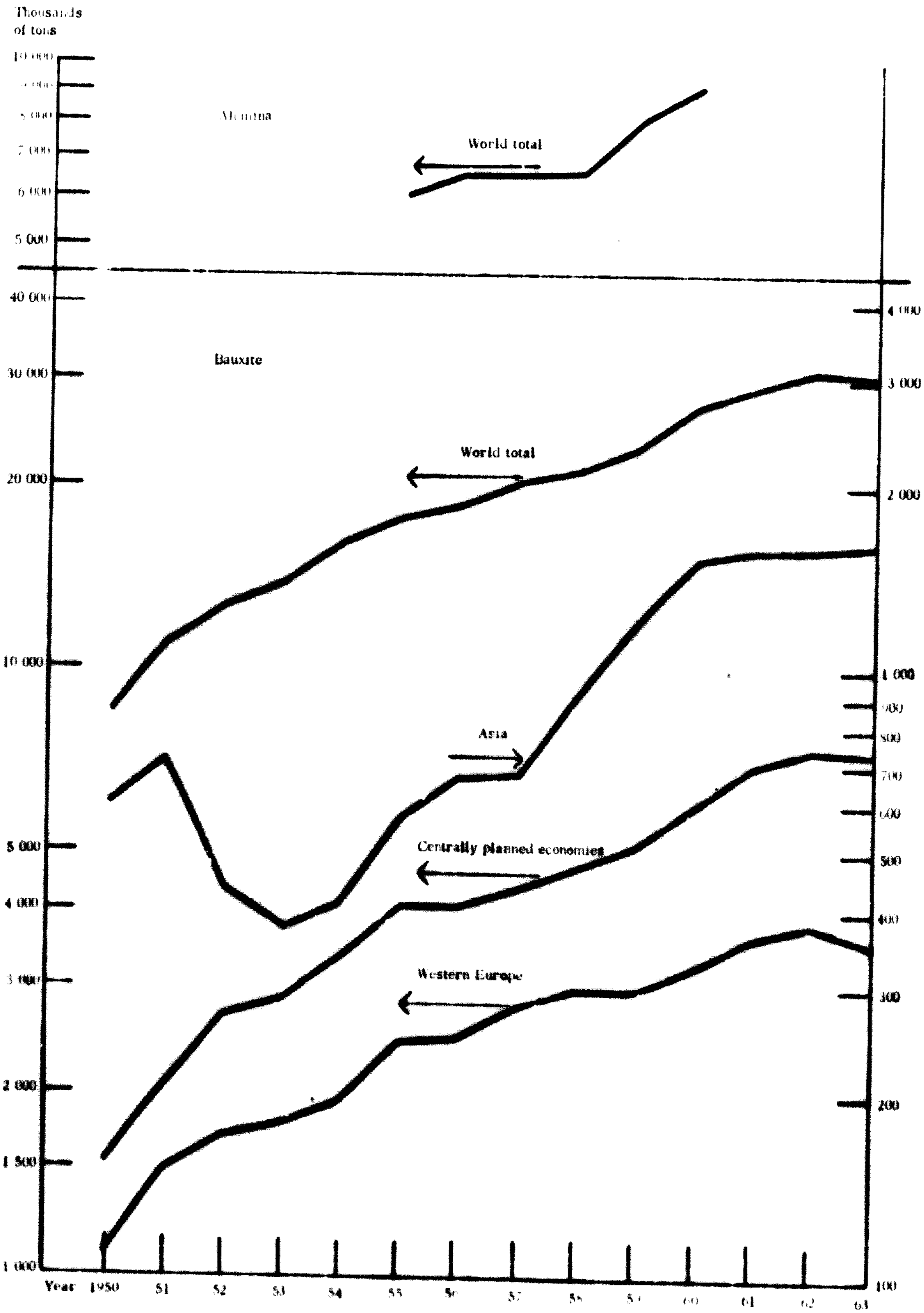

Fig. VII. World production of alumina and bauxite, 1950-1963

Fig. VII (continued)

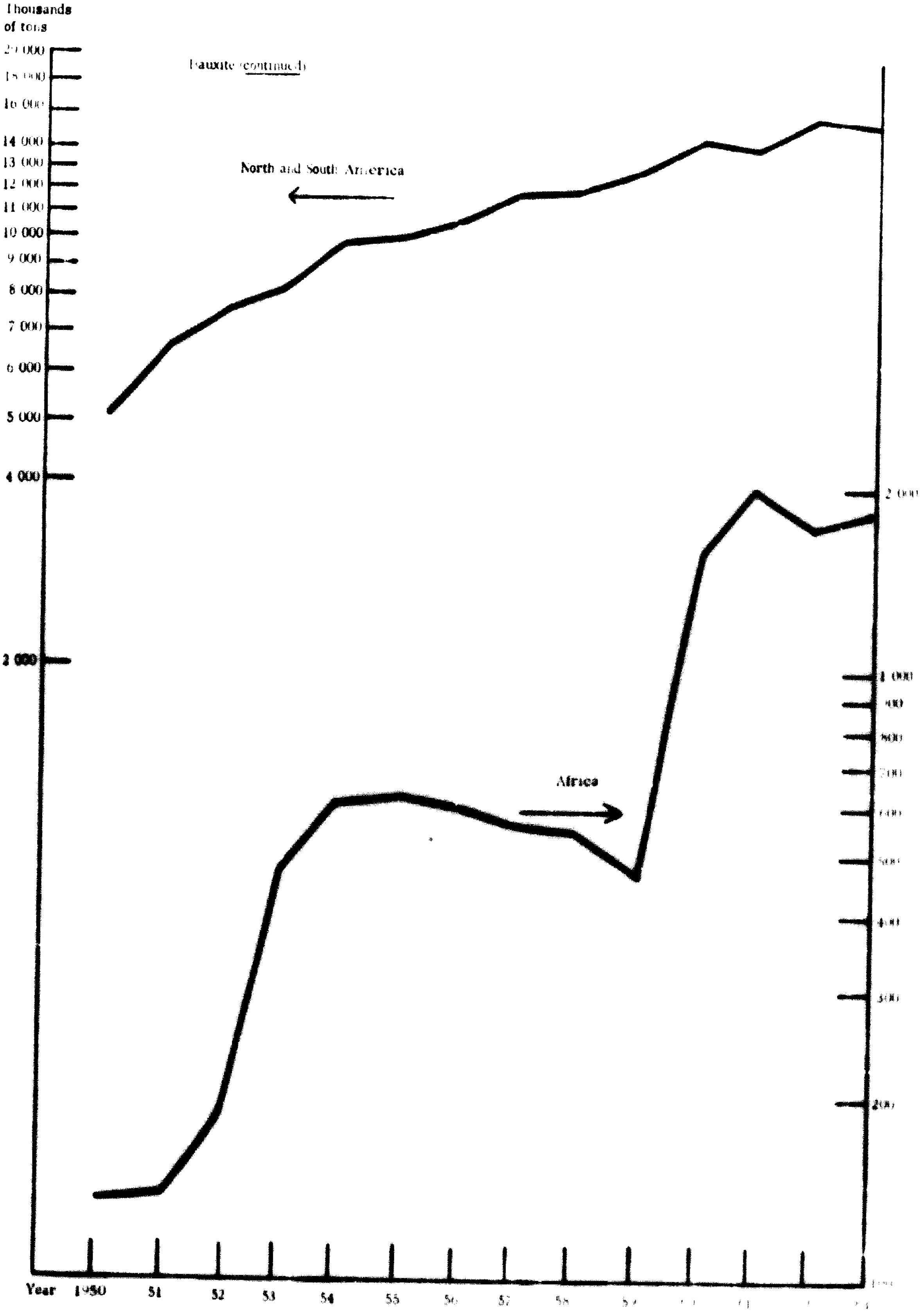

TABLE 33. WORLD PRODUCTION OF ALUMINA, BY COUNTRY, 1955-1960

(Thousands of tons)

Producing country	*1955*	*1956*	*1957*	*1958*	*1959*	*1960*
Africa						
Guinea		—		—	—	182
Total, Africa	—		—	—	—	182
North America						
Canada[a, b]	1,000	1,000	700	900	800	1,000
Jamaica (exports)	184	207	436	373	399	665
United States[c]	2,737	2,971	2,962	2,745	3,429	3,458
Total, North America	3,921	4,178	4,098	4,018	4,628	5,123
Asia						
China (Taiwan)[a]	10	20	20	20	20	20
India	13	17	17	20	24	26
Japan	136	158	151	218	294	349
Total, Asia	159	195	188	258	338	395
Western Europe						
France	342	338	443	515	558	586
Germany (Federal Republic)[d]	300[a]	320[a]	415	370	406	430
Italy	151	159	189	191	202	218
United Kingdom[a]	95	100	120	120	120	120
Total, western Europe	888	967	1,167	1,196	1,286	1,354
Centrally planned economies						
China (mainland)	23	45	49	59	140[a]	160[a]
Eastern Germany	46	54	49	51	54	58
Hungary	152	151	152	167	189	215
USSR[a]	800	900	1,000	1,100	1,300	1,500
Yugoslavia	40[a]	47	50[a]	50[a]	60[a]	66
Total, centrally planned economies	1,061	1,197	1,300	1,427	1,743	1,999
Oceania						
Australia	8[a]	17	20	22	27	30
Total, Oceania	8	17	20	22	27	30
Other countries[a]	20	30	30	40	50	70
WORLD TOTAL	6,057	6,584	6,803	6,961	8,072	9,153

SOURCE: United Kingdom. Overseas Geological Surveys, *Bauxite, Alumina and Aluminium*.

[a] Estimated.

[b] Figures for Canada exclude the production of crude fused alumina by the artificial abrasives industry, which was as follows (tons): 1955 – 158,000; 1956 – 162,000; 1957 – 195,000; 1958 – 98,000; 1959 – 136,000; 1960 – 166,000.

[c] Total United States production of calcined alumina and aluminium oxide products (including hydrate, activated and tabular alumina) was as follows (thousands of tons, calcined equivalent): 1955 – 2,855; 1956 – 3,075; 1957 – 3,073; 1958 – 2,846; 1959 – 3,579; 1960 – 3,595.

[d] Total production of alumina hydrate in the Federal Republic of Germany was as follows (tons, calcined equivalent): 1955 – 347,000; 1956 – 370,000; 1957 – 475,000; 1958 – 423,000; 1959 – 474,000; 1960 – 502,000.

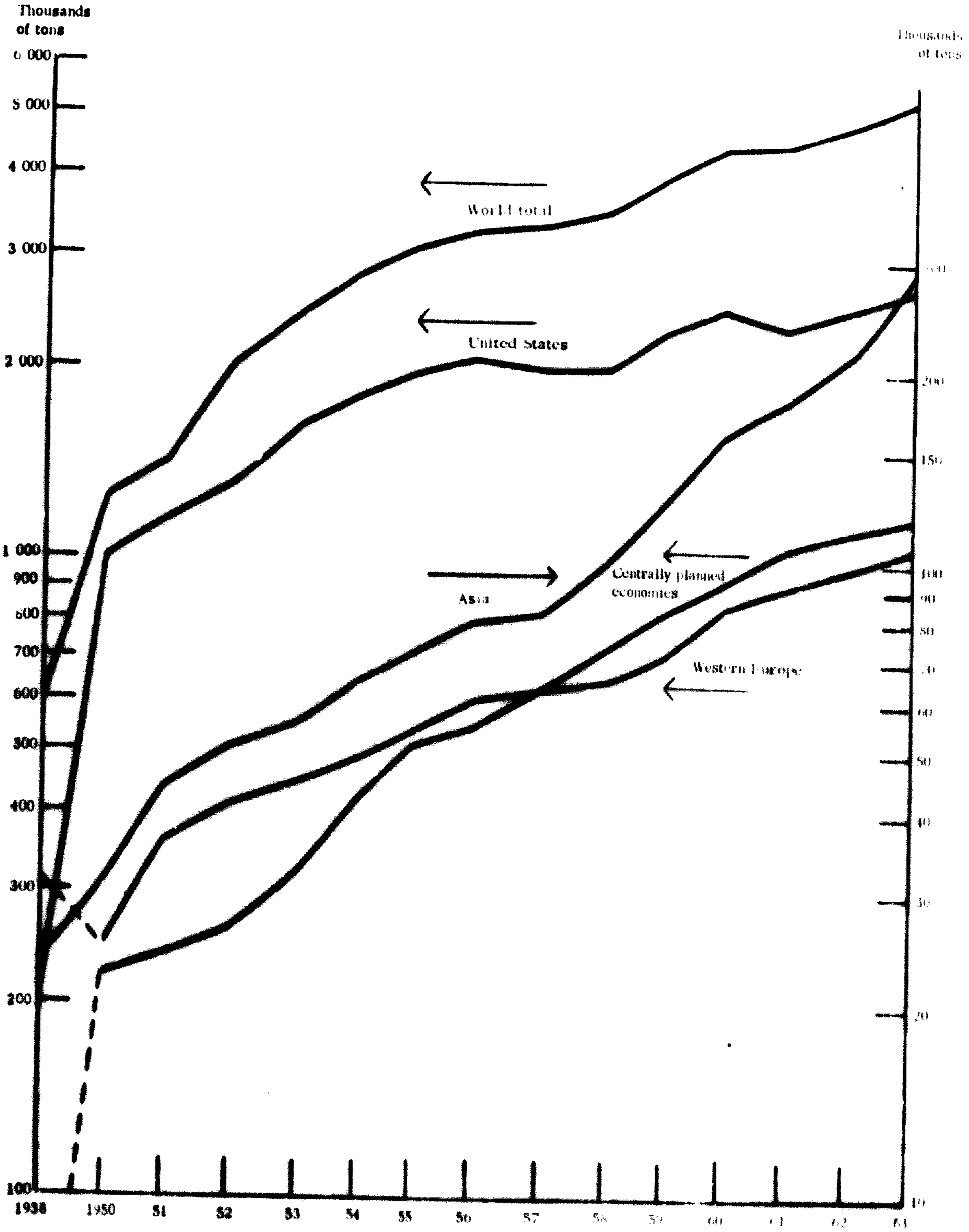

Figure VIII. Production of primary aluminium, 1938-1963

TABLE 34. WORLD PRODUCTION OF PRIMARY ALUMINIUM, 1938 AND 1950-1963

(Thousands of tons)

Country	*1938*	*1950*	*1952*	*1954*	*1956*	*1958*	*1959*	*1960*	*1961*	*1962*	*1963*
Africa											
Cameroon	—	—	—	—	—	32	42	44	46	52	53
Percentage of total world production						0.9	1.0	1.0	1.0	1.0	1.0
North and South America											
Brazil	—	—	1	2	6	12	18	16	19	29	35
Canada	65	360	453	509	653	545	544	691	603	626	654
United States	130	652	850	1,325	1,523	1,425	1,773	1,828	1,727	1,921	2,098
Total, North and South America	195	1,012	1,304	1,836	2,092	2,011	2,335	2,535	2,349	2,576	2,787
Percentage of total world production	33.1	67.1	64.1	65.4	65.5	56.9	57.0	55.8	51.3	51.5	51.2
Asia											
China (Taiwan)	5	2	4	7	9	9	8	8	9	11	12
India	—	4	4	5	7	8	17	18	18	35	54
Japan	18	25	43	53	66	85	100	133	154	172	224
Total, Asia	23	32	51	65	82	102	125	159	181	218	290
Percentage of total world production	3.9	2.1	2.5	2.3	2.5	2.9	3.1	3.5	4.0	4.4	5.3
Western Europe											
Austria	4	18	37	48	59	57	66	168	67	74	77
France	45	61	106	120	150	169	173	235	280	295	298
Germany (Federal Republic)	161[a]	28	101	129	147	137	151	169	173	178	209
Italy	26	37	53	58	64	64	75	84	83	81	91
Norway	29	45	51	61	93	122	145	165	172	206	219
Spain	1	2	4	4	14	16	21	29	36	45	46
Sweden	2	4	8	11	13	14	16	16	16	16	18
Switzerland	27	19	27	26	30	32	34	39	42	50	60
United Kingdom	23	30	29	32	28	27	25	29	33	35	31
Total, western Europe	318	244	416	489	598	637	706	834	902	980	1,049
Percentage of total world production	53.9	16.2	20.5	17.4	17.9	18.3	17.3	18.3	19.7	19.6	19.3
Centrally planned economies											
China (mainland)	1	—	—	—	5	30	70	70	70	80	80
Czechoslovakia	—	—	—	3	21	18	40	40	50	50	50
Eastern Germany	—	2	15	21	30	28	35	40	40	38	40
Hungary	2	7	15	28	30	38	46	50	51	53	56
Poland	—	—	—	3	21	23	23	26	48	48	47
Romania	—	—	—	—	10	10	10	10	10	10	10
USSR[b]	50	209	230	360	430	550	630	700	800	850	900
Yugoslavia	1	2	3	4	15	22	19	25	27	28	36
Total, centrally planned economies[b]	54	220	263	431	562	762	873	961	1,086	1,157	1,219
Percentage of total world production	9.2	14.6	12.9	14.9	16.9	20.6	21.3	21.1	23.7	23.1	22.4
Australia	—	—	—	—	9	11	12	12	13	17	42
Percentage of total world production					0.3	0.3	0.3	0.3	0.3	0.3	0.7
WORLD TOTAL	590	1,508	2,034	2,821	3,343	3,555	4,093	4,545	4,577	5,000	5,440

SOURCE: As for table 32.

[a] Pre-war Germany; from 1950, figures refer to Federal Republic of Germany.

[b] Estimated.

TABLE 35. CONSUMPTION OF ALUMINIUM IN SELECTED COUNTRIES, 1938 AND 1950-1963

(Thousands of tons)

Country	*1938*	*1950*	*1952*	*1954*	*1956*	*1958*	*1959*	*1960*	*1961*	*1962*	*1963*
Africa											
South Africa	—	1	2	4	5	7	7	11	10	14	14
Other	—	1	1	1	2	2	2	2	2	5	5
Total, Africa	—	2	3	5	7	9	9	13	12	19	19
North and South America											
Brazil	—	7	7	17	19	26	27	35	35	49	50
Canada	6	59	82	73	83	92	81	104	115	124	145
Mexico	—	3	2	5	8	12	10	11	11	16	15
Other	1	13	4	16	16	15	14	16	27	27	28
United States	81	823	966	1,260	1,609	1,334	1,845	1,539	1,792	2,086	2,340
Total, North and South America	88	905	1,061	1,370	1,736	1,480	1,976	1,706	1,979	2,302	2,578
Asia											
India	—	6	5	8	10	16	24	25	30	49	62
Japan	50	19	33	46	66	81	113	151	185	184	258
Other	—	3	3	6	8	10	12	14	20	25	25
Total, Asia	50	28	41	61	84	106	148	189	235	258	345
Western Europe											
Austria	—	6	16	26	36	31	34	37	38	38	39
Belgium-Luxembourg	2	5	13	17	32	41	48	64	69	68	68
Denmark	1	3	3	3	3	5	6	6	6	6	5
Finland	—	1	2	1	2	4	6	3	5	6	4
France	31	55	90	99	135	143	168	213	202	235	243
Germany (**Federal Republic**)	173	50	92	133	173	190	228	304	290	302	315
Italy	26	48	52	61	72	63	83	99	105	115	128
Netherlands	—	4	6	8	9	7	12	14	12	14	20
Norway	1	6	12	14	15	18	16	18	18	19	19
Spain	1	4	5	7	16	27	27	20	20	23	35
Sweden	7	14	22	22	27	32	36	38	34	40	51
Switzerland	12	12	28	27	37	32	42	48	48	54	46
United Kingdom	45	184	224	229	281	236	294	360	284	287	319
Other	1	2	2	2	2	5	7	8	11	11	11
Total, western Europe	300	394	568	648	841	835	1,007	1,231	1,141	1,218	1,323
Centrally planned economies											
China (mainland)[a]	2	2	2	3	6	60	80	90	80	85	85
Czechoslovakia[a]	4	14	15	20	34	36	44	46	56	60	60
Eastern Germany[a]	—	2	14	30	43	60	65	75	85	85	85
Hungary[a]	3	6	10	18	24	22	37	40	42	46	50
Poland[a]	—	—	6	18	25	28	33	40	54	55	55
USSR[a]	57	215	225	350	380	465	553	632	715	734	800
Yugoslavia	—	3	3	4	13	16	25	41	36	39	42
Other[a]	1	2	1	5	14	16	16	17	25	25	25
Total, centrally **planned economies**	67	244	276	448	539	704	853	981	1,093	1,129	1,202
WORLD TOTAL	505	1,579	1,957	2,542	3,226	3,160	4,029	4,160	4,495	4,926	5,467

SOURCE: As for table 32.

[a] Estimated.

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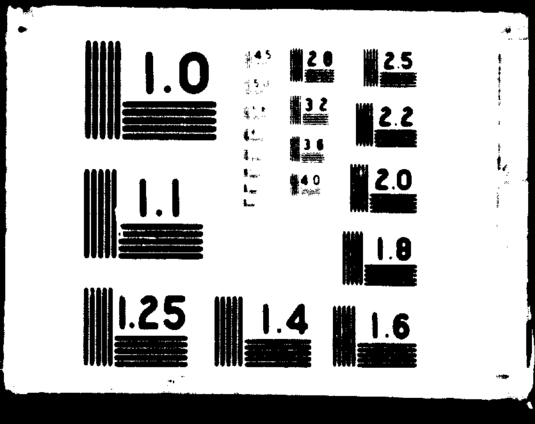


TABLE 36. *Per capita* CONSUMPTION OF ALUMINIUM IN SELECTED COUNTRIES, 1950-1961 (kilogrammes)

Country	*1950*	*1952*	*1954*	*1956*	*1958*	*1959*	*1960*	*1961*
South Africa	0.08	0.2	0.3	0.3	0.5	0.5	0.7	0.6
Brazil	0.1	0.1	0.3	0.3	0.4	0.4	0.5	0.5
Canada	4.3	5.7	4.8	5.2	5.4	4.6	5.8	5.6
Mexico	0.1	0.1	0.2	0.3	0.4	0.3	0.3	0.3
United States	5.4	6.1	7.7	9.5	7.6	10.4	8.5	9.8
India	0.02	0.01	0.02	0.03	0.04	0.06	0.06	0.07
Japan	0.2	0.4	0.5	0.7	0.9	1.2	1.6	2.0
Austria	0.9	2.3	3.7	5.2	4.4	4.8	5.2	5.4
Belgium-Luxembourg	0.6	1.4	1.9	3.5	4.4	5.1	6.8	7.3
Denmark	0.7	0.7	0.7	0.7	1.1	1.3	1.3	1.3
Finland	0.2	0.5	0.2	0.5	0.9	1.4	0.7	1.1
France	1.3	2.1	2.3	3.1	3.2	3.7	4.7	4.4
Germany (Federal Republic)	1.0	1.9	2.7	3.4	3.6	4.3	5.7	5.4
Italy	1.0	1.1	1.3	1.5	1.3	1.7	2.0	2.1
Netherlands	0.4	0.6	0.8	0.8	0.6	1.1	1.2	1.0
Norway	1.8	3.6	4.1	4.3	5.1	4.5	5.0	5.0
Spain	0.1	0.2	0.2	0.5	0.9	0.9	0.7	0.7
Sweden	2.0	3.1	3.1	3.7	4.3	4.8	5.1	4.5
Switzerland	2.6	5.8	5.5	7.3	6.2	8.0	9.0	8.7
United Kingdom	3.7	4.4	4.5	5.5	4.6	5.7	6.9	5.4
Czechoslovakia[a]	1.1	1.2	1.5	2.6	2.7	3.2	3.4	3.6
Eastern Germany	0.1	0.8	1.8	2.6	3.7	4.0	4.6	5.0
Hungary[a]	0.6	1.1	1.9	2.4	2.2	3.7	4.0	4.5
Poland[a]	—	0.2	0.7	0.9	1.0	1.1	1.3	1.5
Yugoslavia	0.2	0.2	0.2	0.7	0.9	1.4	2.2	2.0

SOURCE: As for table 32. [a] Estimated.

TABLE 37. FRANCE AND UNITED STATES: CONSUMPTION OF BAUXITE, BY INDUSTRY, 1960
(Percentage of total)

Industry	*France*	*United States*
Alumina	87.5	91.6
Abrasives	4.8	3.2
Chemical	...[a]	3.4
Refractory	1.8	1.1
Other	5.9	0.7
TOTAL	100.0	100.0

SOURCE: *Annales des mines* (Paris 1961); United States Department of the Interior, Bureau of Mines, *Minerals Yearbook, 1960* (Washington, D.C.).

[a] Figures for the chemical industry not separately reported.

TABLE 38. CONSUMPTION OF ALUMINIUM, BY INDUSTRY, SELECTED COUNTRIES, 1960

Country and industry	*Percentage*
China (Taiwan)	
Electrical	21.4
Household and commercial supplies	14.3
Transportation	5.7
Building and construction	43.0
Canning and packaging	11.4
Other	4.3[a]
TOTAL	100.00
India	
Electrical	35.5
Household and commercial supplies	24.4
Transportation	15.5
Building and construction	6.7
Canning and packaging	6.7
Other	11.1[b]
TOTAL	100.00
Germany (Federal Republic)	
Transportation	26.35
Machinery and equipment	12.70
Electrical engineering	15.84
Building and construction	6.56
Packaging	10.62
Home and office appliances	4.25
Other[c]	23.69
TOTAL	100.00
Italy	
Transportation	41.73
Machinery and equipment	6.95
Electrical engineering	7.69
Building and construction	10.25
Packaging	9.88
Home and office appliances	8.05
Other[c]	15.45
TOTAL	100.00
United States	
Direct military uses	29.8
Building materials	12.8
Consumer durable goods	10.0
Transportation	9.5
Motor vehicles	8.3
Machinery and equipment (excluding electrical)	9.2
Construction	9.2
Electric power construction	6.9
Destructive uses	5.2
Electrical and communications equipment	5.0
Containers and packaging	3.4
Exports, chemicals, photography, etc.	5.9
TOTAL	100.00

(continued in next column)

SOURCE: United Nations, *Bauxite Ore Resources and Aluminium Industry of Asia and the Far East* (Sales No.: 63.II.F.2); United States Department of the Interior, Bureau of Mines, *Minerals Yearbook, 1961*.

[a] Including machinery.

[b] Including food and farming.

[c] Including chemicals, food and agricultural appliances; power; iron, steel and other metal producing industries; metal industries not elsewhere specified, and miscellaneous.

TABLE 39. TRADE IN ALUMINIUM, SELECTED COUNTRIES, 1951-1961

(Tons)

Item and country	*1951*	*1952*	*1953*	*1954*	*1955*	*1956*	*1957*	*1958*	*1959*	*1960*	*1961*
Imports											
Austria[a]	46	82	55	55	59	106	197	262	395	278	141
Belgium-Luxembourg[a]	14,375	12,789	12,743	18,362	27,056	33,075	27,748	42,068	49,389	64,388	69,641
France	1,461	3,780	350	1,590	1,063	7,029	8,827	29,114	33,332	54,142	42,505
Germany (Federal Republic)[b]	9,987	9,690	16,540	20,521	43,794	39,176	40,633	67,694	90,066	181,008	138,716
Italy[a]	3,598	4,020	7,988	4,985	6,278	12,024	17,284	5,685	16,032	34,065	25,706
Japan				1,376	2	2,524	9,138	406	14,823	22,967	32,389
Netherlands[a]	5,874	6,748	6,173	8,205	11,400	10,038	8,445	9,076	14,251	14,681	13,805
Norway	1,694	1,586	2,295	1,078	72	1,112	129	1,582	191[e]	550[e]	2,408[e]
Spain[c]	1,472	878	2,763	2,751	2,334	2,948	5,134	11,097	6,483	1,746	3,939
Sweden	11,688	15,119	14,680	15,408	18,925	19.768	16,021	20,965	21,519	28,114	24,022
Switzerland[d]	5,120	4,948	3,359	8,853	9,839	9,547	10,172	7,034	15,912	16,401	10,502
USSR	...	...	...	...	7,000	9,700	—	—	—	—	—
United Kingdom[a]	180,112	241,145	181,678	193,686	262,628	236,019	194,267	213,761	256,191	316,916	239,711
United States	111,059	116,331	272,997	195,272	161,164	196,316	201,538	231,624	217,703	138,475	180,596
Total imports, above countries	346,486	417,116	521,621	472,142	551,614	579,382	539,533	640,368	736,287	873,731	784,081
Exports											
Austria[a]	7,080	10,761	26,237	21,247	25,375	24,387	22,885	32,203	38,247	21,742	28,305
Belgium-Luxembourg[e]	362	107	529	1,688	921	623	540	1,043	930	942	610
France	8,912	9,102	38.628	16,699	22,309	13,170	13,380	40,294	33,284	57,334	106,456
Canada	321,519	374,295	417,026	425,011	459,838	461,753	434,243	438,104	458,438	500,906	441,829
Germany (Federal Republic)[b]	6,090	7,368	25,362	12,274	617	1,467	7,047	4,319	1,781	2,738	3,827
Italy[a]	7,078	4,493	3,131	11,914	4,868	3,182	1,076	9,205	9,818	1,237	89
Japan[e]	7,642	6,703	9,618	8,427	14,286	2,730	239	4,410	172	6	14
Netherlands[a]	222	326	546	434	3,643	662	665	2,242	1,745	657	2,431
Norway	41,881	35,055	48,578	46,339	61,433	79,515	72,194	109,820	132,107[a]	138,139[a]	146,297[a]
Sweden	277	161	162	2,688	597	717	466	3,091	1,844	78	83
Switzerland[d]	2,243	3,419	8,458	7,782	4,596	2,752	2,974	8,659	11,099	7,459	6,079
USSR	...	...	...	...	41,600	59,939	85,400	114,900	77,400	68,000	...
United Kingdom[a]	2,086	1,785	11,540	4,098	3,697	9,837	7,012	2,229	3,725	3,964	5,528
United States	871	1,276	2,173	3,782	5,425	31,440	26,404	47,819	110,046	258,529	116,432
Total exports, above countries	406,263	454,851	591,988	562,383	649,205	692,174	674,525	818,338	880,645	1,061,731	857,980

SOURCE: As for table 32.

[a] Including aluminium alloys.

[b] Including aluminium alloys and secondary aluminium.

[c] From 1953, including Spanish overseas territories.

[d] Including scrap, excluding aluminium alloys.

[e] From 1952, including aluminium alloy scrap.

TABLE 40. EXPORTS OF ALUMINIUM,[a] BY EXPORTING COUNTRY AND PRINCIPAL DESTINATION, 1958-1960

(Thousands of tons)

Exporting country and destination	*1958*	*1959*	*1960*
AFRICA			
Cameroon			
To: France	18	19	32
Other countries	4	20	9
Total exports, Cameroon	22	39	41
NORTH AMERICA			
Canada			
To: United Kingdom	143	147	160
Hong Kong	2	9	15
Australia	14	15	22
Belgium	9	9	11
France	3	17	8
Germany (Federal Republic)	26	31	69
Italy	3	7	11
Mexico	11	4	8
United States	190	152	90
Brazil	5	4	11
Japan	[b]	9	14
Other countries	27	47	74
Total exports, Canada	433	451	493
United States			
To: United Kingdom	23	49	105
Canada	10	1	1
Germany (Federal Republic)	1	17	68
Other countries	13	41	80
Total exports, United States	47	108	254
ASIA			
China (Taiwan)	2	2	[b]
Japan	4	—	—
EUROPE			
Austria			
To: Germany (Federal Republic)	11	10	10
United States	3	10	2
Other countries	18	18	9
Total exports, Austria	32	38	21
Belgium-Luxembourg	1	1	1
Czechoslovakia[c]	2	1	—
France			
To: Belgium	14	21	32
United States	13	8	12
Other countries	22	22	27
Total exports, France	49	51	71
Germany (Federal Republic)	4	2	3
Hungary	17	8	10
Italy	9	10	1
Netherlands	2	2	1
Norway			
To: United Kingdom	22	36	36
Germany (Federal Republic)	16	21	19
Italy	[b]	2	10
Sweden	14	13	19
United States	20	29	26
Other countries	36	29	26
Total exports, Norway	108	130	136
Poland	1	—	—
Spain	—	—	11

(continued on following page)

TABLE 40 *(continued)*

Exporting country and destination	*1958*	*1959*	*1960*
Sweden	3	2	[b]
Switzerland	10	12	7
USSR			
To: United Kingdom	11	17	7
Czechoslovakia	10	2	4
Eastern Germany	24	28	33
Netherlands	22	6	1
China (mainland)	20	[b]	1
Other countries	26	23	21
Total exports, USSR	113	76	67
Yugoslavia	6	—	—
WORLD TOTAL	867	937	1,121

SOURCE: United Kingdom, Overseas Geological Surveys, *Bauxite, Alumina and Aluminium.*

[a] Including unwrought aluminium alloys.

[b] Quantity less than 500 tons.

[c] Estimates only, based on data available in trade accounts of importing countries.

TABLE 41. EXPORTS OF BAUXITE, BY EXPORTING COUNTRY AND PRINCIPAL DESTINATION, 1958-1960
(Thousands of tons)

Exporting country and destination	*1958*	*1959*	*1960*
AFRICA			
Ghana			
To: United Kingdom	196	148	176
Germany (Federal Republic)	11	—	17
Netherlands	—	—	17
Japan	—	—	14
Total exports, Ghana	207	148	224
Guinea			
To: Canada	188	237	593
Germany (Federal Republic)	60	39	84
Other countries	12		17
Total exports, Guinea	260	276	694
Mozambique	3	6	4
NORTH AMERICA			
United States			
To: Canada	10	13	25
Other countries	2	4	4
Total exports, United States	12	17	29
LATIN AMERICA			
Brazil	3	3	2
British Guiana			
To: United Kingdom	22	28	43
Canada	989	1,019	1,401
France	22	19	22
Germany (Federal Republic)	10	22	34
Italy	5	15	18
United States	281	373	535
Argentina	4	4	5
Japan	9	11	8
Other countries	22	23	29
Total exports, British Guiana	1,364	1,514	2,095
Dominican Republic[a]			
To United States (total)	—	420	631
Jamaica[a]			
To United States (total)	4,799	4,197	4,148

(continued on following page)

TABLE 41 *(continued)*

Exporting country and destination	*1958*	*1959*	*1960*
Haiti			
To United States (total)	317	307	341
Surinam			
To: Canada	177	156	296
United States	2,629	3,109	3,142
Other countries	14	73	139
Total exports, Surinam	2,820	3,338	3,577
ASIA			
India			
To: Japan	1	10	59
Other countries	20	13	28
Total exports, India	21	23	87
Indonesia			
To: Australia	80	32	—
Germany (Federal Republic)	69	—	—
Argentina	14	—	—
Japan	223	211	342
Total exports, Indonesia	386	243	342
Malaysia			
To: Australia	—	19	76
China (Taiwan)	15	—	15
Japan	232	345	354
Other countries	—	—	3
Total exports, Malaysia	247	364	448
Sarawak			
To: China (Taiwan)	36	28	22
Japan	57	175	238
Total exports, Sarawak	93	203	260
EUROPE			
Austria			
To Germany (Federal Republic) (total)	9	6	6
France			
To: United Kingdom	115	120	130
Belgium	—	17	3
Germany (Federal Republic)	173	123	164
Other countries	16	11	15
Total exports, France	304	271	312
Greece			
To: United Kingdom	37	50	52
France	10	15	24
Germany (Federal Republic)	280	266	303
Norway	34	35	30
Spain	16	14	12
USSR	441	444	426
Other countries	5	17	44
Total exports, Greece	823	841	891
Hungary			
To: Czechoslovakia	312	237	258
Eastern Germany	198	197	197
Poland	18	23	34
Other countries	2	2	2
Total exports, Hungary	530	459	491
Yugoslavia			
To: Eastern Germany	—	23	28
Germany (Federal Republic)	398	384	517
Italy	178	173	220
Other countries	7	12	25
Total exports, Yugoslavia	583	592	790
WORLD TOTAL	12,817	13,309	15,490

SOURCE: As for table 40.

[a] Dry equivalent tons.

TABLE 42. VALUE OF FABRICATED ALUMINIUM PRODUCTS, UNITED STATES, DECEMBER 1962

Product	*Cents per pound*	*Dollars per ton*
Sheet		
Pure aluminium and common alloys, 0.025-inch (0.64-mm) thickness:		
Coiled	37.0–42.3	815– 933
Cut to length	43.9–46.4	967–1,022
Building sheet, 0.050-inch (1.27-mm) thickness:		
Coiled	35.5	782
Cut to length	39.5	870
Circles		
From coiled stock, 0.025-inch (0.64-mm) thickness, 12-inch (30-cm) diameter and over	47.0	1,036
Foil		
0.0035-inch (0.09-mm)	56.1	1,236
0.00035-inch (0.009-mm)	75.6	1,666
Plate		
Strong alloy, 0.25–0.75-inch (6.4–19-mm) thickness, cut to length	59.5	1,289
Extrusions		
Factor 18-20, weight per foot, 0.5–1.5 lbs (3.6–11.0 kg/m):		
Solid profile	40.5–61.2	893–1,348
Hollow profile	50.5–88.5	1,113–1,950
Electrical conductors		
ACSR (aluminium cable with steel core)	33.5	782
All-aluminium cable	40.3	888
Conductor alloy cable	41.4	978
Wire and rod		
Coiled 3/8-inch (9.5-mm) redraw rod:		
Pure aluminium	28.0	617
Conductor alloy	31.2	688
Screw machine stock rod	59.2–66.2	1,305–1,460

TABLE 43. WORLD PRODUCERS OF ALUMINA, END-1961

Country, company and plant locations	*Capacity*
AFRICA	
Guinea	
FRIA, Compagnie internationale pour la production d'alumine, Fria	480,800
NORTH AMERICA	
Canada	
Aluminium Company of Canada, Ltd., Arvida	1,134,000
Jamaica	
Alumina Jamaica, Ltd.:	
Kirkwine	489,900
Ewarton	244,900
Total, Jamaica	734,800
United States	
Aluminum Company of America:	
Mobile, Alabama	894,000
Bauxite, Arkansas	381,000
Point Comfort, Texas	340,200
Reynolds Metals Company:	
Hurricane Creek, Arkansas	794,700
La Quinta, Texas	662,200
Kaiser Aluminum and Chemical Corporation:	
Baton Rouge, Louisiana	771,100
Gramercy, Louisiana	390,100
Ormet Corporation, Burnside, Louisiana	313,000
Total, United States	4,546,300
Total, North America	6,415,100
LATIN AMERICA	
Brazil	
Aluminio Minas Gerais, Ouro Preto	15,000
Companhia Brasileira do Aluminio, Sorocoba	30,000
Total, Brazil	45,000
British Guiana	
Demerara Bauxite Co., Mackenzie	222,300
Total, Latin America	267,300
ASIA	
China (Taiwan)	
Taiwan Aluminium Corporation, Takao	29,000
India	
Indian Aluminium Co., Ltd., Muri	18,000
Aluminium Corporation of India, Ltd., Jaykaynagar	5,000
Total, India	23,000
Japan	
Showa Denko Company, Yokohama	104,000
Nippon Light Metals Company, Shimizu	185,200
Sumitomo Chemical Company, Kikumoto	120,200
Total, Japan	409,400
Total, Asia	461,400
WESTERN EUROPE	
France	
Péchiney, Compagnie de produits chimiques et électrometallurgiques:	
Gardanne	321,100
Salindres	100,400

(continued on following page)

TABLE 43 (continued)

Country, company and plant locations	Capacity
Société d'électro-chimie, d'électro-métallurgie et des aciéries électriques d'Ugine, La Barasse	99,800
Société française pour l'industrie de l'aluminium, St. Louis-les-Aygalades	59,900
Total, France	581,200
Germany (Federal Republic)	
Aluminium GmbH, Martinswerke	139,700
Vereinigte Aluminium-Werke AG:	
Lippewerk	129,700
Innwerk	109,800
Gebrüder Guilini, GmbH, Ludwigshafen	119,700
Total, Germany (Federal Republic)	498,900
Italy	
Montecatini, Società Generale per l'Industria Mineraria e Chimica, Porto Marghera	86,200
Società Alluminio Veneto per Azioni (Sava), Porto Marghera	99,800
Total, Italy	186,000
Norway	
Norsk Aluminium Company, Høyanger	17,000
Sweden	
A.B. Svenska Aluminium-Kompaniet, Kubikenborg[a]	8,000
United Kingdom	
British Aluminium Company, Ltd.:	
Burntisland	61,000
Newport	45,700
Total, United Kingdom	106,700
Total, western Europe	1,397,800
CENTRALLY PLANNED ECONOMIES	
China (mainland)	
Fushun	22,000
Nanting	39,900
Total, China (mainland)	61,900
Eastern Germany	
Vereinigte Aluminium-Werke AG, Lauta	90,700
Hungary	
Bonataler Alaunnerde, Almásfüzitö	115,000
Ungarriodre Bauxit Gruben AG, Ajka	60,000
Bauxite Industrie AG, Magyaóvár	35,000
Total, Hungary	210,000
USSR	
Soviet Aluminium Trust:	
Boksitogorsk	150,000
Kamensk-Uralskiy	350,000
Krasnoturinsk	350,000
Pikalevo	800,000
Volkhov	80,000
Zaporozhye	200,000
Total, USSR	1,930,000
Yugoslavia	
Lopare	8,000
Mostar	8,000
Strnisce (Kidrecevo)	50,000
Total, Yugoslavia	66,000
Total, centrally planned economies	2,358,600
OCEANIA	
Australia	
Comalco Industries Proprietary, Ltd., Bell Bay	35,000
WORLD TOTAL	11,416,000

SOURCE: United States Department of the Interior, Bureau of Mines, *Minerals Yearbook, v. I, 1961.*

[a] The plant is in standby condition. Some electrical parts have been removed.

TABLE 44. WORLD PRODUCERS OF ALUMINIUM METAL, 1961[a]

(Tons)

Country, company and plant locations	Annual capacity of plant
AFRICA	
Cameroon	
Cie. camerounaise de l'aluminium, Péchiney-Ugine, Edea	44,900
NORTH AMERICA	
Canada	
Aluminium Company of Canada, Ltd.:	
Arvida	338,400
Shawinigan Falls	63,500
Isle Maligne	104,300
Kitimat	174,200
Chryslum, Ltd., Beauharnois	34,500
Canadian British Aluminium Company, Ltd., Baie Comeau	81,600
Total, Canada	796,500
United States	
Aluminum Company of America:	
Alcoa, Tennessee	142,500
Badin, North Carolina	42,800
Massena, New York	136,000
Point Comfort, Texas	127,000
Rockdale, Texas	136,000
Vancouver, Washington	88,450
Wenatchee, Washington	98,400
Evansville, Indiana	158,800
Reynolds Metals Company:	
Arkadelphia, Arkansas	50,000
Jones Mills, Arkansas	99,900
Listerhill, Alabama	172,400
Longview, Washington	55,000
San Patricio, Texas	86,200
Troutdale, Oregon	83,000
Massena, New York	90,700
Kaiser Aluminum and Chemical Corporation:	
Chalmette, Louisiana	224,500
Mead, Washington	159,700
Tacoma, Washington	37,200
Ravenswood, West Virginia	131,500
Anaconda Aluminum Company, Columbia Falls, Montana	59,000
Harvey Aluminum, Inc. The Dalles, Oregon	68,000
Ormet Corporation, Clarington, Ohio	163,300
Total, United States	2,409,350
Total, North America	3,205,850

(continued on following page)

TABLE 44 *(continued)*

Country, company and plant locations	*Annual capacity of plant*
LATIN AMERICA	
Brazil	
Electro-chemica Brasileira, S.A., Oura Preto (Minas Gerais)	13,000
Companhia Brasileira do Aluminio, São Paulo	10,000
Total, Latin America	23,000
ASIA	
China (Taiwan)	
Taiwan Aluminium Corporation, Takao	14,000
India	
Aluminium Corporation of India, Ltd., Asansol	2,500
Indian Aluminium Company, Ltd.:	
Alwaye	10,000
Hirakud	20,300
Hindustan Aluminium Corporation, Ltd., Rihand	20,300
Total, India	53,100
Japan	
Showa Electric Industry Company:	
Kitakata	34,000
Omachi	12,100
Nippon Light Metals Company:	
Kambara	56,700
Niigata	31,000
Sumitomo Chemical Company:	
Kikumoto	31,000
Nagoya	14,300
Total, Japan	179,100
Total, Asia	246,200
WESTERN EUROPE	
Austria	
Salzburger Aluminium GmbH, Lend	10,000
Vereinigte Aluminium-Werke AG, Ranshofen	67,100
Total Austria	77,100
France	
Péchiney, Compagnie de produits chimiques et électrométallurgiques:	
Chedde, Haute-Savoie	5,100
La Praz, Savoie	2,700
La Saussaz, Savoie	8,600
St-Jean-de-Maurienne, Savoie	66,500
L'Argentière, Hautes-Alpes	15,900
Rioupéroux, Isère	10,600
Auzat, Ariège	16,300
Sabart, Ariège	16,000
Noguères, Hautes-Pyrénées	90,000
Société d'électrochimie, d'électrométallurgie et des aciéries électriques d'Ugine:	
Venthon, Savoie	16,000
Lannemezan, Hautes-Pyrénées	38,000
Total, France	285,700
Germany (Federal Republic)	
Aluminium GmbH, Rheinfelden, Baden	45,000
Vereinigte Aluminium-Werke AG:	
Erftwerk, Grevenbroich	28,100
Innwerk, Toeging	52,900
Lippewerk, Lünen	38,100
Total, Germany (Federal Republic)	164,100
Italy	
Montecatini, Società Generale per l'Industria Mineraria e Chimica:	
Mori	12,000
Bolzano	41,500
Società Alluminio Veneto per Azioni (Sava), Porto Marghera	27,200
Società dell'Alluminio Italiano (Sai), Borgofranco Ivrea	5,500
Total, Italy	86,200
Norway	
Aardal og Sunndal Verk A/S:	
Aardal	98,000
Sunndalsora	49,900
Det Norske Nitridaktieselskap:	
Eydehavn	9,300
Tyssedal	17,500
Norsk Aluminium Company, Høyanger	14,000
Mosjøen Aluminium Company, Mosjøen	32,200
Total, Norway	220,900
Spain	
Empresa Nacional del Aluminio, S.A.:	
Valladolid	11,000
Aviles	7,400
Aluminio Español, S.A., Sabinanigo, Huesca	6,000
Aluminio de Galicia, S.A., La Coruna	8,000
Total, Spain	32,400
Sweden	
A.B. Svenska Aluminium-Kompaniet:	
Mansbo	2,200
Kubikenborg	13,000
Total, Sweden	15,200
Switzerland	
Aluminium Industrie AG (AIAG), Chippis	27,900
Usine d'aluminium de Martigny, S.A., Martigny	5,000
Total, Switzerland	32,900
United Kingdom	
British Aluminium Company, Ltd.:	
Kinlochleven	10,200
Lochaber	25,400
Total, United Kingdom	35,600
Total, western Europe	950,100
CENTRALLY PLANNED ECONOMIES	
China (mainland)	70,400
Czechoslovakia	
Svaty Kriz	49,900
Eastern Germany	
Elektrochemisches Kombinat, Bitterfeld	34,900
Hungary	
Magyarsoviet Bauxit Ipar:	
Felsögalla-Totis	15,000
Ajka	15,000
Inota	29,900
Total, Hungary	59,900
Poland	
Skawina Aluminium Works	45,400
Romania	10,000
USSR	
Soviet Aluminium Trust:	
Kamensk-Uralskiy	119,700
Kandalakcha	24,900
Krasnoturinsk-Bogoslovsk	124,700
Stalinsk	119,700

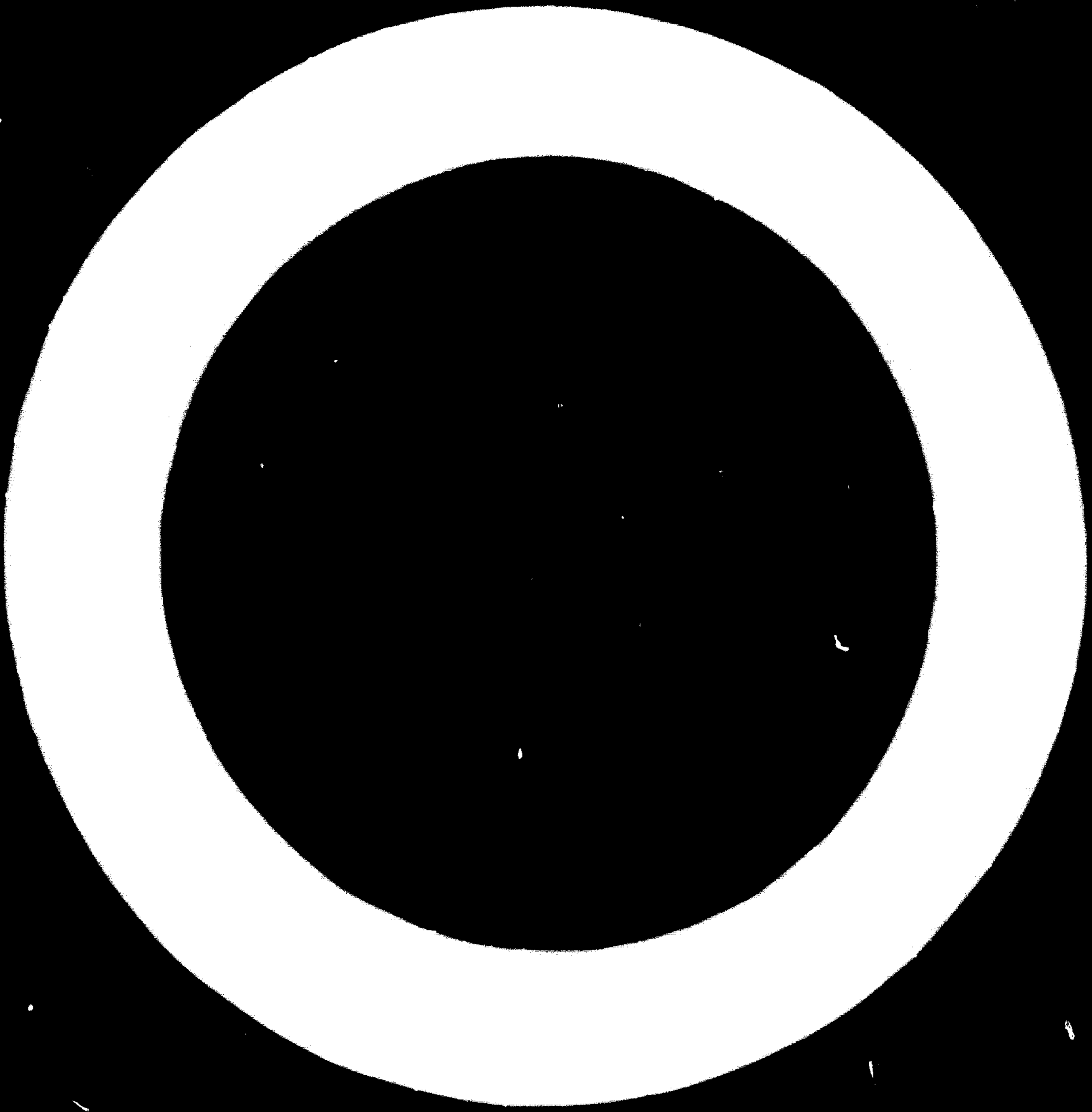
(continued on following page)

TABLE 44 (*continued*)

Country, company and plant locations	*Annual capacity of plant*
Volkhov	44,900
Erivan	24,900
Zaporozhe (Dneprovoskiy)	99,800
Sumgait	69,900
Nadvoitsy	20,000
Stalingrad	200,000
Total, USSR	848,500
Yugoslavia	
Razina	4,100
Lozovac	3,600
Strnisce (Kidrecevo)	29,900
Total, Yugoslavia	37,600
Total, centrally planned economies	1,156,600
OCEANIA	
Australia	
Australian Aluminium Production Commission, Tasmania	13,200[a]
WORLD TOTAL	5,639,850

SOURCE: As for table 43.

[a] Including capacities being built in 1961.



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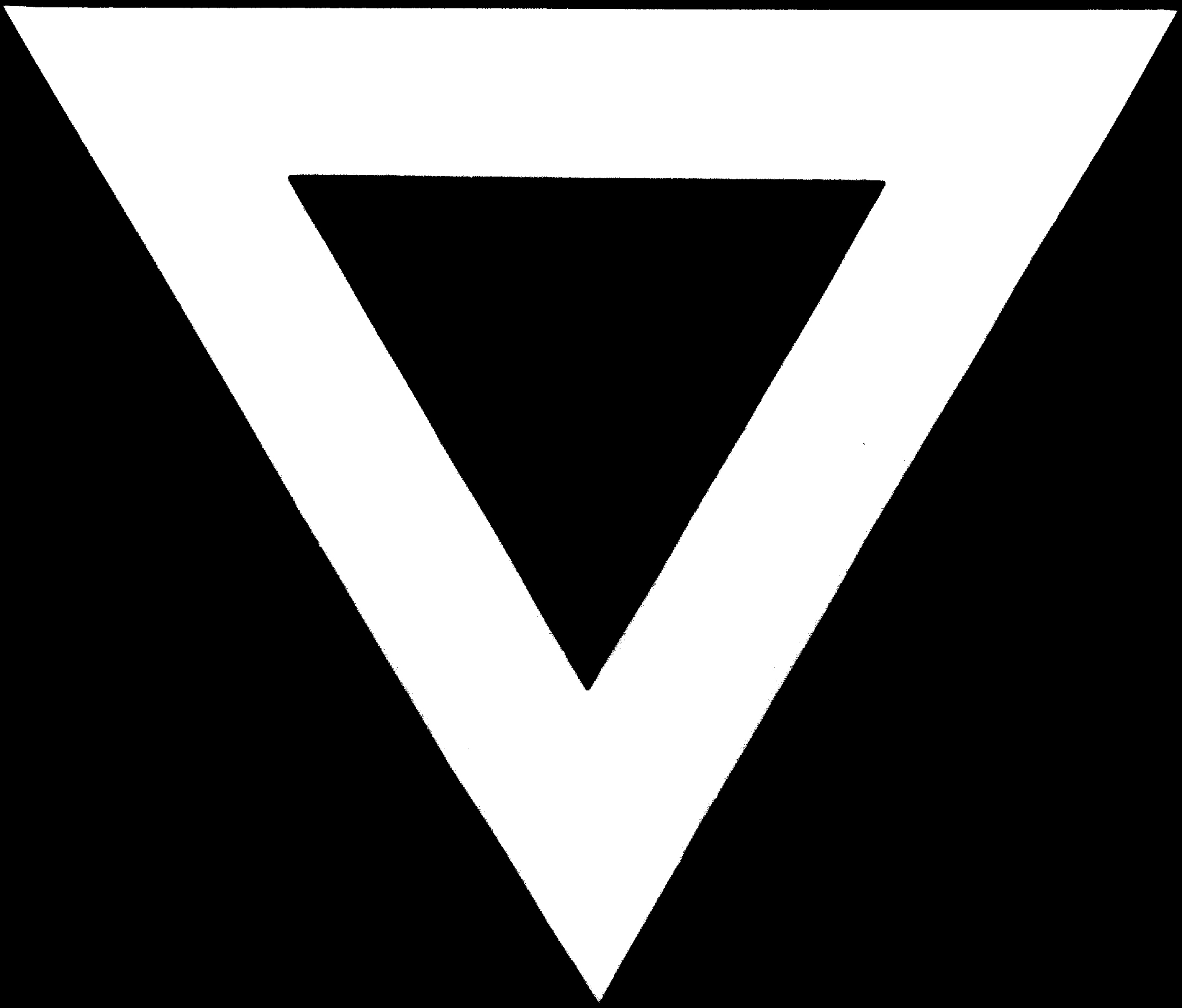

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