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THE PRESENT STATUS OF ALUMINA AND ALUMINIUM PRODUCTION IN THE WORLD AND IN DEVELOPING COUNTRIES. PROSPECTS OF DEVELOPING AN ALUMINIUM INDUSTRY [1]

by

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[1] The views and opinions expressed in this paper are those of the author and do not necessarily reflect the views of the Secretariat of UNIDO.

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SUMMARY

Most of the world's bauxite reserves and a large proportion of the world's undeveloped water power are located in tropical and sub-tropical belts, mostly in developing countries. Natural conditions exist therefore for establishing alumina and aluminium reduction plants in many of these countries.

Aluminium is now a basic industry and competitive production units require large investments. Plants of economic size therefore produce much more than can be absorbed by the limited market of a country in early stage of development. For these reasons outlets to world markets are necessary and establishment of an aluminium industry is more easily achieved with participation of one of the major aluminium companies.

The aluminium industry is vertically integrated and highly international in character. At the same time aluminium consumption shows one of the fastest growth rates for a major commodity. The major aluminium companies are eager to develop new sources of alumina and primary metal, provided the projects are economically sound and provided the countries involved offer a secure economic and political climate for long-term investment.

Support of foreign governments and particularly of international agencies may be more acceptable to emerging countries, but governments usually attach political conditions and agencies have limited financing possibilities.

Developing countries can, within reason, apply pressure to have foreign companies interested in their bauxite process it locally, such as Australia has successfully done. However, terms must be reasonable so that projects are not killed in their infancy; the Australian Government's handling of their bauxite concessions should be carefully studied in this connexion.

Various aluminium producers have developed designs and practices that differ considerably, due to different conditions and also to some extent due to local traditions in the industry. It is therefore desirable to engage the services of independent advisers to evaluate and compare available technologies, and recommend the selection most suitable for a particular project before making a final choice. Each of the major aluminium companies usually thinks, at least officially, that it has the best technology. Unbiased evaluation and advice should be sought therefore.

New direct reduction processes do not present a threat to conventional alumina and aluminium reduction plants within the foreseeable future. On the other hand, the advent of cheap nuclear power could within a few years provide new possibilities for economic aluminium reduction plants in industrially developed countries where the main aluminium markets are and will be for many years to come.

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I. DEVELOPMENT OF THE ALUMINIUM INDUSTRY

Early developments

1. Aluminium was produced from 1855 to 1889 by reduction of cryolite or sodium aluminium chloride with sodium metal in small quantities and was very expensive. The aluminium industry started in the United States in 1888 and in 1889 in France following the invention of the electrolytic process simultaneously by Héroult in Europe and by Hall in the United States. Initially the aluminium industry was limited to a few of the most advanced industrial nations at that time such as Switzerland, France, Great Britain and the United States. At about the same time the Bayer process developed in Germany provided a cheap source for the pure alumina required as intermediary for the electrolytic process.

2. Electrolytic aluminium production required a large amount of power and industrially developed countries soon searched for cheap water power outside their borders for expansion. Thus Alcoa, the only United States producer at that time, developed water power resources in Canada, while British, French and later United States capital developed water power resources in Norway for subsidiary aluminium reduction plants. It is interesting to note that Canada and Norway were underdeveloped countries at that time and that foreign capital created vast aluminium enterprises which have contributed greatly to the economic development of these countries and to the high standard of living they now enjoy. It may be relevant to point out also that the stable economic and political climate of Canada and Norway made these countries safe for foreign investment and that this circumstance contributed greatly to the attraction of cheap power.

3 In its early days the Europeen aluminium industry was based almost entirely on European bauxite, mainly from southern France, Hungary, Yugoslavia, and Greece, while the North American aluminium industry mostly relied on United States bauxites. from the Carolinas and Arkansas. However, the leading aluminium producers in Europe and the United States soon found out that better bauxite qualities could be obtained in overseas countries, at that time colonies such as the Gold Coast, Sierra Leone, British Guyana and Surinam, to mention those where large-scale bauxite mining operations were first established.

4. At that time the tendency of the main producers - Alcoa in the United States, Alais, Froges et Camargue (now Pechiney) in France, A.I.A.G. (now Swiss Aluminium Co.) and The British Aluminium Company - was to concentrate the alumina production and fabricating facilities in their own countries where the main aluminium markets were. These markets were initially almost entirely civilian, the first uses of

aluminium being for such items as cooking utensils and electric cables. However, this changed with the advent of the First World War and many military uses were found for aluminium; this resulted in great expansion particularly in the United States. Germany was blockaded and suffered from a deficiency of copper and other base metals which prompted her to create a domestic aluminium industry. There already existed a Swiss-owned plant in Germany based on hydroelectric power from the Rhine, but now the Vereinigte Aluminium-Werke was formed to produce aluminium with thermal power and this laid the foundation for a large German aluminium industry. The German aluminium industry was therefore a war development one rather than being based on low cost hydroelectric power such as the other early aluminium producers.

Between the World Wars

5. The years between the World Wars saw the growth of the aluminium industry and the pioneer work in fundamental metallurgy such as alloys, heat treatment, fabricating methods and surface treatments which laid the basis for the wide use which aluminium has since found. It was also a difficult period for the aluminium industry with the depression in the 1930's creating over-production of the metal. To meet this problem the major aluminium companies founded the Aluminium Alliance Co. with headquarters in Basle, Switzerland, which purchased, stockpiled and redistributed surplus aluminium from member companies. Chaotic price cutting conditions, which disorganised so many other industries during the depression years, were averted by this arrangement.

6. It was at this time (1932) that the first aluminium reduction plant was built in the Soviet Union. It was built at Volkovsk near Leningrad with technical assistance from the French company Alais, Froge et Camarque (now Pechiney). At the same time a process was developed for producing alumina, as well as potash and cement, from the vast nepheline-syenite deposits of the Kola peninsula. The Soviet Union is deficient in good grade bauxite so other raw materials had to be used as the Soviet Union followed a policy of self-sufficiency.

The Second World War

7. From the advent of Hitler to power, Germany planned for a second world war and greatly expanded its aluminium industry so that Germany was the leading producer, ahead of the United States, at the outbreak of the Second World War. To accomplish this, Germany developed her vast lignite deposits as the main power source. A similar development took place in Japan, where the Yalu River and Manchuria coal provided the main power sources.

8. The Second World War saw an unprecedented expansion of the aluminium industry in all belligerent and many neutral countries. In 1940 Germany overran most of Western Europe and Britain turned to Canada with her vast power resources. The Aluminum Company of Canada increased production at a rapid pace and made Arvida the largest aluminium plant in the world with a capacity of close to 400,000 tons per year, more than the entire German production. After its entry into the war in December 1941, the United States proceeded to expand aluminium production on a huge scale and at an astonishing speed. At the end of 1943, after only two years, the United States had increased its production capacity from about 300,000 to about 2,000,000 tons of aluminium per year. To achieve this vast increase great ingenuity was shown. Aluminium plants were built in big cities such as New York, using existing DC power surplus and large quantities of silver borrowed from the United States Treasury for use as bus-bars as no metal has a higher electric conductivity than silver.

9. At the same time, Germany had overrun important aluminium producing countries such as Norway and France, and immediately took steps to keep up and expand aluminium production in occupied areas. Norway, in particular, had the largest undeveloped water power resources in German-occupied territory and Germany founded an organization known as Nordag to build a number of large aluminium plants in Norway. However, Norwegian sabotage, allied bombing, hazardous shipping lanes and difficult climatic conditions foiled this grandiose plan. In contrast, aluminium expansion went ahead undisturbed on the allied side in faraway Canada and the United States.

10. In 1942 the Germans overran the large Soviet alumina and aluminium plants in the Ukraine, and in the Leningrad area aluminium plants came into the firing zone. New plants were built farther east, partly with moved equipment, but the Soviet Union nevertheless suffered from an acute shortage of aluminium so that large quantities had to be sent by Britain, Canada and the United States. Great Britain, for example, shipped most of her aluminium stockpile to the Soviet Union via the very hazardous shipping route to Murmansk and Archangelsk.

Post-war developments

11. At the end of The Second World War the United States and Canada had built up large aluminium production capacities while many of the European aluminium plants were destroyed, damaged or outdated. Large metal stockpiles in North America had a depressing effect. Many feared that it would take a long time before civilian consumption would require the vast facilities built in North America during the war. However, the transition to a booming peace economy in North America, and the

rehabilitation of West European economy went faster than expected and already in 1948 the aluminium industries were working at capacity and expanding on both sides of the Atlantic.

12. An important change in the structure of the aluminium industry took place in the United States, where Alcoa's prewar monopoly was broken as wartime government plants were sold to the newcomers Kaiser and Reynolds who have since grown to giants of almost the same size as Alcoa. Other Unites States companies went also into the aluminium field, creating a highly competitive climate for the North American aluminium industry. At the same time, Alcan, formerly controlled by the same interests as Alcoa, became a competitor of Alcoa as the result of United States antitrust proceedings.

13. In Western Europe a rapid growth of the aluminium industry took place, with large aluminium reduction plants being built, particularly in France and Norway, and large fabrication plants in the most industrially developed countries such as Great Britain, France, Germany, Switzerland, Sweden, Italy and Belgium. Western Europe's cheap water power resources were practically exhausted with the exception of the Scandinavian Peninsula, and new aluminium reduction plants in France and Holland were therefore based on natural gas and on lignite power in Germany.

14. New power sources and bauxite limitations forced Western Europe to look elsewhere for satisfying rapidly expanding aluminium needs. Great Britain, the largest fabricator of aluminium in Western Europe, continued to get aluminium from Canada, traditionally its main source. France built its first overseas aluminium reduction plant in the Cameroons.

15. Eastern European countries also showed great interest in expanding their alumina and metal production, in particular Yugoslavia and Hungary with important bauxite reserves. However, Poland and Rumania also built aluminium plants, with French technical assistance, and East Germany proceeded to replace some of its former aluminium production capacity which had been confiscated and reinstalled in the Soviet Union at the end of the war.

16. Aluminium production was greatly expanded in the Soviet Union after the war. The large pre-war plants in the Ukraine and at Stalingrad - now Volgograd - were rehabilitated but the main effort in recent years has taken place in Central Siberia where the huge water power resources of the Siberian rivers, such as the Angara, have been developed. However, lack of high grade bauxite deposits is still a problem for the Soviet aluminium industry and it therefore relies to a considerable extent on imported Hungarian alumina and Greek diaspore bauxite, and on other domestic aluminium raw materials such as nepheline.

17. The only country outside North America and Europe which possessed an important aluminium industry before the war was Japan. A few years after the war Japan started its spectacular economic expansion requiring increasing quantities of aluminium. Japanese policy has been to meet its aluminium requirements from domestic production in spite of high power cost and lack of bauxite. The Japanese alumina and aluminium industry has therefore grown very rapidly in recent years; it has probably passed 300,000 tons and is expected to reach 500,000 tons per year in a couple of years.

18. One of the most interesting features of the postwar aluminium picture is that the interest in aluminium has become universal. Aluminium industries have therefore sprung up in a number of countries in Africa, Asia, South America and the Pacific area, and hardly any country has not in recent years investigated the possibility of establishing an aluminium industry. The most spectacular developments are taking place in countries with a large population and potential market such as India and Brazil, in countries with large bauxite deposits such as Australia, Jamaica, Surinam, Guinea, and Guyana, and in countries striving for economic independence such as Mexico and South Africa.

Present situation and future outlook

19. The present situation is illustrated by the tables included with this article showing bauxite and aluminium production, exports and imports in the world according to the latest available statistics. Production statistics for alumina are not available for many countries because alumina is an intermediary product which is often not shown separately; however, tables showing world alumina exports and imports are included with this article. These tables are taken from Commonwealth Economic Committee: "Non-ferrous Metals", London, 1966.

20. With regard to alumina production, the present situation is that most alumina plants are still located in the main aluminium metal producing countries, rather than in bauxite producing countries. This has historical reasons since the alumina industry first grew up in the old established aluminium producing countries, and this situation has been perpetuated by tariff protection afforded by these countries against alumina imports, and also probably to some extent by the major aluminium companies' reluctancy to invest the large sums required in bauxite producing countries. Whatever the reasons, the present situation is that developing countries with bauxite deposits still export most of their bauxite in unprocessed form. This is illustrated by the table showing 1960 production figures for bauxite, alumina and aluminium, taken from "Bauxite, Alumina and Aluminium", published 1962 by the United Kingdom's Overseas Geological Surveys. The figures

are not up-to-date unfortunately because alumina production figures are not published in all countries. Since 1960 several alumina plants have been built in developing countries, in particular Harvey's plant at St. Croix in the Virgin Islands (this is, however, administratively United States territory), Alcoa's plant in Surinam, Alcan's plant in Guyana, and additional capacity in Brazil, India and Formosa; the Fria plant in Guinea has reached a production of more than 500,000 tons per year and a large alumina plant with a capacity of nearly 1,000,000 tons per year will be built in Jamaica by a consortium including Kaiser, Reynolds and Anaconda. At the same time, however, considerable expansion of alumina production facilities has taken place in industrially advanced countries such as the United States and Japan who import their bauxite and in Australia where some of the world's largest bauxite deposits have been discovered in the course of the last ten years. The general trend appears to be towards locating new alumina production facilities near the bauxite sources, that is to a considerable extent in developing countries.

21. The table shows an even more striking concentration of aluminium reduction capacity in industrially advanced countries. Substantial aluminium reduction facilities have been added since 1960 in a few developing countries, such as Ghana (Kaiser's Volta project), Surinam and Mexico (Alcoa), Brazil, Taiwan and India (mainly Alcan and Kaiser); a government-owned reduction plant is planned in the United Arab Republic and another planned in Iran. Nevertheless, by far the greatest expansion has taken place and is being planned in industrially advanced countries, where expansion is going on rapidly, particularly in the United States, Norway and Japan, and where several countries have joined the ranks of aluminium producing nations, such as Greece, the Netherlands, Rumania, while others are in the planning stage, such as South Africa. In aluminium metal production one cannot therefore discern much of a trend towards bridging the gap between the advanced and the developing countries.

22. Of all common metals aluminium has shown the fastest consumption increase in recent years and this trend is expected to continue for a number of logical reasons such as the desirable qualities of, and wide applications for the metal, the large resources of high grade raw materials, and the lack of other non-ferrous metal ores in many parts of the world. The expected average growth rate is of the order of 6 per cent per year, corresponding to a world production of primary metal of nearly 12,000,000 metric tons in 1975 and nearly 16,000,000 in 1980 if projected on a cumulative basis from 7,000,000 tons in 1966.

II. MAIN ECONOMIC FACTORS

23. The main factors affecting the economics of alumina and aluminium production are raw materials, electric power and fuel, labour, markets, transportation, plant size, capital and technical know-how. Each of these factors will be discussed, including their effect on the possibilities of establishing alumina and aluminium industries in economically and technically underdeveloped countries.

Bauxite and other alumina raw materials

24. Bauxite is and will be, as far ahead as one can see, by far the main raw material. Bauxite is the result of tropical surface weathering of aluminous rocks and is therefore mainly found in the tropical and warm zones of the earth. It is therefore deficient in many of the industrially advanced countries with the large aluminium industries such as the United States, Soviet Union, Germany, Great Britain, Japan and Canada. However, there exist enormous deposits in the warm climate zones on both sides of the equator and bauxite will therefore always be plentifully available in a peaceful world with free commercial exchange.

25. The aluminous minerals in bauxite are alumina trihydrate (gibbsite), alumina monohydrate (in two different crystal forms - boehmite and diaspore) and corundum. Of these, gibbsite and boehmite are the most soluble in the Bayer process and fortunately also the prevalent minerals in most bauxites. European bauxites are of the monohydrate type and some Greek bauxites contain substantial amounts of diaspore and corundum. Surinam, Guyana and some West African, as well as Malayan and West Australian bauxites are of the trihydrate type. Many of the bauxites found recently in large quantities, for example in Jamaica and in Queensland, are predominantly trihydrate but with significant contents of monohydrate as well; these "mixed bauxites" now probably represent the largest tonnage of bauxite used by the aluminium industry.

26. Practically all the world's alumina is produced from bauxite by the Bayer process. Since the infancy of the aluminium industry a large number of processes, mostly based on extraction with acids or with solutions of strongly acid salts, such as ammonium sulphate, have been proposed for recovering alumina. Such processes have particularly been suggested for the treatment of materials other than bauxite, such as various clays, alumina-rich coal ashes, leucite, nepheline, andalusite, labradorite and alunite. These raw materials are not suitable for the Bayer process, primarily because of their high silica contents. They have been used to some extent in war-time when sufficient bauxite was not available in some countries, and these raw materials could be used again in an emergency. However, the world

reserves of bauxite are very large and other raw materials will probably not be extensively used as long as the normal supply of bauxite is not impeded by emergencies such as war and political instability in the bauxite mining countries. The only non-bauxite raw material which is used today on a large scale is nepheline, a sodium-potassium-aluminium silicate containing approximately 34 per cent Al_2O_3. It is obtained as a by-product from the beneficiation of apatite mined on a large scale on the Kola Peninsula. This nepheline is used for the production of alumina in the Soviet Union, whereby potash is obtained as a by-product.

27. Practically all bauxite produced in the Western Hemisphere, Africa, Asia and Australia is mined by open-pit methods. In Europe some bauxite is produced by underground mining but also there most of the production comes from open-pit operations. Open-pit mining of bauxite consists usually of removing overburden, mining the bauxite and finally replacing the overburden when this is prescribed. Conditions vary greatly with respect to thickness and nature of overburden, thickness of bauxite layer and other conditions. Bauxite quality, including extractable alumina content, undesirable impurities such as reactive silica, moisture content and red mud settling characteristics also vary greatly. Local economic conditions, such as climate and distance from tidewater or navigable rivers also affect the economy of bauxite production. No general rule can therefore be given for minimum economic size of bauxite mining operations. The largest individual operations are now of the order of one to two million tons of bauxite per year. The opening up of large bauxite mining operations requires large investments for necessary mechanical equipment and for preparing large areas for mining, bearing in mind that the surface is often covered with tropical jungle sometimes above a thick layer of moist humus. In addition, large investments are often required for railway and ship loading facilities.

Bayer Alumina Process

28. Practically all the world's alumina production is still by the Bayer process, a very flexible process capable of treating a wide range of bauxite qualities and also capable of producing a wide range 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 using high throughput production units and highly efficient heat recovery systems. Trihydrate bauxite has been treated continuously for a number of years, and now the more refractory monohydrate bauxites can also be treated continuously.

29. According to conventional North American practice, trihydrate bauxite is digested at approximately 4.8 atmospheres (50 psi) and 145° C (290° F). A large

proportion of the heat is recovered by flashing the digested slurry from 145° to 105° C (290 to 220° F) in two to four stages, and the recovered heat is used to preheat the incoming caustic solution. The large Fria trihydrate plant recently built in Guinea, West Africa, uses digestion at atmospheric pressure; this simplifies considerably design and maintenance.

30. In European Bayer practice, monohydrate bauxite is digested at 20 to 50 atmospheres (280 to 700 psi) and 180 to 250° C (355 to 480° F). At these high temperatures and pressures the continuous handling of slurries presents many technical problems and conventional monohydrate Bayer practice has therefore hitherto been based on batch operation. However, these difficulties have gradually been overcome and continuous processing is now becoming standard practice also for monohydrate bauxites.

31. A large proportion of new bauxite sources developed in recent years supply "mixed bauxites", predominately trihydrate but with significant amounts of monohydrate present as well. Large bauxite deposits of this type have in recent years been developed in the Caribbean area, particularly in Jamaica, Haiti and Puerto Rico, and in Australia. The treatment of these bauxites is complicated by reprecipitation of initially dissolved trihydrate, as monohydrate, undigested monohydrate in the bauxite acting as seed. This problem has been overcome by short digestion time at elevated temperature and pressure. Digestion conditions for "mixed bauxite" range from 28 to 40 atmospheres (400 to 560 psi) and 220 to 250° C (430 to 480° F). The trend is to use lower caustic concentration than in European practice, resulting in less solution to be evaporated and hence lower steam consumption. Heat is recovered from the digested slurry in the continuous process by six to ten heat exchanger stages.

32. Initially the Bayer process used sodium carbonate as caustic make-up but practically all plants have now switched to sodium hydroxide which permits a higher caustic level and consequently a better utilisation of the equipment, and in particular the hydrate precipitation sections of the plant. There are also other advantages. Alumina plants are reported to have increased their throughput as much as 20 to 30 per cent in some cases by changing from sodium carbonate to sodium hydroxide. Another reason for this trend is the availability of cheap sodium hydroxide solution, delivered in bulk by large tankers; this is economically significant since most new large alumina plants are now built in coastal locations.

33. The physical form of alumina is influenced by alumina hydrate precipitation conditions and by alumina calcining conditions. The use of so-called "floury" or "mineralised" alumina has become common in recent years, because its high angle of

repose and thermal insulation characteristics are favourable for the operation of certain types of aluminium reduction cells.

34. To summarise the trend in alumina production it can be said that:

(a) The Bayer process has been greatly improved in recent years and will certainly produce most of the world's alumina requirements for many years to come.

(b) Continuous digestion has become standard practice for all types of bauxite, and continuous precipitation is also being widely adopted.

(c) It is now possible to treat efficiently a large variety of bauxite qualities, including "mixed bauxites".

(d) Fuel consumption has been greatly reduced as the result of improved heat exchanger efficiency.

(e) Plant capacity has been increased by using sodium hydroxide instead of sodium carbonate.

Auxiliary raw materials

35. The main auxiliary raw materials in aluminium production are fluorides (cryolite and aluminium fluoride), and anode materials, i.e. low ash coke and pitch.

36. The only known large natural cryolite deposit at Ivigtut in Greenland is practically exhausted. Most present and all future fluoride requirements will therefore be based on processing fluorspar (calcium fluoride) of which there exist large deposits in the world in Newfoundland, Mexico, France, Spain, Sweden, China, South Africa and the Soviet Union.

37. Practically all the low ash coke used as anode material is petrol coke, of which there are adequate supplies today. Petrol coke could however, become a bottleneck if the aluminium industry grows faster than petroleum refining and its substitutes may therefore acquire importance in the future. Tar coke has been used extensively in Germany but this is a limited source. Gilsonite could become an important substitute but the largest potential source of carbon is of course coal from which ash can be removed by methods such as chlorine volatilisation. Carbon requirements would be sharply reduced by the use of aluminium reduction cells with permanent anodes but there is no indication of the successful development of such a cell.

Electric power

38. Electric power is the most important economic factor in aluminium production. Electrolytic aluminium reduction on an economic scale requires large quantities of cheap power. Great technical efforts have therefore been made - and are still being made - to reduce power requirements by improving the electrolytic process.

Best results to date are the order of 13.5 KWH per kilo (6.2 KWH per pound) but this figure is based on low current density cells and large bus-bar cross-section, both of which result in high investment. Reduced power consumption achieved in recent years is due mainly to lower anode and cathode resistance, larger cells (up to 150,000 amperes) with better thermal efficiency, better anode level and power regulation resulting in lower interpolar voltage, better current distribution and bus-bar design resulting in better current efficiency and less magnetic disturbances, crustbreaking and alumina feeding at correct intervals resulting in better control of anode effects, and use of floury alumina in some cases. The lowest power consumption figures are achieved with prebake anodes and the present trend is therefore from Soderberg to prebake anodes, reversing the trend of ten to fifteen years ago.

39. Actual power consumption is still several times the theoretically required amount, and it can be safely predicted that power consumption will be further reduced in years to come. This will probably be achieved by further increasing cell size - 250,000 ampere cells are currently being tested - by perfecting automatic cell voltage control now introduced on an experimental basis by many major producers, by further mechanisation of alumina charging and crustbreaking, and by further imporvement of anode and cathode quality. Recent developments reducing cell voltage, such as high conductivity electrolytes with lithium salts and titanium boride cathode conductors, may be adopted for commercial plants.

40. Power from coal, lignite, natural gas and in particular from hydroelectric power developments, is used for aluminium production. Of these power sources, natural gas requires the lowest investment per kilowatt installed, but fuel cost is usually comparatively high. Hydroelectric developments, on the other hand, usually require the highest investment but are very cheap to operate. Amortisation and interest on capital always form a large proportion of the power cost.

41. The lowest power costs are found in old aluminium plants with their own fully amortised hydroelectric power plants. In such cases, power costs can be as low as 1 U.S. mill and this is probably the case for some plants in Canada and Norway. The highest power cost paid for aluminium production is probably about 7 mills; it is believed that some plants in Western Europe and Japan have power costs of this order, particularly when purchasing power from outside power companies or national grid systems.

42. The maximum power cost for economic production of aluminium depends on the other costs in each case, of which labour is the most important. In North America with its high labour cost the maximum is about 4 mills whereas Western European

and Japanese plants can compete with up to 6 or 7 mills power.

43. Aluminium reduction plants have until now been located close to cheap power sources but two recent developments will give more freedom of choice for the location of future plants. The first of these is high voltage AC and DC transmission, which will for example provide economic power transmission at about 800 KV from Churchill Falls in Labrador to points 2,000 to 3,000 kilometers away. The other important development is nuclear power which is rapidly becoming cheaper. A few months ago Rio Tinto Zinc Corporation proposed to build a nuclear powered aluminium reduction plant in Great Britain and now several other companies are seeking to do the same.

44. Electric power is of much less economic significance in alumina production. Nevertheless a large alumina plant requires a considerable amount of power and this is a problem if no power source exists at the best plant site, which is often close to the bauxite mine. The Bayer process requires large amounts of steam and in many cases steam production is therefore combined with electric power generation. This combination is particularly attractive when treating monohydrate or mixed bauxites because of the required high steam pressure.

Labour

45. With rising living standards labour becomes an increasingly important economic factor also in the aluminium industry. Great efforts are being made therefore, to reduce labour requirements, particularly in North America and Western Europe where living standards and therefore labour costs are highest.

46. These efforts are directed mainly towards large production units, removal of manual labour by mechanisation, and reduction of supervision by automatic controls.

47. Labour requirements for bauxite mining have been greatly reduced in recent years by extensive use of modern mechanical equipment such as bulldozers, draglines, large trucks and in particular enormous rotary bucket excavators which have been in use for some years now in Surinam and Guyana.

48. Bayer alumina plant operating labour requirements have been reduced by the adoption of large units and the now almost universal change-over to continuous operations. Maintenance labour requirements have been reduced substantially by improved descaling methods and the use of synthetic filter fabrics.

49. Labour requirements are important in aluminium reduction plants because of the large number of electrolytic cells which have to be looked after. To reduce these requirements the trend, particularly in North America, is to use teams with mobile

equipment, who perform a single operation - such as alumina charging, crustbreaking metal tapping, etc. - on a large number of cells, rather than the older system of individual workmen performing all the operations on a few cells. The trend is also to limit the number of cells by using large units but the possibilities in this direction are limited by the magnetic problems arising from large amperages and the increased investment for larger cells requiring lower current densities, more complex bus-bar systems and more intensive cooling. The present limit is about 150,000 amperes but larger cells are being tested and the development of large cells will probably not stop at this size.

30. It is in aluminium fabrication - casting, extrusion, rolling, and other processes - that labour content is highest and also in this field labour saving efforts are most pronounced. Again, the trend is towards larger units and mechanisation. Modern continuous rolling mills for aluminium use ingots weighing up to 12 tons; rolling speeds and rolling mill power drives are continuously increasing. Complicated and large shapes are produced by pressure diecasting. In wire and cable manufacture the trend is towards automated rod mills but also towards direct casting and rolling of rod by the Properzi process. Similar advances are made in the finishing operations where high speed slitters, continuous stretching and flattening machines, continuous resquaring machines, continuous paint and anodising lines and flash anneal furnaces are reducing labour requirements.

Aluminium markets

51. Aluminium is used for a large variety of products and aluminium consumption in a country reflects its standard of living. Consequently aluminium consumption per inhabitant is far higher in the rich industrially developed countries than in underdeveloped countries, as shown by the figures below, taken from *Trends in the World Aluminum Industry* by Sterling Brubaker:

Advanced countries	Kg Al/year per capita (1964)
United States	15.6
Switzerland	10.1
Canada	9.8
Germany	9.7
Great Britain	9.5
Norway	9.4
Austria	8.6
Sweden	8.2
Belgium-Luxembourg	5.3
France	5.0
Denmark	5.0
New Zealand	4.5
Finland	4.0
Japan	3.8
Italy	3.5
Netherlands	3.2
Intermediary countries	
Yugoslavia	2.3
Spain	1.7
Greece	1.0
Developing countries	
Venezuela	1.0
Brazil	0.6
Mexico	0.5
Columbia	0.5
India	0.2

52. The influence of this factor on the prospect of developing an aluminium industry in countries still at a low level of industrial development will be discussed later.

Transportation

53. Because of its international structure the aluminium industry is profoundly affected by the rapidly changing world transportation pattern. Transportation costs are bound to play a major role in an industry in which the main raw material, bauxite, is found mostly in tropical and subtropical countries whereas the product, aluminium, is consumed mostly in industrially developed countries of the temperate zone.

54. Great changes are happening these days to transportation costs of bulk materials such as bauxite and alumina. Ocean freight costs are being greatly reduced by the use of large bulk carriers and at the same time, mechanical loading and unloading equipment is lowering terminal costs. Overland rail freight charges, on the other hand, show a tendency to increase in most countries.

55. The result of this is that it has become economical for the major aluminium producers to bring in bauxite or alumina from distant sources, using large bulk carriers. To take full advantage of this situation the source of bauxite or alumina as well as the receiving aluminium reduction plant, should be located close to tidewater. Here are some examples of this trend. Swiss Aluminium Company is developing a bauxite deposit in Northern Australia where a large alumina plant will be built; from there alumina will be shipped in 60,000 ton ships to the company's aluminium reduction plants in Norway, Iceland, Holland, United States and other countries. Similarly, Péchiney is shipping its part of Queensland Alumina Co.'s production to the Intalco plant on the North-west coast of the United States, which Péchiney owns jointly with American Metal Climax. American Metal Climax has made a long-term contract to import its part of Intalco's alumina requirements from Alcoa of Australia Ltd. in Western Australia. We see therefore Australia rapidly becoming the world's largest exporter of alumina in spite of its remote location, thanks to the spectacular reduction in ocean bulk freight costs in recent years.

56. Alumina is much cheaper to transport than bauxite. The main reason is, of course, that two to three tons of bauxite are required to produce one ton of alumina. Additional factors are the greater ease of handling alumina with modern bulk charging and discharging equipment, and the necessity of drying the bauxite before shipment in some cases. It is therefore usually more economical to process bauxite into alumina on the spot than to ship the bauxite to alumina plants in the aluminium producing countries. From this it follows that the most economic location for future alumina plants is as close as possible to bauxite deposits and also as close as possible to deep sea shipping facilities; this is also important from the viewpoint of utilizing low cost ocean bulk transportation for bringing in fuel oil and caustic soda in solution.

57. The transportation of molten aluminium metal, by truck or railway car, has been in use for some years in the United States and Canada. This technique saves substantial handling costs as well as the cost of casting and remelting ingots, but is only applicable to large tonnages. Liquid metal transportation will undoubtedly be used on an increasing scale in the future, at least in industrially developed countries.

Plant size

58. With the growth of the industry the sizes of competitive alumina as well as aluminium reduction plants have increased and this trend will certainly continue. Whereas a 100,000 tons per year alumina plant and a 20,000 tons per year aluminium reduction plant were considered large units before the last war, now the major aluminium companies usually think in terms of alumina plants with a capacity of at least 300,000 tons and aluminium reduction plants with a capacity of at least 100,000 tons.

59. Economic circumstances vary so much that the minimum plant size must be determined in each individual case. However, the following sizes for alumina plants are given as an indication, in tons alumina per year production capacity:

(a) Self-contained alumina plant in North America, Japan or Europe: say 150,000 in Europe and Japan and about 250,000 in North America.

(b) Alumina plant connected with mining of a bauxite deposit (for example in Australia, Surinam, Jamaica, West Africa): about 200,000. The minimum economic size can, however, be considerably larger than this if the project requires a costly infrastructure, such as a new railway line or harbour; the Fria plant in Guinea, initially designed for 480,000 tons, is an example of this. On the other hand, Alcoa of Australia started a couple of years ago a very profitable alumina production of 200,000 tons per year at Kwinana in Western Australia; in this case excellent port facilities existed only 28 miles (45 kilometers) from the bauxite deposit at Jarrahdale.

In this connexion it should be pointed out that the economy of an alumina plant improves with increasing capacity up to about 660,000 tons Al_2O_3 per year (2,000 tons per operating day) which is the largest unit size in operation today, although most modern plants are based on units with capacities from 200,000 to 330,000 tons per year. A larger plant will therefore consist of two or more parallel production units, and further cost savings become less marked.

60. It is more difficult to give any general rules about the minimum economic size of aluminium reduction plants. Even the largest aluminium reduction cell is a small production unit and the electrolytic process thus provides great flexibility with respect to plant size. The main cost items in aluminium reduction are electric power and labour, besides transportation costs for alumina and metal. Consequently a small reduction plant can be competitive provided power cost is low, particularly where this can be combined with a tidewater location. This is, for example, the case in Norway and in North-western United States. It was also the case in the Alps where there are many small French and Swiss plants but now power

has become expensive in this area. To give some idea of minimum competitive sizes for aluminium reduction plants under present economic conditions, it can be mentioned that new projects in North America have been based on a production of at least 100,000 tons per year, in Europe on 30,000 to 80,000 tons per year, and in Japan most recent projects have been initially planned for 30,000 to 50,000 tons per year.

61. Economies are achieved by vertical integration such as the combination of bauxite mining with alumina production, aluminium reduction and fabrication. Smaller plants can therefore become competitive when several production stages are vertically integrated. This has been done in Brasil, Australia, Norway, Switzerland, Canada, Japan and the United States.

Capital requirements

62. Alumina, aluminium reduction and modern fabrication plants require large investments, and also the infrastructure required such as electric power generation and transmission, port facilities, preparation of bauxite mining and town-sites where projects are located in virgin territory.

63. The magnitude of the investment is illustrated by the published cost of some recent aluminium and alumina projects.

Queensland Alumina Ltd., Gladstone, Australia

Type of plant: alumina from "mixed bauxite"
Capacity: 600,000 long tons/year
Production started: 1967
Total cost: $US 117,000,000 (including some infrastructure investments)

Fria, Guinea, West Africa

Type of plant: alumina from low-grade trihydrate bauxite
Capacity: 480,000 metric tons/year
Production started: 1963
Total cost: $US 150,000,000, (including mining and transportation facilities)

Alumina Partners of Jamaica, Mandeville, Jamaica

Type of plant: alumina from "mixed bauxite"
Planned capacity: 950,000 short tons/year
Planned start: 1969 - 1970
Estimated cost: $US 185,000,000

Intalco, Bellingham, Washington, United States

Type of plant: aluminium reduction plant

	Capacity	Cost, $US	Started
Stage I	76,000	65,000,000	1966
Stage II	76,000	45,000,000	1967
Stage III	76,000	45,000,000	1968
Total	228,000	155,000,000	

Intalco, Bellingham, Washington, United States (continued)

Includes alumina unloading and storage facilities, but no power facilities beyond rectifier transformers.

Aluminium de Grèce, Saint Nicholas, Greece

Type of plant:	(a) Alumina from monohydrate bauxite (b) Aluminium reduction plant
Capacity:	200,000 metric tons/year alumina 72,000 metric tons/year aluminium
Production started:	1966
Total cost:	$US 130,000,000, (including infrastructure investments such as a bauxite cargo ship and contributions towards town-site.)

Technical know-how

64. The technology of alumina and aluminium production, as well as aluminium fabrication, is well known in general. However, the leading aluminium producers spend vast amounts on research and details of their latest technical improvements are usually not available to outsiders. An important factor in connexion with a new aluminium project is therefore to obtain full access to up-to-date technology, including plant design, operating practice and training facilities.

III. STRUCTURE OF THE ALUMINIUM INDUSTRY

65. The aluminium industry has always been characterised by vertical integration. This was due initially to the necessity for pioneer producers such as Alcoa in the United States, The British Aluminium Company in Great Britain, Péchiney in France and Alusuisse in Switzerland, to develop raw materials and markets for the new metal. There were no existing organisations experienced in manufacturing and selling aluminium products, so they had to do it themselves. The trend towards vertical integration has become even more pronounced in recent years, reaching a point where it is almost impossible for an independent bauxite, alumina, aluminium reduction or aluminium fabricating operation to survive in the competitive environment of the free enterprise economies.

66. At the same time leading companies, which were originally national in character have gradually extended their interest to all countries of the world where foreign companies are allowed to operate.

67. A large proportion of the aluminium industry in free enterprise economies from bauxite mining to marketing of finished aluminium products, is now controlled by comparatively few companies. These companies have in the course of years acquired control over most of the known bauxite deposits, mostly through their own exploration efforts but also by systematically purchasing bauxite deposits from smaller mining companies, and by obtaining long-term mining concessions from governments involved. As a result of this policy major companies have also obtained effective control of the alumina industry, and it is believed that there is now only one independent producer of alumina in the free enterprise economies of the world.

68. The aluminium reduction industry has traditionally been much more spread out but also here the giants have been growing at the expense of independent producers. In Europe one of the largest producers, Aardal og Sunndal Verk in Norway, with an annual capacity of more than 200,000 tons and owned by the Norwegian Government, found it difficult to carry on as an independent supplier of primary metal while one after the other of their customers - the independent fabricators in Europe - came under control of the large, mostly North American aluminium companies. Aardal og Sunndal Verk was therefore forced by circumstances to come to an arrangement which gives Alcan factual control of the Norwegian company.

69. But it is in the fabricating field that the large companies have been most aggressive. Thus the proportion of fabricated aluminium products supplied by independent fabricators in Europe has sunk from about 50 per cent in 1958 to about 25 per cent now, and will undoubtedly be further reduced in years to come. The large companies have bought out the independents in order to secure outlets for their primary metal by controlling the fabricating industry. In Europe one has, for example, seen Kaiser and Alcan acquire control of two leading independent fabricators in Great Britain, while Alcan and Kaiser have moved into West Germany and Swiss Aluminium into Holland and Italy; at the same time, Péchiney has acquired control of most of the French and Belgian fabricating industry. In North America the picture is similar; American Metal Climax has acquired control of three of the largest independent fabricators in the United States (and, incidentally, of one in Germany), Alcan has taken over three or four fabricating companies in the United States while Reynolds has obtained control of a rolling mill and extrusion plant, which were formerly independent, in Canada.

70. The giants of the aluminium industry have in recent years even taken over complete integrated companies which found themselves handicapped in the keen international competition, usually for lack of capital to expand at a sufficient rate. Some years ago, Reynolds Metal Company acquired The British Aluminium Company, by

far the largest in Great Britain, after a fight in which Alcoa was the loser in the fight for control. In Japan, Alcan acquired 50 per cent of Nippon Light Metals Ltd., by far the largest integrated aluminium company in that country. Similar developments took place in Australia, Brazil and elsewhere.

71. Most of the new plants, whether alumina, aluminium reduction or aluminium fabricating plants, recently built in the world outside of North America, are controlled by, or have substantial participation by major companies. For example, Alusuisse owns or controls aluminium reduction plants built and planned recently in Holland, Iceland, Italy and Norway; Péchiney-Ugine controls Aluminium de Grèce; Harvey has major participation in the Alnor plant in Norway; Alcan in the Mosal and new Lista plants in Norway; Kaiser is in technical control of the Volta project in Ghana and a major participant in Comalco in Australia, while Alcoa owns or controls important new integrated aluminium industries in Australia and Surinam; Alcan and Kaiser in India, and so on.

72. In the United States, however, this trend has been almost reversed. The large established companies, Alcoa, Kaiser and Reynolds, have grown even larger but at the same time new independent producers have emerged, first Anaconda, then Harvey, Comet, and now two or three new companies plan to enter the aluminium field. The reason this could happen in the United States is obviously that the market is so large that a newcomer can start immediately on an economic scale, and that capital is available for very large industrial projects. On both counts the United States is quite unique in the world of today.

IV. RECENT TRENDS IN ALUMINIUM TECHNOLOGY

73. The aluminium industry is a young and aggressive industry. It spends large amounts on research and industrial development, and this has resulted in continuous improvements of the present production methods as well as great efforts to develop basically new processes.

Bauxite exploration and mining

74. All major aluminium companies as well as government agencies have intensified exploration for bauxite in recent years, utilizing modern exploration techniques. Bauxite mining, carried on an ever-increasing scale, has adopted modern mass handling methods using for example as for open pit coal and lignite mining, large rotary excavators, movable draglines with light weight aluminium trestles.

Alumina production

75. Research is directed mostly towards improvement of the conventional Bayer process and its adaptation to the newly found "mixed" bauxites. To a lesser degree research is directed towards the utilisation of raw materials other than bauxite. This may be a major field of research in the Soviet Union.

Aluminium reduction

76. Research in aluminium reduction is directed mostly towards larger cells, reduced power consumption, reduced labour requirements through mechanisation and control including computerised operations and new materials of construction to improve cell life. At least one of the major producers is currently developing a bipolar cell which, if successful, could greatly increase cell productivity.

Aluminium fabrication and finishing

77. This is probably the most active field of research because it is the area of greatest potential labour savings and because it is directly connected with the search for new markets.

78. New fabricating techniques being developed particularly in North America and Western Europe will create significant changes in fabrication, technology in industrially developed countries in coming years. Among these developments can be mentioned continuous casting of sheet, recently adopted for a large new rolling mill in Norway, rolling and extrusion of aluminium pellets and powder, explosion forming, new strip and rod casting methods, new alloys and new surface finishing techniques.

New direct reduction processes

79. Aluminium technology has remained based on the Bayer alumina process and the Hall-Heroult electrolytic reduction process since the earliest beginning of the aluminium industry. These processes require large investments. The Bayer process can only be economically applied to certain aluminous raw materials and the electrolytic reduction process requires large numbers of small production units, hence rather high labour requirements. Economic incentive exists for developing processes which would produce aluminium directly from ores without going through the alumina stage, thus avoiding expensive electrolytic cells with low individual production capacity.

80. The idea of producing aluminium by direct reduction of aluminium compounds in electric resistance or arc furnaces is not new. However, this development has gained impetus in the last twenty years and technically feasible solutions have been found. Semi-commercial plants have been built by Aluminium Company of Canada, for

the subchloride process, jointly by Péchiney and Ugine for the carbothermic process and by Reynolds Metal Company for the segregation process.

81. Aluminium Company of Canada (Alcan) has been working on the subchloride process which is based on the existence of aluminium monochloride AlCl (also known as aluminium subchloride) which under certain conditions of temperature and pressure decomposes into aluminium trichloride and aluminium metal according to the reversible reaction:

$$3\,AlCl \qquad AlCl_3 + 2\,Al$$

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 volatilised as aluminium monochloride. The gaseous aluminium monochloride 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 volatilisation or distillation step.

82. The earliest process of this kind was patented by Alcoa in 1939. In this process impure aluminium, aluminium carbide, etc., were treated with fluorides such as AlF_3, MgF_2, CaF_2, cryolite, etc., at 900° to 1300° C. The condensate was a mixture of fluorides and purified aluminium metal, which could be separated by remelting the condensate. I.G. Farbenindustrie took out a German patent in 1940 based on a similar treatment of ferroaluminium with fluorides at 1050° to 1200° C.

83. The first patents on the volatilisation of aluminium with chlorides were taken out by Vereinigte Aluminium-Werke in Germany in 1943, and in 1944 High Duty Alloys Ltd. took out patents which specify the use of $AlCl_3$ vapour for extracting aluminium from a preheated aluminium containing material. These patents were based on the work carried out by P. Gross at the Fulmer Research Institute in England. The patents were later transferred to International Alloys Ltd. and Almin Ltd., from whom they were acquired by Aluminium Laboratories Limited, a company belonging to the Alcan group.

84. During the last twelve to fourteen years Aluminium Laboratories Limited has carried out extensive development work at Arvida, Quebec, culminating in the building of the large pilot plant which has already been mentioned. Alcoa also looked into this process in a pilot plant at East St. Louis but the work was abandoned in 1953. Other leading aluminium companies which have investigated the subchloride process are Swiss Aluminium Ltd., V.A.W. (German), Ugine and Kaiser. The basic

patents have expired but Alcan has taken out a large number of patents on process and design details in recent years.

85. Alcan decided in 1960 to build a 6,000 to 8,000 tons per year pilot plant at Arvida, Canada but ran into difficult problems when applying the process on this large a scale. These difficulties, mainly connected with corrosion and transfer of impurities, caused long delays and large additional expenses until Alcan gave up the project in 1967.

86. Péchiney in France has been working on a carbothermic process for a number of years. A number of patents have been issued to Péchiney, the earliest dating from 1951. This development has resulted in the building of a large pilot plant at Nogueres, France in 1960-1962, jointly owned by Péchiney and Ugine. The Péchiney patents describe a number of process steps which can be used in various combinations. However, the process now being investigated at the Nogueres experimental plant appears to consist of the following three main steps:

(a) Bauxite is reduced in electric furnaces in two stages. First the impurities are reduced with a limited amount of carbon (probably metallurgical coke) and removed as an Fe-Si-Ti alloy. This leaves a fairly pure molten alumina, which is probably tapped and granulated for use in the second step of the process.

(b) The fused alumina is reduced with additional carbon (probably petrol coke) to a mixture of metallic aluminium, aluminium carbide Al_4C_3 and aluminium suboxide Al_2O. Bayer alumina, which is probably purer than the electrothermically produced alumina, can also be used as raw material for this step.

(c) The molten $Al-Al_4C_3-Al_2O$ mixture is slowly cooled whereby a spongy material is formed consisting of an aluminium carbide crystal lattice with the voids filled with molten aluminium. Pure aluminium is separated from this mixture and the aluminium carbide is recycled, probably to the second reduction step.

87. Other variants have apparently also been tried out in the Nogueres pilot plant, such as reduction at a very high temperature (probably 2300° to 2400° C) resulting in an $Al_2O-Al-CO$ gas mixture which is reduced to Al_4C_3 in a coke filled tower; the aluminium carbide can be decomposed into aluminium metal and graphite at above 2000° C.

88. Also this process has encountered serious problems, mainly due to considerable volatilisation of aluminium (mostly as suboxide) at the high temperature required (1800° to 2000° C), and also due to the problems connected with aluminium carbide formed in the process. Péchiney and Ugine are probably continuing research on this process on a modest scale but it is reasonable to believe that the process is still far from economic exploitation.

89. Péchiney has also taken out a number of patents on a process involving aluminium nitride AlN as intermediary product but it is not believed that the nitride process has been developed beyond small-scale experimentation.

90. Reynolds Metals Company has been working for some time on a direct reduction process. The first step consists of reducing bauxite directly in an electric furnace to an aluminium-silicon-iron-titanium alloy, and is thus similar to the first step in the Alcan process. The alloy is subjected to controlled solidification by slow cooling, and the constituents are subsequently separated by fine grinding, flotation and magnetic separation. The process is primarily being developed for producing aluminium-silicon alloys and it is doubtful that it can be used for producing pure aluminium.

91. The development of Alcan's and Péchiney-Ugine's new electrothermic processes has met with so many technical difficulties that Alcan has abandoned further large-scale work on their process; the Péchiney-Ugine process is also believed to be far from commercialisation. The Reynolds process, if successful, would probably be limited to the direct production of aluminium-silicon alloys and would therefore have only limited application. It is therefore reasonably safe to state that these and similar new processes will not influence the aluminium industry for a number of years - say the next ten years. Even if a direct reduction process should become suitable for commercial exploitation in five to ten years from now - which is very unlikely - this would not render conventional plants immediately obsolete because such companies as Alcan, Péchiney, Ugine and Reynolds all have enormous investments in conventional alumina and electrolytic aluminium plants and undoubtedly will wish to continue operating these at a profit.

92. When evaluating the possible future impact of the new processes it is important to keep in mind that the Bayer alumina and the Hall-Heroult electrolytic reduction processes have by no means yet reached ultimate perfection. The conventional processes are being further improved and a number of present developments will certainly result in substantial future economies.

V. ALUMINIUM INDUSTRY POTENTIAL OF DEVELOPING COUNTRIES

93. A developing country can usually, at a modest investment and with some tariff protection, establish a small-scale aluminium fabricating industry to satisfy local demand for pots and pans, and other articles which are comparatively simple to produce. Indeed, most developing countries have small aluminium hollowware plants

and in many cases small rolling mills, extrusion plants and jobbing foundries.

94. However, the prospects that developing countries have for establishing basic aluminium industries, that is, alumina and aluminium reduction plants, is the next consideration.

95. Most of the world's bauxite resources and a large proportion of the world's undeveloped water power resources are both located in countries with little industrial development in tropical and sub-tropical regions. Many of these countries in need of new jobs and production to combat under-employment and improve living standards have the necessary natural resources within their borders. This is the case in West and Central Africa, Central and South America, and South and South East Asia. Yet these resources often remain undeveloped or not utilised to the full benefit of the country. What are the limiting factors, and what are the problems that have to be overcome when a developing country wishes to establish a basic aluminium industry?

96. The main limiting factor is probably the large investments required for alumina and aluminium reduction plants of economical size. The output of an internationally competitive plant is usually much larger than can be absorbed locally, operation of such a plant must therefore, to a considerable extent, be based on exports to areas of high consumption.

Possibilities through existing aluminium companies

97. It has already been explained that leading aluminium producers have become vertically integrated and increasingly international in their structure. These large companies are continuously striving to broaden their raw material basis - including bauxite, alumina and primary aluminium - to satisfy the rapidly expanding world demand for aluminium. Practically all these companies are basically interested in participating in alumina and aluminium reduction projects in developing countries, provided the projects are economical; that is, provided they will create competitive new sources of alumina or aluminium metal for export to world markets in which these international companies have fabricating plants and sales organisations. In such cases, large aluminium companies can in effect be expected to compete for the privilege of establishing such plants. Their reputation and influence in the main money markets such as Western Europe, the United States and lately Japan, is usually such that they can finance projects involving very large sums of money. In many cases they can also exert influence and guarantee the technical and economic results needed to obtain financing support from governments of countries with funds available for foreign investment.

98. From this it is evident that large aluminium companies wish to establish basic aluminium industries in developing countries, and that they are capable of making financial arrangements for the very large amounts of money involved. Their objective is, of course, to profit from such projects for a number of years commensurate with the very substantial financial and technical efforts made. This means that, besides the natural conditions existing for a competitive project, economically and politically stable conditions must also exist in the country in order to make such an investment and effort attractive. Furthermore, existing conditions and the past record of the country must be such that one can reasonably expect these stable conditions to last for a number of years into the future. The importance of future stability is obvious when one considers that in most cases an alumina or aluminium reduction plant is planned for future expansion in stages and may only reach its ultimate economy ten to fifteen years after building the initial stage. The risks about which the private investor needs reassurance are primarily confiscation - often called nationalisation - future tax squeeze, imposition of price control systems which limit profits, and currency controls which prevent repatriation of dividends.

99. Unfortunately, many of the countries with substantial bauxite and in some cases also water power resources, have gone through political upheavals and economic crises in recent years; such a record of course makes a company, whose responsibility it is to safeguard its shareholders' money, very reluctant to invest large sums in the country. It can take many years to re-establish a political and economic climate attractive to private capital. In many countries formerly under colonial rule one has witnessed an excessive nationalism which is psychologically very understandable but which has had an unfortunate effect on the desire of foreign private capital to invest in these countries.

100. Private companies have not been entirely without blame with respect to their operations in developing countries. Often they have wielded more economic power and exerted more political pressure than is palatable to local governments and native populations, and have tended to keep local management in the hands of their own nationals. In some cases aggressive and greedy companies must share the responsibility for the corrupt conditions which have developed. They have often preferred extraction of bauxite to processing it locally, thereby depriving developing countries of income and employment.

101. Major aluminium companies are now well aware of this problem and of their responsibilities as demonstrated by the fact that practically all alumina and aluminium plants built in recent years in developing countries have been created with

the assistance and in most cases the participation of major aluminium companies. The companies are also training and using local people to operate and administer these plants.

Possibilities through foreign governments and international agencies

102. A private company's possibilities are limited by its responsibility to invest safely and profitably in the interest of its shareholders. Certain developing countries, because of recent performance, present economic and political risks which a private company cannot take even if natural resources exist. Governments and international agencies, such as the United Nations and the World Bank, serve wider purposes and are today prepared to take greater economic risks in order to promote policies that will benefit developing countries.

103. Thus, the governments of several leading industrial countries are willing to guarantee investments made by private companies in developing countries looked upon as economically risky. Some countries, such as France and Great Britain, are actively promoting and economically assisting programmes of industrial development in their former colonies. From the standpoint of the receiving country, however, investment or guarantee by a foreign government is usually connected with political conditions or influence, whether expressed or tacitly understood.

104. International agencies are probably the most palatable foreign source of investment to a developing country; there is a minimum of political pressure and it is psychologically easier to accept aid from an organisation of which one is a member. However, international organizations have been quite limited to date in their investment capacity, and they often suffer from the bureaucracy and incompetency which can be typical of very large organizations.

Tariff barriers against developing countries

105. Tariff barriers protect the aluminium reduction industry in most industrially advanced countries, and also the alumina industry in some. Thus the United States has import duties on both alumina and aluminium, and the Common Market on aluminium. Japan is also heavily protecting its aluminium reduction industry. The Soviet Union and other centrally-planned economy countries do not allow any free imports whatsoever. These restrictions limit, and in some cases make inaccessible the most important alumina and aluminium metal markets to developing countries. This is possibly one of the most serious barriers against development of an alumina or aluminium reduction industry in many underdeveloped countries.

106. The importance of this factor is clearly illustrated by the fact that important alumina and aluminium reduction industries have been established by private companies in areas which have, besides natural resources, also duty free access to industrially developed countries. Thus Alcoa has developed an integrated alumina-aluminium industry in Surinam, and Péchiney with Ugine an aluminium reduction plant in the Cameroons; both countries have free access to the European Common Market through associate membership.

107. Actually there is little or no justification for alumina tariffs. Most of the industrially developed countries are highly deficient in bauxite, and it is more economical to process bauxite close to its source. The alumina tariffs in industrially developed countries with no bauxite or comparatively small bauxite resources such as the United States, Japan, Germany, Italy and Great Britain, have therefore contributed to the lack of development of bauxite countries.

108. The case of the United States must come under particular scrutiny because of its importance as the world's largest importer of raw materials for the aluminium industry. The United States imposed for years a duty of 1/4 cent per pound alumina (equal to $US 5.50 per metric ton) and built up a huge alumina industry behind this tariff wall. The duty was temporarily suspended in 1957, when Harvey entered into a long-term alumina contract with a Japanese supplier; since then, United States companies such as Intalco and Conalco have been increasingly dependent on imported alumina and it is therefore unlikely that this duty will be reimposed - although the notion that it is formally only temporarily suspended creates a climate of uncertainty for any alumina project in a developing country, based on export to the United States. In this connexion it is interesting to note that until Alcoa very recently built an alumina plant in Surinam, United States companies had not built a single alumina plant in the Caribbean area or in South America, where they, however, mined bauxite on a huge scale.

109. In Europe the situation is no better. Great Britain and Switzerland have import duties on alumina, and the European Common Market has decided on a common outside tariff of 11 per cent *ad valorem*, as from 1968 (unless the Kennedy Round agreement resulted in a reduction). Japan has also followed a policy of producing all of its alumina requirements within its own borders, thereby preventing the establishment of alumina industries in such countries as Malaya and Indonesia, its traditional bauxite suppliers. Only quite recently Japan broke this rule when Mitsubishi entered into a long-term contract for alumina supply from Australia; this, however, was due to the Australian Government's firm stand concerning production of alumina in Australia as a condition for granting bauxite mining concessions.

110. The Soviet Union is the world's second largest aluminium producer and has very little good quality bauxite within its borders. The Soviet Union should therefore have been a natural and large market for alumina which could have helped developing countries to build up alumina industries. However, the Soviet Union has followed a policy of self-sufficiency based on less economic substitute raw materials, such as nepheline; the modest imports of bauxite and alumina have come from Greece and Hungary.

111. Major aluminium producing countries with duty free imports of alumina are Canada and Norway. Alcan, the major Canadian producer, built alumina plants in Jamaica and Guyana some time ago and has been expanding ever since, although the company still operates its original alumina plants in Arvida, Quebec. Norway, on the other hand, does not offer an easily accessible alumina market for developing countries because the Norwegian aluminium industry is largely controlled by large international companies (Alcan, Alcoa, Alusuisse, Reynolds and Harvey) providing alumina from their own sources.

112. Primary aluminium is protected to an even greater degree by import duties in the advanced industrial countries where the large aluminium markets are. The United States' duty is 1.25 cents per pound (5 per cent *ad valorem* at the present price); the European Common Market outside tariff will be 11 per cent *ad valorem* from 1968 (unless reduced by the Kennedy Round) and the Japanese duty is 13 per cent *ad valorem*. Of the important markets, only Great Britain allows duty free import. In this connexion it is interesting to note that some developing countries are charging excessive import duties, although they do not even produce aluminium themselves in some cases; thus Brasil and Indonesia charge 50 per cent *ad valorem*, and India 45 per cent (35 per cent duty plus 10 per cent surcharge).

113. Fabricated products such as strip, sheet, tube, rod, wire and extruded shapes are the most protected aluminium products. Import tariffs amount to 2.5 cents per pound in the United States, 15 per cent *ad valorem* in the European Common Market (from 1968), 20 per cent in Japan, 12.5 per cent in Great Britain, and 50 to 140 per cent in some developing countries such as Brasil, India and Indonesia.

114. Tariffs on aluminium metal are also in many cases obsolescent because the availability of electric power cannot keep up with the rapidly increasing demand in industrially developed countries. Thus Switzerland, France, Great Britain, Germany and Japan have no cheap power sources left and must actually in some cases now deny power to aluminium plants because of increasing demands for general distribution and for industries which can afford to pay more for power than the aluminium industry. It seems illogical that these countries should try to keep out metal from

countries which can potentially provide it in abundance and at low cost. This situation could change easily if the aluminium reduction industry can be expanded economically in industrially developed countries on the basis of nuclear power. This development, which seems probable today, is therefore a serious threat to developing countries that wish to establish an aluminium industry, as already explained.

Table 1

World production of bauxite

(thousand tons, gross weight)

	Average [illegible]	Average [illegible]	1959	1960	1961	1962	1963	1964	1965
Commonwealth									
Jamaica a/	380	4,496	5,186	5,745	6,663	7,493	[illegible]	7,780	8,514
Guyana	2,450	2,141	1,674	2,471	2,374	3,036	2,343	[illegible]	2,638
Australia	5	19	15	69	36	89	[illegible]	784	1,360
Malaysia b/	97	483	509	737	663	575	[illegible]	[illegible]	[illegible]
India	64	176	315	381	468	548	[illegible]	[illegible]	[illegible]
Ghana	184 c/	164 c/	148 c/	198 c/	201	239	[illegible]	[illegible]	[illegible]
Sierra Leone	-	-	-	-	-	-	[illegible]	[illegible]	[illegible]
Rhodesia	-	-	-	-	-	1	2	2	2
Pakistan	-	2	2	1	-	-	-	-	-
Total	2,989	7,482	7,768	9,595	10,385	11,962	11,106	12,591	14,409
E.E.C.									
France	1,032	1,609	1,729	2,038	2,190	2,106	1,973	2,395	2,680
Italy	207	291	290	305	302	304	264	236	240
Germany (Fed.Rep.)	5	4	4	4	4	5	4	4	5
Total	1,243	1,904	2,023	2,347	2,586	2,433	2,241	2,635	2,855
Other countries									
Surinam	2,751	3,257	3,376	3,400	3,351	3,202	3,453	3,986	4,330 e/
Guinea	154	516	296	1,170	1,739	1,427	1,638	1,652	1,640
United States a/	1,996	1,659	1,700	1,998	1,208	1,369	1,525	1,601	1,655
Yugoslavia	464	842	802	1,029	1,213	1,311	1,265	1,373	1,530
Greece	206	769	904	870	1,102	1,300	1,361	1,046	1,280
Dominican Republic a/	-	183 d/	489	676	737	695	761	887	867
Indonesia	413	308	381	309	413	484	485	638	600 e/
Haiti a/	-	219	255	268	263	370	327	373	380
Brazil	19	76	95	119	110	108	167	130	150
Others this group	24	33	35	33	28	29	36	22	23
Total	5,487	7,872	8,263	9,934	10,204	10,345	10,938	11,468	12,674
Total of above groups	9,709	17,278	18,054	21,876	23,085	24,720	24,285	26,694	30,088
Soviet Union e/	800	2,620	2,990	3,450	4,000	4,200	4,300	4,300	4,700
Hungary	944	1,080	923	1,171	1,334	1,445	1,360	1,464	1,485
China e/	-	175	300	350	400	400	400	400	400
Rumania	12	63	70	67	68	30	10	7	12
Total	1,835 f/	3,880	4,285	5,060	5,800	6,075	6,050	6,170	6,595
World total	11,625 f/	21,160	22,300	26,935	28,885	30,795	30,335	32,865	36,595

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a/ Dried bauxite equivalent.

b/ Of which Sarawak

1962	1963	1964	1965
285	155	150	136

c/ Exports.

d/ Average 1959-60; production started in 1959.

e/ Estimated by the U.S. Bureau of Mines.

f/ Excluding production in China, if any.

[illegible]

[illegible]

([illegible])

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]									
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	-	[illegible]	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	-	-	-	-	-	-	[illegible]	[illegible]	[illegible]
[illegible]	8	[illegible]	[illegible]	[illegible]	[illegible]	173	133	93	[illegible]
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	([illegible])
[illegible]									
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	-	-	-	-	-	1	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]									
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13	[illegible]	[illegible]	[illegible]
[illegible]	75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	75	[illegible]	([illegible])
Total	[illegible]	3,773	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]
[illegible]

Table [illegible]

World estimated imports of bauxite

(thousand tons, gross weight)

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Commonwealth									
Canada a/	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
United Kingdom	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Australia	-	[illegible]	67	[illegible]	[illegible]	70	[illegible]	1	[illegible]
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Europe									
Germany (Fed.Rep.)	638	1,152	898	1,300	1,539	1,300	1,404	1,507	1,640
Italy	145	303	233	276	[illegible]	[illegible]	[illegible]	373	[illegible]
France	3	33	44	60	110	100	100	144	135
Others	2	10	24	11	10	7	13	9	[illegible]
Total	788	[illegible]	1,199	1,648	1,985	1,765	[illegible]	[illegible]	[illegible]
Other countries									
United States b/	[illegible]	7,172	[illegible]	[illegible]	[illegible]	10,695	9,863	[illegible]	[illegible]
Japan	[illegible]	604	847	1,077	1,130	[illegible]	1,309	[illegible]	[illegible]
[illegible]	[illegible] c/	33	38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	3	87	9	[illegible]	[illegible]	[illegible]	65	[illegible]	[illegible]
[illegible]	30	34	35	[illegible]	30	[illegible]	[illegible]	30	[illegible]
[illegible]	14	13	13	6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	5	5	-	10	[illegible]	13	13	17	[illegible]
Others this group	9	23	85	47	60	51	[illegible]	35	[illegible]
Total	3,786	[illegible]	9,169	10,073	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Soviet Union d/	[illegible]	[illegible]	447	[illegible]	[illegible]	303	[illegible]	[illegible]	[illegible]
Czechoslovakia e/	38	[illegible]	[illegible]	[illegible]	351	363	[illegible]	[illegible]	([illegible])
East Germany	162 f/	234	251	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Poland	6 f/	[illegible]	24	35	59	[illegible]	59	79	([illegible])
Total	607	885	964	986	1,117	[illegible]	[illegible]	[illegible]	([illegible])
World total	7,580	12,615	13,435	15,450	[illegible]	[illegible]	[illegible]	17,535	[illegible]

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a/ The share of bauxite in Canadian combined imports of bauxite and alumina has been estimated for the years [illegible]-63 from the export statistics of supplying countries. From 1964 the figures are official imports.

b/ Partly dried and partly calcined.

c/ Average 1950-54.

d/ Figures comprise exports to the Soviet Union from Hungary 1949-55 inclusive and in 1965, and Soviet imports from Greece from 1955 onwards.

e/ Imports to the country concerned from Hungary and Yugoslavia.

f/ 1949 only.

Table [illegible]

[illegible]

([illegible])

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]									
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	-	-	-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	-	[illegible]	-	[illegible]	-	-	-	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]									
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] ([illegible])	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]									
[illegible]	-	[illegible]	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	-	-	-	-	-	[illegible]
[illegible]	[illegible]	[illegible]	-	-	-	-	-	-	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]

(Thousand tons, gross weight)

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]									
[illegible] a/	16.0	102.0	362.0	405.0	590.0	630.0	660.0	777.7	[illegible]
[illegible]	(–)	0.6	0.4	0.4	0.6	10.2	36.5	71.4	[illegible]
[illegible] b/	–	0.5 c/	6.1	7.1	6.7	5.0	4.0	5.0	[illegible]
[illegible]	(–)	3.5	18.3	16.5	16.9	17.3	4.6	8.3	1.0
Total a/	16.0	102.3	[illegible]	431.0	[illegible]	660.5	704.4	[illegible]	[illegible]
[illegible]									
Germany (Fed.Rep.)	–	0.7	0.1	1.0	35.5	35.0	38.3	30.2	27.6
[illegible]	0.1	7.4	0.2	41.0	113.0	160.9	165.7	[illegible]	[illegible]
[illegible]	7.4	[illegible]	[illegible]	9.6	5.0	9.4	16.2	16.0	[illegible]
[illegible]	1.3	[illegible]	7.8	7.8	7.6	7.8	7.7	6.0	[illegible]
Italy	0.1	8.6	0.9	0.7	1.1	4.9	5.0	4.9	2.7
Total	8.9	[illegible]	[illegible]	[illegible]	160.0	[illegible]	[illegible]	146.0	[illegible]
[illegible]									
[illegible]	90.3	282.7	[illegible]	[illegible]	[illegible]	[illegible]	417.5	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	75.0	[illegible]	167.7	171.7	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	151.8	[illegible]	[illegible]
[illegible] a/	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.8	[illegible]	130.2
[illegible]	7.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	90.5	90.5	213.7
[illegible]	–	[illegible] b/	[illegible]	73.6	[illegible]	83.3	123.0	90.6	83.6
[illegible]	16.0	[illegible]	30.1	31.2	25.7	30.9	36.5	67.2	60.8
[illegible]	–	–	–	–	0.3	0.2	40.1	40.3	34.8
[illegible]	1.3	4.3	6.1	6.3	1.6	1.8	21.4	36.8	46.7
Others this group	0.5	16.3	16.9	15.3	14.0	21.0	15.7	26.2	(85.0)
Total	[illegible]	[illegible]	770.9	797.9	943.4	1,046.5	1,226.0	1,336.4	1,487.0
Poland	4.0	44.5	48.0	53.0	86.0	106.9	87.5	91.8	80.0
[illegible] a/	21.9	5.8	–	–	–	–	–	44.0	(80.0)
[illegible]	4.1 h/	20.6	16.7	25.5	20.8	16.7	18.0	41.5	[illegible]
[illegible] g/	14.5	33.1	22.0	21.7	21.7	17.7	14.8	15.1	(15.0)
[illegible] f/	–	0.9	1.8	1.1	–	–	0.9	0.8	(–)
Total	46.0	104.9	83.5	101.3	128.5	141.3	121.2	193.2	([illegible])
World total	305	995	[illegible]	1,395	[illegible]	2,100	2,275	2,530	2,535

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a/ The share of alumina in Canadian combined imports of bauxite and alumina in [illegible] has been estimated from the export statistics of the supplying countries. From [illegible] the figures are official imports.
b/ [illegible] to and including [illegible].
c/ [illegible]
d/ [illegible]
e/ [illegible] imported into [illegible] in [illegible], [illegible], [illegible] and 1954.
f/ [illegible] exports to [illegible], Germany (Fed. Rep.) and Italy.
g/ Imports to the country concerned from Hungary, Germany (Fed.Rep.) and Yugoslavia.
h/ Average 1951-54.

Table [illegible]

World production of primary aluminium

(thousand tons)

	[illegible]	[illegible]	1959	1960	1961	1962	1963	1964	1965
[illegible]									
Canada	400.6	540.3	510.0	600.4	598.1	616.3	648.3	730.7	760.9
[illegible]	-	9.2	11.4	11.7	11.8	16.2	41.3	70.7	85.4
India	3.9	10.8	17.8	18.0	18.1	16.8	50.5	51.7	[illegible]
United Kingdom	25.7	25.9	24.5	28.9	30.3	34.0	30.6	31.7	35.6
Total	[illegible].1	600.2	5[illegible].0	718.9	655.7	701.2	766.7	986.0	9[illegible].1
[illegible]									
France	[illegible].3	144.6	17[illegible].3	234.7	273.0	[illegible].8	2[illegible].7	3[illegible].0	3[illegible].1
Germany (Fed.Rep.)	7[illegible].7	[illegible].8	[illegible].6	168.3	160.6	175.0	[illegible].5	[illegible].4	23[illegible].5
Italy	4[illegible].6	61.0	73.8	83.3	80.0	80.0	90.1	113.2	[illegible].0
Total	[illegible].6	[illegible].4	[illegible].9	481.3	5[illegible].9	544.0	5[illegible].2	6[illegible].6	6[illegible].7
[illegible]									
United States	[illegible].4	1,[illegible].6	1,[illegible].7	1,790.7	1,699.7	1,891.0	2,064.8	2,[illegible].2	2,[illegible].4
Japan	[illegible]	81.6	[illegible].6	111.1	151.3	168.7	[illegible].4	[illegible].6	[illegible].3
[illegible]	[illegible]	[illegible].5	[illegible].6	162.2	168.8	202.6	215.1	2[illegible].2	271.6
[illegible]	[illegible].7	[illegible]	[illegible].5	66.9	66.6	78.9	75.2	76.5	77.5
[illegible]	[illegible].0	[illegible].3	31.8	30.1	41.5	48.8	60.2	63.2	66.1
[illegible]	3.4	17.8	[illegible].3	28.3	37.1	44.0	44.8	[illegible].9	[illegible]
[illegible]	-	[illegible]	[illegible].6	41.2	46.8	56.4	50.1	[illegible].7	40.7
[illegible]	8.6	[illegible].1	[illegible].9	24.7	27.0	27.5	35.3	[illegible].2	[illegible].7
[illegible]	7.1	11.3	[illegible].6	18.7	15.6	15.9	27.8	33.0	[illegible].1
[illegible]	6.7	16.7	17.8	17.9	19.7	19.8	27.3	[illegible].2	[illegible].1
[illegible]	3.6	7.9	7.4	8.1	8.9	10.8	11.7	19.1	[illegible].6
[illegible]	-	-	-	-	-	-	5.2	17.4	18.9
Total	1,[illegible].7	1,9[illegible].1	2,[illegible].9	2,335.9	2,283.0	2,550.4	2,8[illegible].5	3,151.2	3,[illegible].6
Total above groups	1,[illegible]7.4	2,910.7	3,104.8	3,550.1	3,465.6	3,796.4	4,176.4	4,720.6	5,[illegible].4
Soviet Union b/	200.0	530.0	615.0	665.0	8[illegible].0	890.0	950.0	9[illegible].0	1,060.0
China c/	0.5	35.0	60.3 c/	80.0	100.0	100.0	100.0	100.0	100.0
[illegible]	3.0	26.8	35.6	30.4	49.2	49.2	5[illegible].0 d/	59.0 d/	62.0 d/
[illegible]	28.5	30.1	44.9	4[illegible].8	50.3	51.9	54.6	56.0	57.[illegible]
[illegible]	0.[illegible]	22.0	[illegible].4	25.6	46.9	47.3	4[illegible].9	47.0	46.6
East Germany b/	[illegible] a/	33.5	34.0	39.0	39.0	37.0	3[illegible].0	40.0	4[illegible].0
Total	275	605	810	900	1,170	1,175	1,250	1,[illegible]	1,5[illegible] d/
World total	1,965	3,605	3,995	4,455	4,635	4,970	5,425	5,[illegible]	6,[illegible]

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a/ [illegible] production started in 1957.
b/ Estimated by the U.S. Bureau of Mines.
c/ [illegible] production.
d/ Including Rumania [illegible].

[illegible]
[illegible]

Table 2

[illegible]

(thousand tons)

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]									
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	-	-	-	[illegible]	[illegible]	[illegible]
Total [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]									
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]									
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
World total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible] figures started in [illegible].

[illegible]

Table [illegible]

[illegible]

(thousand tons)

	Average [illegible]	Average [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]									
United Kingdom	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	[illegible]	270.4	[illegible]	[illegible]	275.0	345.1	[illegible]	395.0	[illegible]
[illegible]									
Germany (Fed. Rep.)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Netherlands	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	[illegible]	161.9	[illegible]	[illegible]	286.0	290.0	314.2	[illegible]	[illegible]
[illegible]									
United States	[illegible]	[illegible]	[illegible]	[illegible]	177.0	377.6	371.4	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	[illegible]	[illegible]	376.5	476.4	378.6	571.9	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	97.6	[illegible]	[illegible]
World total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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a/ [illegible]

b/ [illegible] and [illegible] for the Soviet Union the figures exclude imports

c/ [illegible]

d/ [illegible]

e/ [illegible]

f/ [illegible]

g/ [illegible]

h/ [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[redacted]

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