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First Consultation on
the Non-Ferrous Metals Industry

Budapest, Hungary
30 November - 4 December 1987

Issue Paper II

TECHNOLOGICAL ALTERNATIVES IN THE NON-FERROUS METALS INDUSTRY*

Prepared by
the UNIDO Secretariat

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CONTENTS

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Corrigendum

Page 16

The first line of the source should read Directory of Research and Development Institutions

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1. Introduction

It is obvious that the socio-economic conditions, the quality of the ores and availability of production inputs (e.g. energy, infrastructure, skilled labour, capital) is very different in developing countries from the relevant conditions in developed countries. Therefore, the technological options considered as being the more suitable for developed countries might not be the most advantageous for developing countries. This might particularly be the case when analysing the options related to the size of the plant.

The apparent advantages in constructing an optimum-size plant are often not realized in developing countries. Among the specific difficulties which often arise in large projects are the following:

(a) time of construction for large plants is usually longer, with higher costs and greater difficulties in arranging utilities, ancillary facilities and infrastructure than small plants;

(b) large plants tend to experience more technical operating problems than small plants, maintenance may be more problematic, and technological rigidities are more likely to occur;

(c) operating rates tend to be lower in large plants than in smaller units, thus increasing average fixed costs;

(d) great dependence, in general, on exports to the world market at a time of decrease or slow growth of world demand, as well as price deterioration;

(e) large plants present less flexibility in the process of integration of the non-ferrous metals sector with the other sectors of the economy at the national and regional levels.

(f) large plants demand important investment and financial resources, at a time in which many developing countries have debt problems.

The rapid technological change occuring in some mineral processing industries also has implications for developing countries' ability to establish processing facilities. Certain developments, such as the production by continuous casting of aluminium sheets and strips, permit the construction of plants on a much smaller scale than was previously thought economical, opening the way for processing for internal consumption in many developing countries.

On the other hand, new developments such as continuous casting in copper have the effect of making it more difficult for producers located at considerable distances from major markets to compete effectively.

There are however other aspects to be considered in the selection of a technology such as the quality of the ore, the price of the energy, the transportation costs and the possibilities of increasing the surplus of foreign currency to develop key sectors of the economy.

2. Existing and emerging new technologies in the non-ferrous industries 1/

According to their socio-economic conditions, developing countries should take full advantage of the technological improvements to make better use of their resources and attempt a more integrated development at the national and regional levels. In this context special emphasis has to be given to the analysis of technological alternatives for the fabrication of semis and finished products.

2.1 Production of non-ferrous metals up to refinery

From production up to refinery there are some technological developments that should be taken into account in order to improve the productivity of present installations or in new projects.

In order to decrease production costs, particularly energy costs, the conventional copper sulphide flow sheet has undergone significant changes since the 1970's: increasing the size in mining and milling equipment for economies of scale; introduction of column-flotation in the field of concentration for the separation of different minerals, basically in the copper industry and for by-product molybdenum recovery; and intensification of chemical, pyro-metallurgical processes by injection of oxygen through which reactions are speeded up, the capacity of furnaces increases and the products are obtained at a lower cost.

A particularly convenient technology has been developed for treatment of sulphide and oxice ores by hydro-metallurgical means, which avoids expensive traditional concentrating and smelting steps with all their impact on the environment. Several countries are interested in the improvement of the technology of processing polymetallic copper-containing ores.

The extraction of bauxite, its refining into alumina as well as the production of the metal by electrolysis are well established technologies. Although a steady improvement of these processes is taking place, fundamental changes are not expected before the end of this century. The new technological developments are aimed at decreasing the cost of energy as well as for a better exploitation of capital goods due to their increasing cost.

In the lead and zinc industries, which handle higher grade and more complex ores, but on a smaller scale than copper, significant improvements in technology are visible not so much in the concentrating stage, where classical technologies and flotation concentration are practically and conveniently adjusted to every specific ore and its metallurgical problems, but rather in the pyrometallurgical stage. Here, apart from specific processes for individual treatment of each metal, alternatives exist for a collective treatment of bulk concentrates to improve considerably overall metal recoveries and costs. The high complexity of these ores and significant difficulties in separation of individual metals by differential flotation, generally result in high metal losses. Thus, processes such as the Imperial Smelting and Sulphate Roasting Process attract increasing attention.

1/ Annex I presents the different technological alternatives for the non-ferrous metals.

New pyrometallurgical technologies also include the Sherritt Pressure Sulphuric Acid (PSA) leach process, the emerging Kivcet process from the USSR, the Outokumpu Process (OKP) from Finland, the QSL process from Germany, etc.

All these processes should be given due attention with the idea that even if not all individual developing countries are in a position to install their own plants, they can conveniently agree on some regional plants which will handle their combined production with a higher efficiency.

Tin is now experiencing difficult times in view of the collapse of the International Tin Council and the sharp drop in tin prices. One way to cope with these problems is to concentrate on more economically effective methods. In this respect, a relatively cheap and effective method of flotation for tin fines is brought to attention. Also, the fuming process has received increasing consideration because of its more effective possibilities to eliminate impurities and increase recoveries into final product.

In nickel the technological improvements are oriented towards increasing energy saving and the rate of metal recovery. In this respect special attention should be given by developing countries to the new developments that are emerging in the hydrometallurgical processes, in particular to the treatment of limonite-type lateritic ores with sulphuric acid.

2.2 Production of semis and finished products of aluminium and copper

The production of semis and finished products seems to be a key aspect for developing countries, due to the flexibility in the sizes of the plants and many possibilities to increase the horizontal integration at the national and regional levels.

Sizing of semi-production lines is a complex question. There are certain semi-products for which the transport is only economical within a very limited area. Fortunately, many semi-products can be produced in relatively small-sized plants. In the case of aluminium, this is typical for extruded products. Rolled aluminium products on the other hand are transportable even to long distances, but the size of their economic production is much larger. The size of economic rolling mills - including hot-rolling - is at least 40,000 tpy. Cold rolling mills could be of a smaller size than the hot ones. Cast-rolling units could be smaller, even 10,000 tpy units might be viable. Such production lines operate, however, advantageously in conjunction with a smelter, and the spectrum of the semis production with this type of equipment is narrower than with the usual rolling mills, and the fabrication of some high-alloyed aluminium products is not possible. It is ideal to have hot and cold rolling mills at the same place, otherwise an intermediate product has to be shipped to the cold mill, but it is also a common practice to set up cold mills processing coils.

In many developing countries there are great possibilities of producing finished products of non-ferrous metals. As examples we can mention wire and cable manufacturing, facilities producing kitchenware and other utensils, containers and certain non-ferrous products for the building industry.

Regarding the selection of main technological systems for the production of copper semis the following might be taken into consideration:

a) continuous casting processes, due to their low energy consumption and capital investment, decreased environment pollution, flexible production capacity, high productivity and high product quality;

b) wire rod production technology should be matched to the local or regional demand;

c) cold rolling mills equipped with hydraulic screwdown and automatic thickness regulation. Hot mills should be selected only for very high demand or special cases;

d) indirect presses offer a number of advantages, but at present horizontal direct presses are more flexible regarding the product mix. Having a suitable extrusion press, lower demand for wire rod can be temporarily covered by compromising on the size of the coils;

e) technological route for copper tube manufacturing should be selected on the basis of several factors. In a plant having free capacity on a cold rolling mill, welding tubes from strip and drawing them on skinner blocks could be a good solution. In the case of a plant having free capacity on the exisiting extrusion press, reduction on drawing benches can be a optimal solution offering a very wide product mix. One of the most efficient ways for the production of medium and small size tubes is the continuous casting - pilger rolling - spinner block drawing;

f) when establishing copper and copper-alloy or aluminium and aluminium alloy semifinished product manufacturing, special emphasis has to be put on recycling production and collected scrap. The better the scrap is separated the higher is its value. High economy can be achieved using every scrap for its proper purpose.

3. Main directions of research and development activities

In the context of the most promising areas for technological development in developing countries, the main lines of research seem to be those related to:

a) better use of polymetallic resources whenever appropriate with possible extraction of all useful components;

b) energy savings and the handling of materials in mining operations;

c) energy savings and processing efficiency increments in comminution operations, including semi-autogenous grinding and cyclone classification;

d) substantial improvements in flotation technology through greater volume flotation cells, introduction of new types of flotation cells, such as column cells, and improved reagent formulae;

e) greater use of hydrometallurgical, energy and capital saving technologies as reflected in bacterial leaching, solvent extraction and electrowinning technologies;

f) introduction of processes which perform conversion of the metal content of minerals, both of sulphide and non-sulphide character, into the metallic state with the lowest consumption of energy, as for example in the SX/EW and segregation processes;

g) improvement of the effectiveness of the Bayer alumina production technology through better adjustment of digestion and precipitation where appropriate, intensification of red-mud washing in order to reduce caustic consumption and produce a mud less harmful to the environment;

h) greater emphasis on byproduct recovery in all phases of base metals production, including flotation separation, hydrometallurgical, pyrometallurgical and electrometallurgical separation. A number of important metals, such as gold, silver, molybdenum, cobalt, bismuth, selenium and rhenium, gallium and vanadium, can serve as valuable byproduct credits to reduce production costs of base metals. Also, non-metallic components such as sulphur and arsenic may be recovered at a profit;

i) organization of the processing and better valorization of intermediates. If appropriate, manufacturing of the following products, e.g.: artificial white bauxite; special aluminas; abrasive and refractory materials on alumina basis; different metal compounds sulphates, oxides, etc.; aluminium 99.99. Organization of collection, processing and use of recycled metals;

j) introduction of modern oxygen technology in base metals smelting in all its possible forms, with a clear aim towards optimization of results both economically and capacity-wise;

k) realisation of systematic cost reduction in the existing aluminium smelters through improved control of electrolyte composition, temperature, and cell operation;

l) possibilities of production of a broader spectrum of semis from aluminium and copper alloys through continuous casting;

m) reconstruction of existing rolling mills and equipping them with hydraulic screw-down system, electronic drive regulating circuits, automatic thickness and shape control and regulation;

n) confection of studies related with optimization of scale of operations for a determined process or technology, which can come from economy of scale or through miniaturization of plants more in accordance with national necessities and possibilities. Design of appropriate equipment, particularly for the production of semis;

o) systematic study of potential advantages for expansion of existing facilities through improved and intensified technologies versus construction of new plants.

Practical implementation of new technologies in the non-ferrous based metals area in developing countries will require a rather complex and imaginative combination of work at existing research facilities, universities and national research centres, along with work at industrial-type research organizations and engineering firms.

Several high-standard research and development institutions are operating in developing countries in the non-ferrous metals industries 2/. Their contribution can be relevant to the introduction of new technologies in the industrial practice; particularly the assessment of the viability of new processes and technology might be important.

4. Final considerations

The strategies of development as well as the financial constraints define in a certain way the main lines for the selection of the technologies.

Within the framework of the above and that which has been presented in this issue, it would be of special interest for the participants of this meeting to discuss, among others, the following:

a) technological improvements to increase the productivity of the existing production facilities of non-ferrous metal products. In this context, special emphasis should be given to the analysis of the possibilities of energy savings, broader application of hydro-metallurgy and processing of polymetallic ores;

b) technological alternatives for the production of semis and finished products by small and medium-size plants, which requires reasonable amounts of investment;

c) main lines of research and development to be implemented for the mastering of the non-ferrous technologies by producers in developing countries of non-ferrous metals products;

d) possible programmes of co-operation between developed and developing countries and among developing countries that could contribute to: the increase of productivity of existing facilities in developing countries; installation of new capacities for the production of semis and finished products; and the mastering of the non-ferrous metals technologies by developing countries.

2/ See Annex 2 where research and development activities in the field of non-ferrous metals in Latin America, Africa and Asia are presented.

CHARACTERISTICS OF THE MAIN TECHNOLOGICAL PROCESSES USED IN THE NON-FERROUS METALS INDUSTRIES

1. Aluminium

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

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

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

Size of units plays an important role in the economy of production. The size of an alumina plant has grown from 120,000-150,000 tpy to a line capacity of 300,000-500,000 tpy. Hence plant capacities often reach or surpass 1 million tpy. On the other hand, smelters nowadays are built with capacities of about 100,000 to 300,000 tpy, the actual capacity depending on the line capacity.

The development in semi-products' fabrication tends to be more dynamic. Although the basic production methods have been well-known for decades, the efficiency of these processes as well as the production of products with increased quality parameters lie steadily in the fore of recent development. Sizing of semi-production lines is a complex question. However in general they can operate economically at relatively small size plants.

Approximate optimum capacities for the large-scale manufacture of some selected finished items are dealt with in Table 1.

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

TABLE 1: ECONOMICALLY FEASIBLE MINIMUM SIZE OF FACILITIES AND THEIR INSTALLATION COSTS (smelting = 100)

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

2. Copper

Most copper today is processed by mining, waste leaching and cementation, concentrating, smelting, and refining. Open-pit mining is more common than underground mining and overburden or waste contains some copper. Frequently the waste is leached to extract the copper, which may be recovered by passing the leach solution through a bed of scrap iron, precipitating metallic copper, and dissolving the iron; the last operation is called cementation.

The copper ore from the mine, often containing less than 1% copper, is transported to the concentrator where it is first crushed and then ground with water. The ground ore slurry enters flotation cells, where copper concentrates are collected as a froth. Following dewatering, they enter the smelter. In the smelter the sulfide minerals react with oxygen and fluxes to produce impure copper metal, SO_2, and slag. Smelting occurs in two steps.

In the reverberatory furnace, the copper concentrate is melted to produce matte, the mixed sulfides of copper and iron. Next, air is blown through the matte in the converters, producing impure copper plus a slag containing the iron. The impure copper is then cast into anodes and purified by plating onto pure copper in an electrolytic tankhouse.

Other hydrometallurgical processes include the direct leaching of ore followed by recovery of copper by cementation or electrowinning. Recently, however, hydrometallurgical treatment of concentrates in lieu of smelting is being developed in order to avoid the high cost of environmental control facilities required for new smelters.

In order to decrease production, particularly energy costs, the conventional copper sulphide flowsheet consisting of crushing, grinding, flotation, dewatering, smelting and refining, underwent very significant changes since the mid seventies with the following main trend.

Escalation of size in mining and milling equipment to bring about reductions in operating and maintenance costs (the so-called economies of scale); intensification of chemical, pyrometallurgical processes by injection of oxygen, by which reactions were sped up and capacity of furnaces increased; replacement of expensive pyrometallurgical processes with high energy consumption by less expensive hydrometallurgical processes which promote chemical reactions at lower temperatures and with a more thorough treatment of materials.

In mining, technological improvements range from improved and more efficient explosives to more accurate and greater mobility drills. In mine ore handling systems, improvements have ranged from in-pit movable crushers to development of fleets of giant trucks and change to large tonnage transportation (away from trains and trucks) and huge conveyors.

Comminution operations account for over 50% of overall milling (crushing-grinding-classification-concentration-dewatering) costs. Classification operations generally include intermediate comminution operations after removal of material already reduced to a specified size.

In this respect, in the last two decades a fundamental change in classification technology has been taking place almost universally by replacing rake and bowl classifier technology with hydrocyclones. The tremendous advantages of hydrocylones are their effective classification and separation of fines, low consumption of spare parts, very small size of equipment, permitting to double grinding capacity under the same roof, and their easy adaptation to automatic controls of the grinding circuit.

Autogenous grinding is the grinding of ore by itself rather than by special metallic or nonmetallic grinding bodies distinct from the ore. However, autogenous grinding by itself is not always successful for crushing and grinding big chunks of rock, due to a deficiency in the rock media, or when frequent changes in quality of media occur. In this case in order to assure smooth operation, large steel grinding balls are added in quantities between 2% and 10% of the total volume. Currently, most of such semi-autogenous mills carry less than 5% by volume of such steel balls, while the traditional ball mills use a 45% by volume ball charge. In most porphyry copper operations today, which treat large tonnages between 20,000 and

150,000 tons per day, semi-autogenous mills replace secondary and tertiary crushing and the rod mill grinding stage.

In the area of concentration, a technologically new system for replacement of traditional flotation cells was developed recently in Canada. This is the so-called column flotation. The idea offers a number of advantages in the separation of different minerals, particularly in the copper industry and in the area of byproduct molybdenum recovery.

The principal characteristic of this column is that it has no moving parts, and solids are kept in suspension by rising bubbles alone.

Hydrometallurgy, in particular the leaching technology, proved to be a safe, efficient and cost effective method for a number of metals, which include copper, gold and uranium. These chemical processes can be carried out in a number of ways, starting with in situ leaching, when fragemented and fractured material is not excavated, or by the heap leaching method when the broken rock is dumped on specially prepared pads and sprinkled with leach liquors which are conveniently recirculated. Leaching can also be carried out at atmospheric pressure or in closed vessels at elevated temperature and pressure. It can be purely chemical, using acid, caustic soda or cyanide, or biological using particular strains of bacteria. The bacteria do not actually leach the materials but rather render them amenable to subsequent chemical leach by speeding up the oxidation of the sulphide minerals.

Leaching is a relatively cheap and simple technology, easy to introduce since it requires little in the way of sophisticated equipment. Leach liquors obtained either by in situ, heap, vat or agitation leaching, are conducted for purification to a solvent extraction unit and then subjected to reduction to the metallic state by electrowinning (to copper cathode).

While sulphide ores can be cheaply leached by ferric solutions helped by bacterial leaching technology, with oxides treated by more conventional acid leaching, the new solvent extraction technology gives a possibility to effectively clean such solutions for their final electrowinning step to produce high-purity (99.9% Cu) cathode. This SX/EW technology is now highly popular in developed countries, such as the USA and Canada.

More than anywhere else, cost cutting technologies have spread in the pyrometallurgical area, where costs are high because of high energy consumption. One way to cut costs is to decrease the temperature of conversion of minerals into metal, such as is accomplished in the Segregation Process.

The other method is to intensify the process with oxygen injection, through which reactions are sped up, capacity of furnaces increases and products are obtained at a lower cost.

The most successful new smelting process is doubtlessly the Outokumpu Flash Smelting which combines roasting, melting and partial converting into a single process. When only preheated air (to 450°C) was used to supplement the heat generated by the exothermic oxidation of FeS, mattes assayed then only 45-50% Cu, and fuel oil needed to be added to finish the reaction. With the introcuction of oxygen enriched air, the process became completely autogenous and the copper content of the matte increased to 65-70%. With a higher grade of matte, the required converting capacity and energy consumption fell sharply - by as much as 40 to 50 percent. Also, addition of oxygen reduces the volume of gases and increases their SO_2 content from the normal 10-15 percent to as much as 30 percent.

The flexibility of the flash smelting process in terms of treating concentrates of varying composition and controlling matte grade is based on the fact that the degree of oxidation in suspension (flash) smelting can be regulated rapidly and easily by changing the ration of concentrate to oxygen in the process air.

Among other up-to-date copper smelting technologies the El Teniente, Inco, Mitsubishi and Noranda processes should be mentioned.

3. Lead and zinc

The complexity of lead-zinc ores has led to numerous flowsheets for rational recovery of different metal components in the different ore combinations. The major types of ores so far have been lead-zinc-copper ores, lead-zinc ores, copper-zinc ores, and lead-copper ores. the overall recovery of metals in such complex ores, when calculated on their recoverable content into a finished concentrate, rarely exceeds 80 percent. These recoveries are even lower if sulphides are mixed with oxides. In fact, flotation recoveries do not present any difficulties as far as bulk flotation concentrates are concerned. Metal losses start principally in selective flotation.

Therefore, in the treatment of complex lead-zinc sulphide ores two new basic approaches have emerged in the last few years: one, which tries to start pyrometallurgical treatment of bulk concentrates right from the beginning without previous separation of individual concentrates, and the other, which improves technologies for teatment of the individual concentrates.

In the first case, excessive loss of metals in their flotation separation is avoided, and typically 90-95 percent metal recoveries are obtained against the average 80 percent recoveries by other classical methods. The most outstanding in this respect is the Imperial Smelting Process with 13 industrial installations to its credit so far offering an overall recovery of about 95 percent of the metals. However, in some cases the Imperial Smelting Process is not quite suitable for solving all problems, and new, chemical processes are being developed for the same purpose.

In the area of direct smelting of concentrates, like with copper, there are two types of new processes in development: those which use bath smelting, such as the Boliden Kaldo (TBRC) Process, and the QSL Process. The other group of direct smelting furnaces are the flash smelting technologies as developed by Outokumpu and Kivcet.

At any rate, it should be clear that these emerging technologies still have to be convincingly proven in full scale industrial plants.

4. Tin

Under the present conditions of the tin market economically more effective methods are particularly important for this industry. Among them the fuming process and an efficient method of flotation for tin fins merit special attention.

During the 1970's, an increasing proportion of lode tin was mined, due to the gradual exhaustion of sources of alluvial tin. It has become increasingly difficult to obtain high-grade tin concentrates at a high recovery from lode material. Rather than lose an increasing amount of tin by attempting to upgrade the concentrates, there has been a trend towards the fuming processes, which give a medium grade concentrate of 40-50 percent Sn at high recovery rates of over 90 percent. This compares with 50 percent or less recovery for obtaining concentrates of about 60 percent Sn by mineral processing methods.

Fuming, in favourable cases, may replace mineral processing altogether to produce a concentrate directly from the ore. But this certainly requires high-grade ores to start with. Fuming normally requires products of 7 percent Sn and more.

In an endeavour to recover more of the fine tin produced by ever finer grinding to liberate cassiterite, particularly if this is intimately associated with sulphide minerals, flotation has been widely introduced, not merely to float sulphides away from cassiterite concentrates, but also to float cassiterite from the gangue minerals. Although the production of this flotation concentrate can boost tin recovery significantly, by 20 percent and more, the product is very low-grade, around only 20 percent Sn, and calls for new methods of treatment.

5. Nickel

The treatments used to recover the nickel from sulfide and lateritic ores differ considerably because of the ores' different physcial characteristics. The sulfide ores, in which the nickel, iron, and copper occur in a physical mixture as distinct minerals, are amenable to initial concentration by mechanical methods, eg, flotation and magnetic separation. The lateritic ores are not susceptible to these physical processes of beneficiation and chemical means must be used to extract the nickel. There are two main types of lateritic ores: limonite and serpentine containing deposits.

Pyrometallurgical Processes. Sulfide ores first undergo crushing and milling operation to reduce the material to the necessary degree of fineness for separation. Froth flotation or magnetic separation processes separate the sulfides from the gangue. Most sulfide ores then undergo a series of pyrometallurgical processes consisting of roasting, smelting, and converting.

Nickel oxide ores can also be processed by pyrometallurgy, they are smelted with a sulfiding material, e.g. gypsum, to produce an iron-nickel matte, that can be treated similarly to the matte obtained from sulfide ores.

Both types of ore can be leached with ammonia. Lateritic, limonite type ores can also be leached with sulphuric acid. Because of possibilities of energy saving and rate of metal recovery this process seems to attract increasing interest. Serpentine-type lateritic ores are mainly used for ferro-nickel production. Among possible development of nickel production technology, are plasma-smelting for the direct extraction of the metal from the ores and the use of organic solvents for the separation of nickel from solutions.

Annex 2

RESEARCH AND DEVELOPMENT IN DEVELOPING COUNTRIES

Table 1. Research and Development in Latin America

Country	Name of the institution	Resources in million US$, 1985	Activities	Staff
Argentina	INTI	0.5	Extraction of Ni and Co.	14
Brazil	CEPED	13.0	Beneficiation, biological leaching of Cu ores. Review of environmental conditions in Cu mining and ore dressing. Development of Cu alloys for coin fabrication.	160
Brazil	CETEM	2.0	Pilot plant studies of Cu, Pb and Zn ore treatment. Processing of Sn ore fines. Cu and Ni minerals bulk flottation. Electrorefining of Cu with pulsating current.	149
Brazil	CTP	0.5	Environmental control in the Cu and Ni industries.	10
Brazil	IPT de S. Paulo	0.04	Extraction of Cu from complex oxidized ores.	2,600
Chile	CIMM	2.0	Cu ore dressing and metallurgy. Au processing methods for "small mines". Separation of Mo and As. Recovery of rutile from copper tails. Hydraulic transportation systems for solid materials.	300
Chile	INTEC	1.0	Heap leaching Cu-ores, of Au and Ag Gravitational concentration and tailing recovery Cu, Au, Co, W, etc.	72
Chile	INACAP	8.5	Training on process control and automation in the copper industry.	121
Chile	Sociedad Minera Pizarro Lida	n.a.	Exploration and beneficiation of Pb deposits. Alternative Al and Pb technologies. Pb alloying.	6
Chile	Universidad de Tarapaca	0.05	Non-destructive testing, standardization and quality control of metal products.	52
Colombia	CIDI	0.12	Recovery of Zn in an iron and steel plant.	15

Country	Name of the institution	Resources in million US$, 1985	Activities	Staff
Costa Rica	Instituto Tecnologico	0.04	Extraction of Al minerals. Recycling and refining of Al alloys.	8
Ecuador	Politecnica de Litoral	0.06	Al alloying. Scrap recycling and refining. Pure Ni electroforming Zn and Cu alloys.	7
Jamaica	Jamaica Bauxite Institute	n.a.	Improving the processability of Jamaican boehmitic and goethitic bauxites.	26
Mexico	Instituto Politecnico Nacional, Esiquie, Laboratorios pesados de Ingenieria Metalurgica	0.23	Leaching of concentrates of non-ferrous metals. Substructures produced at high temperatures. Optimization of flat rolling sequences.	50
Peru	INGENMET	1.708	Exploration and evaluation of deposits (Cu, Pb, Zn, Ag); (Sn, W, Au). Problems of underground mining, beneficiation of ores. Polymetallic minerals flottation. Bacteriological leaching of Cu minerals.	75
Trinidad and Tobago	Caribbean Industrial Research Institute	6.0	Experimental casting prototype development.	60

Source: Inventory of Research and Development institutions
UNIDO, Department of Industrial Promotion, INTIB, 1987

LIST OF ABBREVIATIONS

Research Institutes

CEPED	Centro de pesquisas e desenvolvimento
CETEM	Centro de Tecnologia Mineral
CTP	Centro de Tecnologia Promon
IPT	Instituto de pesquisas tecnologicas de Estado de Sao Paulo S/A
INTI	Centro de Investigación para las industrias minerales
CIMM	Centro de Investigación Minera y Metalurgica
INTEC	Comite de Investigaciones Technologicas de Corfo
INACAP	Instituto Nacional de Capacitacion Profesional
CIDI	Centro de Investigaciones para el desarrollo integral
INGENMET	Instituto Geologico Minero y Metalurgico
CMRDI	Central Metallurgical Research and Development Institute

Table 2. Research and Development in Africa

Country	Name of the institution	Resources in million US$, 1985	Activities	Staff
Egypt	ASSIUT University Department of Mining and Metallurgy	0.15	Production of Al-Ti, Al-Si alloys. Beneficiation of nepheline-cyanite. Recycling of materials in the Al industry.	28
Egypt	CMRDI	0.7	Activation of bentonites. Cryolite regeneration. Alloy and surface protection development. Cu refining. Pb recycling.	72
Egypt	TABBIN Institute for Metallurgical Studies	1.0	Production of high quality Al castings. Corrosin resistance of Al-alloy castings. Anodizing. Heat treatment of brasses.	50
Kenya	Kenya Industrial Research and Development Institute	0.98	Analysis of metal contamination in canned fruit and vegetable products.	45
Morocco	Direction de la Geologie	2.45	Exploration of deposits of non-ferrous metals. Investigations on precious metals associated with Cu and Pb.	300

Source: Directory of Research and Development Institutions. UNIDO. Department of Industrial Promotion. INTIB. 1987.

Table 3. Research and Development in Asia

Country	Name of the institution	Resources in million US$, 1985	Activities	Staff
China	General Research Institute for Non-Ferrous Metals	n.a.	Beneficiation of ores, process and quality and environmental control, alternative technologies, manufacture of Al and Cu products. Recycling.	1,200
China	Institute of Metal Research, Academia China	3.5	Development of Al- and Ni-based alloys, copper tubes and wire. Quality control in the production of Al and Ni.	1,200
China	Shenyang Aluminium and Magnesium Research Institute	n.a.	Exploration and beneficiation of diaspore bauxite. Surface mining. Engineering for Al industry including main and auxiliary utilities for processing.	900
India	College of Engineering, Department of Metallurgy PUNE	1.8	Ni-Ti shape memory alloys. Liquid forging of Al alloys. Al/Al and Al/Cu rollbonding.	12
India	Indian Institute of Science	0.9	Mechanical alloying of Ni, Cr, ThO_2; Al alloys containing Mn and Li. Al, Cu, Zn castings. Bacterial leaching of lean sulphide ores.	350
India	India Lead PVT Ltd.	0.0126	Improvement of refining process. Desilverization. Pb-Sc, Ca-Pb alloy.	15
Indonesia	Mineral Technology Development Center, Department of Mining and Energy	2.0	Beneficiation of fine and sulphide complex ores. Flotation of galena. Production of Al-sulphate. Scope stability study on primary Sn ore.	106
Republic of Korea	Korea Institute of Energy and Resources	0.14	Origin and exploration of non-ferrous metals deposits in the country.	10
Republic of Korea	Korea Institute of Machinery and Metals	19.0	Development of Ni-base super-alloy castings for gas turbine application.	620

Country	Name of the institution	Resources in million US$, 1985	Activities	Staff
Malaysia	Geological Survey Department	5.39	Mineral exploration and assessment.	127
Pakistan	Metal Industry and Development Centre	n.a.	Development of alloys of non-ferrous metals. Melting and casting processes. Moulding sands.	7
Pakistan	Minerals and Metallurgy Division PCSIR	n.a.	Substitution of imported minerals and mineral-based products. Beneficiation of antimonial Pb ores.	34
Philippines	Metals Industry Research and Development Centre	1.2	Al, Cu castings. Electroplating.	128
Thailand	The Metalworking and Machinery Industries Development Institute	n.a.	Colours of jewellery, centrifugal casting.	7
Thailand	Regional Centre of Mineral Resources	0.027	Exploration and beneficiation of Pb, Zn, Sn, Ni ores.	9

Source: Directory of Research and Development institutions
UNIDO, Department of Industrial Promotion INTIB, 1987