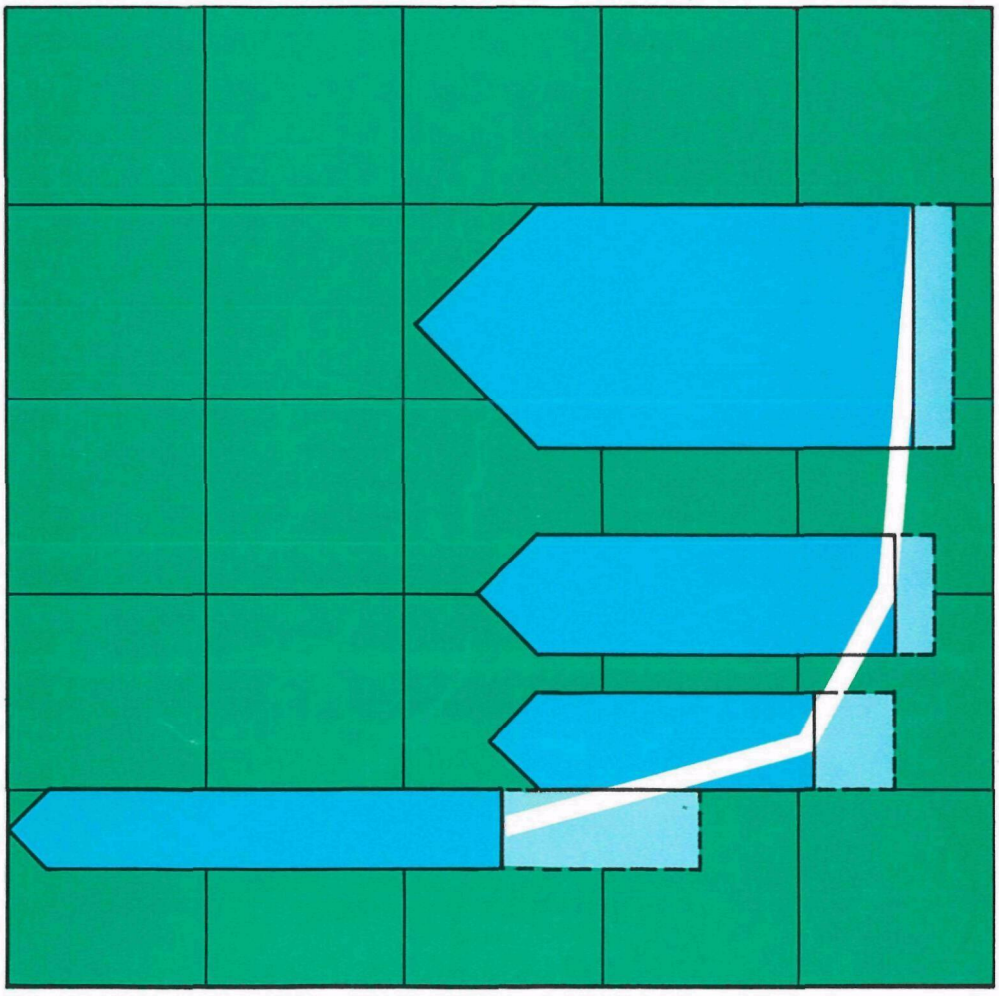
# Economic Impact of Anticipated Pollution Abatement Costs

## Primary Copper Industry

Report to
Environmental Protection Agency



Part 2 Industry Structure

Arthur D. Little, Inc.

# ECONOMIC IMPACT OF ANTICIPATED POLLUTION ABATEMENT COSTS ON THE PRIMARY COPPER INDUSTRY

Report to

ENVIRONMENTAL PROTECTION AGENCY

PART II - INDUSTRY STRUCTURE

Arthur D Little, Inc.

## PART II - INDUSTRY STRUCTURE

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## PREFACE

This report was prepared in rough draft form during March-May 1972. At that point in time, as required by law, the states had submitted their respective plans for implementation of pollution control (SIP or State Implementation Plans) but EPA had not decided whether or not these plans would be acceptable. Because of this, we evaluated the economic impact of pollution control legislation based on control standards that were judged by us to have a high probability of being enforced.

The acceptable SIPs were released by EPA on July 27, 1972 (Federal Register 37, 145, July 27, 1972, pp. 15094-15113). These standards vary significantly from the standards assumed by us for the "base case" in our economic impact analysis. Because of this, our analysis of economic impact, though consistent with the assumptions used by us, is somewhat dated. An analysis of the economic impact of the July 27 regulations would require rewriting of major portions of this report and the analysis would still be incomplete since the requirements for meeting the Secondary Ambient Standards will not be available for another 18 months. Also, these standards have been challenged in court by the industry.

In Appendix A we have included a summary of the major differences between our assumptions and the July 27 regulations and the general consequences.

# I. INTRODUCTION

## A. PURPOSE AND SCOPE

This is one of six reports developed under contract with the Environmental Protection Agency to assess the economic impact on the primary copper, lead and zinc industry that will result from the air and water pollution control requirements anticipated through 1976. For each industry, Part II - Industry Structure - describes industry characteristics and trends and provides the background information relevant to analysis of the economic impact. A detailed analysis of specific economic adjustment problems is given in Part III - Economic Analysis - while Part I is an Executive Summary of both Parts II and III. Each part has been bound separately.

There are several topics that Federal policy-makers must consider when setting regulatory standards. The scope of the present study was basically limited to an analysis of the impact or consequences of a certain set of air and water pollution standards. Topics outside the scope of the present study, but relevant to policy-making would include a cost vs. benefits analysis of pollution control, impact on the industries from Federal regulations in other areas, e.g., Occupational Health and Safety and means for resolving the differences in philosophy on how best to achieve a set of environmental goals.

The primary copper, lead and zinc industries are similar in several respects and for pedagogical reasons, we have covered all three industries in common in certain sections of the reports and these sections are repeated in the other volumes. For the convenience of the reader, these sections have been clearly identified with a footnote.

The purpose of Part II - Industry Structure - is to provide background information in the detail necessary for the understanding of Part III - Economic Analysis. While all significant aspects of the industry have been covered from this viewpoint, the presentation does not claim to be complete in all respects.

## B. APPROACH

The information presented here is based upon our knowledge and experience within the non-ferrous metal industry, plus data available from governmental agencies, the non-ferrous metal industry and technical literature.

Chapter II presents the various pollution abatement regulations which affect the industry; an approximate chronology of events that have occurred since 1969 in this area; the issues which are the basis for

disagreements between the industry and governmental control agencies; and our analysis of published cost data since one of the controversial issues has been the differences in cost estimates prepared by different sources.

The technology of copper production has been reviewed in Chapter III with a special emphasis on technological factors that affect the recovery of sulfur oxide emissions and the strategies available to the primary copper industry for pollution abatement. Included in this chapter is a generalized analysis of the increase in emission control cost that can occur with increasing levels of sulfur recovery.

Chapter IV presents characteristics of the industry from the viewpoint of structure and location aspects; the interdependence of the copper, lead and zinc industries and the flow of materials between these industries; an assessment of the by-products produced by these industries; and finally an aspect of the economic structure of the industry wherein the smelting and refining plants have been essentially service operations in the conversion of concentrates to usable metal and alloys.

In Chapter V the characteristics of the market have been presented and include the uses for copper; supply/demand trends, possible impact on prices and future trade in copper.

Government policies affecting the non-ferrous metal industry are summarized in Chapter VI.

Chapter VII summarizes the outlook for sulfuric acid and by-product sulfur in order to establish the market conditions which will confront the copper smelters recovering sulfuric acid from smelter off-gases as a part of their pollution abatement plans.

In Chapter VIII the financial structure and financial performance of selected producers of non-ferrous metals has been presented.

## II. BACKGROUND

As part of the legislative process resulting from the Clean Air Act of 1970, three types of pollution controls have been proposed which are in various stages of becoming law at Federal and State levels. The first type of controls are the Federal ambient air standards which refer to ground level concentrations of SOx, measured outside plant limits, which permit certain maximum concentrations of pollutants as measured over various periods of time; one hour, one day, one year, etc. There are two levels of Federal ambient air standards. The primary standards define how clean the ambient air must be so that it will not be harmful to human health and the secondary standards define how clean the air must be in order to protect against the known or anticipated effects of air pollution on property, materials, climate, economic values and personal comfort. These secondary standards are more stringent than the primary standards. These standards are shown in Table II-1.

The second is an Emission standard which limits the amount of sulfur that can be discharged to the atmosphere and is usually expressed as a percentage of the total sulfur charged to the smelter. Several states have proposed a 10% limit for the amount of sulfur that can be emitted as sulfur oxides from smelters. (This is also referred to as the 90% sulfur oxide recovery standard.) At the present time, these proposals are either contained in recommendations of the Boards of Health in the respective states or have already been passed as State Law. However, they have not been submitted to the Federal government by two of the states as a part of their respective State Implementation Plans (SIP).

The third is a proposal for a tax on all sulfur emissions. In February 1972, President Nixon proposed to the Congress a 15¢/lb. tax in 1976 on sulfur emissions in regions where the primary air quality standards are not met and a 10¢/lb. tax where the secondary standards are not met. Areas which would reduce emissions to meet both standards would be exempt from any tax. It is expected that sulfur emission taxes will be of no consequence to the industry since ambient air standards are expected to be achieved by 1976.

However, there exist several alternative sulfur tax proposals. For example, one proposes a tax of 15¢/lb. of sulfur emitted regardless of the degree of emission control practiced at the plant. This proposal can have a severe impact on the copper industry, as the following calculation will show:

Each pound of copper entering a smelter has about one pound of sulfur associated with it. Even if the smelter recovers 90% of the sulfur and emits the remaining 10%, the sulfur tax would still amount to about 1.5¢/lb. of copper above and beyond the costs for achieving 90% sulfur recovery. As will be shown in Chapters III and IV of this report, 1.5¢/lb. exceeds

TABLE II-1

FEDERAL AMBIENT AIR QUALITY STANDARDS

| | Primary | Secondary |
|---|---|---|
| Annual Arithmetic Mean | 0.03 ppm ($80\mu g/m^3$) | 0.02 ppm ($60\mu g/m^3$) |
| 24 Hour Maximum (Not to be exceeded more than once/year) | 0.14 ppm ($365\mu g/m^3$) | 0.10 ppm[1] ($260\mu g/m^3$) |
| 3 Hour Maximum (Not to be exceeded more than once/year) | -- | 0.50 ppm ($1300\mu g/m^3$) |

[1] Non-enforceable guideline.

the smelter's profit and represents a sizeable increment over the costs necessary for 90% emission control.

At the present time, there is considerable disagreement between the non-ferrous metal industry and governmental control agencies regarding the status of emission control technology; the cost and ability of the industry to control the emissions to the degree required in some of the more stringent regulations and accomplish this within the proposed time constraints.

We present below an approximate chronology of events that have led to this polarization. This is followed by a short section in which the controversial issues are identified without comment. We have attempted to address to these issues in the body of this report.

A. CHRONOLOGY

1. In December 1967 a contract was negotiated between National Air Pollution Control Administration (NAPCA) and Arthur G. McKee and Company to examine the technical and economic factors bearing on the problems of the control of sulfur oxide emissions from primary copper, zinc and lead smelting industries in the United States. McKee also examined the available systems for sulfur oxide recovery and included an analysis of market factors relating to the sale of sulfur by-products. A report on this subject was published in June 1969 (Arthur G. McKee and Company "Systems Study for Control of Emissions Primary Non-Ferrous Smelting Industry", final report under Contract PH 86-65-85, Volumes 1-3, June 1969).

2. In March 1970, "The Cost of Clean Air", the second report of the Secretary of the HEW was submitted to the Congress in which it was estimated that the copper, lead and zinc industries in operation in calendar year 1967 in 100 metropolitan areas would have to spend $67.6 million in capital investment and $61.4 million in annualized operating cost in order to recover 98.8% of sulfur oxide emissions and 95% of the particulates. Data from the McKee report appear to have been the basis for these calculations.

3. On May 18, 1970, legislation was signed into law in Arizona that allowed the Arizona State Board of Health to establish an emission standard applicable to the smelters. The emission standard was the 10% sulfur emission standard.

4. During May 1970, hearings were held in Montana on the adoption of proposed emission standards in that state, and ultimately resulted in the recommendation of the 90-95% sulfur recovery standard by the Montana State Board of Health.

5. On January 13, 1971, the proposed Federal ambient standards were published by EPA in the Federal Register (Volume 36, No. 21). Two sets of standards were proposed, a primary standard to protect public health and a more stringent secondary standard to protect public welfare. The standards apply only to ambient air quality. The final standards were issued April 30, 1971.

6. In March 1971, "The Economics of Clean Air" was submitted by the EPA to the Congress. The estimated costs to the non-ferrous smelting industry to provide the specified emission control levels were as follows:

| | Control Level (% S Removal) | Cost (Million $) Capital Investment | Annual Cost |
|---|---|---|---|
| Copper (for about 2/3 of the industry) | 94 | 87.0 | 42.0 |
| Lead | 96 | 16.2 | 7.1 |
| Zinc | 93 | 4.7 | 2.2 |

7. On April 20, 1971, a report entitled, "The Impact of Air Pollution Abatement on the Copper Industry", was published by Fluor Utah Engineers and Constructors, Incorporated, based on a study commissioned by Kennecott Copper Corporation in October 1970. This study considered several alternative approaches for pollution abatement and a summary of their results is presented in Table II-2. Overall, their costs were significantly higher than the EPA costs published in March 1971.

8. In October 1971, the Bureau of Mines published, "Control of Sulfur Oxide Emissions in Copper, Lead and Zinc Smelting", Information Circular 8527. The major findings in this report were:

   - Production of sulfuric acid is the only proven technology for removing sulfur oxides from smelter gases.

   - Acid production in the conventional smelter is practical from converter and roaster gases, but under the most favorable conditions only 50 to possibly 70 percent of the smelter plant sulfur oxides can be removed.

   - To achieve a 90% removal of the sulfur in the copper smelting process will be difficult at best and may be more restrictive than is necessary to comply with Federal ambient air quality standards. It will require the incorporation of innovative or developing technology into the conventional smelter to

TABLE II-2

SUMMARY OF RESULTS OF FLUOR UTAH STUDY

| | Present, Proven Technologies | Industry Investment (Millions of $) | Cents/ lb-Cu | TPD Acid Produced | Annual Ambient .031 PPM | Emission Standard 90% |
|---|---|---|---|---|---|---|
| 1. | Case 66 | | | | | |
| | Production Curtailment, Acid Plants, No Scrubber | 308 | 5.2 | 9870 | Yes | No |
| | Additional Capacity 900,000 Tons/Year Copper | 299 | | | | |
| | | 607 | | | | |
| 2. | Case 76 | | | | | |
| | Flash Smelting Add Acid Plants | 572 | 2.8 | 15,129 | Yes | No |
| | Second Level Technologies | | | | | |
| 3. | Case 6 | | | | | |
| | Limestone Scrubbers 17,000 TPD Gypsum | 264 | 3.8 | 4907 | Yes | No |
| 4. | Case 79 | | | | | |
| | Caustic Scrubbers in Series with Limestone Scrubbers - 15,229 TPD Gypsum | 275 | 5.6 | 4944 | Yes | Yes |
| 5. | Case 78A | | | | | |
| | Caustic Scrubbers with Sodium Sulfate Production 8225 TPD Sodium Sulfate | 331 | 16.6 | 4944 | Yes | Yes |

Note: All cases use production curtailment, as necessary, to meet Ambient Air Quality Standards.

Source: Fluor Utah Engineers & Constructors, Inc., "The Impact of Air Pollution Abatement on the Copper Industry", 20 April 1971.

capture the sulfur oxides from the dilute gases. An alternative will be the adoption of completely new smelting processes capable of providing strong sulfur oxide gases suitable for conversion to acid.

- Collectively, about $600 million will be required in the copper industry to make the changes necessary to achieve compliance with a 10% sulfur emission standard. This will result in an average increase in smelting costs of about 4 cents per pound of blister copper. The industry may find it difficult to pass the additional costs on to the ultimate consumer because of the worldwide pricing structure of copper and this might affect the capability of our domestic copper industry to maintain a competitive position in the world market.

9. In November 1971, Charles River Associates, Inc., completed a study for the Council on Environmental Quality on the economic impact of pollution control regulations on the primary non-ferrous industries. Summaries of these reports were published in March 1972. The cost basis used in these reports was essentially the same as presented under item 11 below.

10. The states were required to submit their implementation plans to EPA by the end of February 1972. The 90% emission standard was not included in the State Implementation Plans submitted by the Governors of Montana and Arizona. The state of Washington has a SIP for 90% control only in the Puget Sound area. Hence the situation in these states is still unsettled.

11. In March 1972, EPA submitted "The Economics of Clean Air" to the Congress. The costs to the non-ferrous industry contained in this report were estimated internally by the EPA, unlike the earlier costs which had been developed by sub-contractors. The estimated costs were as follows:

| | Control Level (% S Removal) | Cost (Million $) Capital Investment | Annual Cost |
|---|---|---|---|
| Copper | 90 | 313 | 100 |
| Lead | 90 | 15.6 | 65 |
| Zinc | 90 | 17.7 | 40.7 |

## B. ISSUES

A major issue is the state of the development of technology for control of sulfur oxide emissions. It is generally agreed that within the short timetable required for implementation of pollution abatement programs, sulfur emissions can be reduced to a certain extent by improvements in smelting and/or gas handling coupled with the manufacture of sulfuric acid for disposal. The status of various types of scrubber technology is a source of disagreement. The industry believes that this technology is not proven or tested on an adequate scale in order to guarantee system performance from an operational standpoint.

The 90% sulfur recovery standard is a major issue for several reasons. The industry believes that this standard was imposed on the basis that lime-limestone scrubber technology was an operationally proven technology which is certainly not the case. Also, for most locations, the Federal Primary and Secondary Ambient Standards can be met by several other strategies not based on scrubber technology and by recovering a lower percentage of sulfur. Hence, the industry believes that the 90% recovery standard imposes unnecessary financial burden on them and is not necessary to meet Federal ambient standards.

The cost of pollution control is an issue, even though the differences between industry estimates and EPA estimates have decreased over the past two years. There are several reasons for the differences in the cost estimates that were presented in the "Chronology" section. The non-availability of detailed engineering-design and operating data on lime-limestone scrubbing is one reason because it results in overdesign in order to have adequate flexibility of operation. Another reason for disagreement has been the accounting basis used. For example, some cost estimates have included only the cost of acid plants while others have included the changes and modifications in gas handling systems necessary to obtain gas streams suitable for treatment in the acid plant. Also, the repairs and modifications in gas handling flues and equipment have to take place in operating plants without seriously affecting the production. These costs tend to be higher than the equivalent costs for building similar new facilities. Another reason for disagreement is the use of industry-wide models as opposed to plant-by-plant analysis for calculating the costs.

The superimposed timetable for pollution abatement is another issue because it does not allow the copper producers sufficient time to participate in or await the orderly development of scrubber technology and also the recent developments in copper smelting technology, which might either decrease the costs of capturing sulfur oxides or eliminate the problem entirely (hydrometallurgy). The repeated revision of pollution abatement targets is a related issue since a moving target hinders or prevents the selection of an optimum strategy.

Another issue has been the capability of the non-ferrous metal industry to raise the quantity of capital investment required for what has been called

"a non-productive investment", i.e. an investment which cannot be justified by the usual return-on-investment criteria.

Strategies for meeting ambient standards are also an issue. The industry favors the use of "closed loop" control for controlling ambient SOx concentrations. EPA's latest regulations indicate that it favors the use of permanent SOx emission abatement techniques to achieve ambient air quality.

## C. COMPARISON OF PUBLISHED COST ESTIMATES

In this section, we have attempted to reconcile and delineate the differences between the different cost estimates mentioned in Section A.

There exist four "current" sources for cost estimates - EPA "The Economics of Clean Air" 1972, U.S. Bureau of Mines 1971, Fluor Utah report and Arthur G. McKee 1969. The industry-wide summations presented by these sources are shown in Table II-3.

Our discussions with the engineers at EPA indicate that the latest EPA estimate is based on limestone scrubber cost data similar to that in the Fluor Utah report. Table II-3 indicates that there is general agreement in the calculated costs between this and the Fluor Utah estimate, but a disagreement exists in the assumed efficiency of sulfur removal that could be obtained by this technology.

The Bureau of Mines costs cannot be compared directly with any of the others since they are based on a plant-by-plant analysis and include costs for flue modifications which would have to be carried out in operating plants without a serious loss of production. We believe that these flue modification costs are a major reason for the Bureau of Mines costs being higher than the others. To the best of our knowledge, costs of this type were not included in the EPA estimates ("difference in the accounting basis") and are generally very low in the Fluor Utah report.

In the McKee Report no attempt was made to prepare an industry summary such as given in the Fluor Utah Report; however, both reports contain sufficiently detailed information on estimating procedures and process assumptions to determine if and where significantly different capital cost estimates occur. Consequently, a detailed examination and comparison of the two reports was made to determine those areas wherein major discrepancies might exist, especially those which would significantly affect industry summations. From a number of comparisons we conclude that both McKee and Fluor Utah are consistent in estimating module capital investment requirements for the best developed technologies. Therefore, the major differences between the two estimating procedures are attributable to the following items and are mostly related to assumptions regarding less developed technology:

TABLE II-3

COMPARISON OF COST ESTIMATES

| Source | Approach | % S Removal | Costs: Capital Investment (Million $) | Costs: Annual Cost (¢/lb) |
|---|---|---|---|---|
| EPA - 1972 | Modeling | 90% | 313 | 3.4[1] |
| Bureau of Mines | Plant-by-Plant | 90% | 596 | 4.0 |
| Fluor Utah (limestone-scrubbers)[2] | Modeling | Ambient 0.031 ppm | 264 | 3.8 |
| Fluor Utah (acid plants; curtailment)[2] | Modeling | Ambient 0.031 ppm | 607 | 5.2 |
| Arthur G. McKee | Modeling | ---no industry-wide summations--- | | |

[1] $100 million annual costs; assume 1.5 million tons/year production.

[2] See Table II-2 for other cases.

- The use by McKee of scaling factors, generally to the 0.8 power of the smelter size ratio, across the entire capacity range, whereas Fluor Utah placed upper limits on capacities of individual units which, consequently, demanded that two units be considered above certain maximum sizes.

- The inclusion of flue modification, heat recovery and gypsum disposal facilities by Fluor Utah.

- The requirements by Fluor Utah that parallel lime-limestone scrubbing systems be included to allow for down time and maintenance as well as underrating the system design capacity by 1/3 to allow for surging.

- The inclusion of 10% of installed equipment costs for site preparation and 10% for off-site facilities by Fluor Utah and not by McKee.

It is readily seen that wide variations in total costs can result when these assumptions are applied to specific smelter sizes and then summed for the industry. Consequently, industry totals would be expected to differ when these two approaches are used.

## III. TECHNOLOGY CHARACTERISTICS AND TRENDS*

### A. INTRODUCTION

Copper is widely distributed in nature. The earth's crust is estimated to contain an average of 55 parts per million. However, despite its wide distribution, there are relatively few large copper producing areas in the world. Important copper producing regions are: (1) The Western United States; (2) the western slope of the Andes in Peru and Chile; (3) the central African Copperbelt in Zambia and the Congo (Kinshasa); (4) the Ural Mountains and the Kazakstan region in the U.S.S.R.; (5) the Precambrian area of central and western Canada; (6) the Keweenaw Peninsula of Northern Michigan; and (7) Southwest Pacific.

There are many copper minerals but only a few, chalcocite, chalcopyrite, bornite, chrysocolla, azurite, and malachite, are important commercially. Copper ores occur in many types of deposits in various host rocks. Porphyry copper deposits, however, account for about 90% of the U.S. production and much of the world output, and contain most of the estimated commercial copper reserves of the world. From a processing viewpoint, copper ores can be classified into three categories: sulfide ores, oxide ores and native copper ores.

A sulfide ore is a natural mixture containing copper-bearing sulfide minerals, associated metals and gangue minerals (e.g., pyrites, silicates, aluminates) that at times have considerable value in themselves (e.g., molybdenum, silver, gold, as well as other metals). The majority of the sulfide ores of the world can be classified into three major groups, all of which are represented in the U.S.; namely:

- The porphyry copper and Northern Rhodesian type deposits that carry copper mostly in the form of chalcocite ($Cu_2S$), chalcopyrite ($CuFeS_2$) and bornite ($Cu_5FeS_4$). In these ores, copper ranges from a fraction of one percent to several percent, and iron is generally low. The copper deposits in the southwestern U.S. are of this type.

- Deposits, such as those found in Rio Tinto in Spain, Cyprus and Tennessee, commonly known as cupriferous pyrite, which generally have 1-3% copper as chalcopyrite, and contain abundant amounts of pyrite and pyrrhotite. Generally, copper to iron ratios and copper to sulfur ratios are low.

- Arsenic-bearing copper ores, such as enargite ($Cu_3AsS_4$), with deposits occurring in Butte, Montana; Yugoslavia; Tsumeb, Southwest Africa; and the Philippines.

*Based in part on "Mineral Facts and Problems", U.S. Department of Interior, Bureau of Mines, Bulletin 650 (1970).

The sulfide ores are treated primarily by crushing, grinding and froth flotation to produce a concentrate (or several concentrates) of sulfide minerals and reject the worthless gangue as tailings.

All non-sulfide, non-native ores of copper are termed "oxide" ores; the oxide copper content being measured by and synonymous with solubility in dilute sulfuric acid. An oxide copper ore can contain copper oxide, silicate or carbonate minerals and gangue. In the southwestern U.S., many deposits have a capping of oxide ore, below which can occur a transition zone containing various mixtures of oxidized and sulfide copper minerals occurring together and then the primary sulfide deposit. The oxide ores have been treated metallurgically in a variety of ways; the character of the gangue minerals having a very important bearing on the type of metallurgical treatment used. Oxide ores in the U.S. are treated primarily by leaching with dilute sulfuric acid.

In addition, there are ores in which copper occurs as the native metal. The Lake Superior District in Michigan is the only major source of ore of this type. Although the reserves of this ore are quite extensive, it contributes only a small portion of the total U.S. mine production of copper.

Commonly associated with copper are minor amounts of gold and silver and locally lead and zinc, the recovery of which can have an important bearing on mine profitability. For example, molybdenum, lead or zinc are recovered as sulfides by differential flotation in some plants treating copper ores, and minor amounts of selenium, tellurium, precious metals, etc., are extracted in electrolytic refining. On the other hand, the presence of arsenic, antimony and bismuth in the ores leads to problems in standard pyrometallurgical processing and electrorefining and involves a cost penalty. Similarly, nickel and cobalt can interfere with electrolytic refining but they do not occur in significant amounts with the U.S. copper deposits.

## B. APPARENT RESERVES

Domestic reserves of copper ore in 1964 were reported by the Bureau of Mines* as 75 million tons of metal in ore averaging 0.86 percent copper, assuming recovery at 90% of gross metal content. An additional 58 million tons of copper were estimated in the potential resources and may be recovered with future technological or economic improvements. Arizona, Montana, Utah, New Mexico, and Michigan were the leading states in measured and indicated reserves, with Michigan having the largest inferred reserves. These five states accounted for more than 90 percent of the total reserves, 95 percent of which are in copper ores, and the remainder in mixed or complex base-metal ores.

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*F.D. Everett and H.J. Bennett, "Evaluation of Domestic Reserves and Potential Sources of Ores Containing Copper, Lead, Zinc and Associated Metals", USBM, IC 8325 (1967).

However, almost half of the reported reserve is in states east of the Mississippi River which in 1968 accounted for only about 7 percent of domestic output. The native copper ores in Michigan which, at one time accounted for substantial domestic production and comprise a substantial portion of the reported reserves, are complicated by an erratic mineralization and concealment of outcrops by glacial drift.

A large in-use resource of copper has accumulated and is growing in highly industrialized countries. In the United States, the copper-in-use pool resource has reached an estimated 40 million tons. Comparable data are not available for other countries.

The reserves mentioned above were based on material that could be mined, processed and marketed at profit under the economic and technological conditions prevailing at the time of the inquiry--about 1964.

The reserves at any particular mine are affected by the prevailing economic conditions and depend on the net-backs (net profits at mine) received by the mine. These economic inputs can be translated into a cut-off-grade, which is the metal grade of a block of ore which would produce a predetermined net-back. Thus, any block of ore above the cut-off-grade is mineable while that below the cut-off-grade can be either left in place or mined and discarded as waste. Economic factors such as long-term increases in sales price and lower operating costs from improved technology permit a lowering of the cut-off-grade and consequently, an increase in reserves and mine life. Alternately, any factors that decrease the net-backs to the mine such as increasing operating costs (from pollution abatement or otherwise) and lower prices will result in an increase in the cut-off-grade and a decrease in reserves and mine life. Under extreme pressures, for example when netbacks are lower than out-of-pocket costs, the mine would have to be shut down.

## C. MINING

Copper ores have been mined by open pit or underground methods. Open pit mining produces the largest tonnage of copper values in the U.S.

The operations involved in preparing a mine for ore extraction are called mine development. In underground mines, these operations include principally preparation of openings to and into the ore body, such as tunnels, crosscuts, drifts, raises, and shafts. The major operations in developing an open pit mine are stripping (removal of barren or low-grade overburden) and the establishment of mine transportation systems.

Large disseminated deposits lying at considerable depths, veins, and other deposits of tabular and irregular form which are usually deep are mined by underground workings. There are three distinct types of caving methods used in underground mining--block, top slicing, and sub-level, of which block caving is most important. It consists of dividing suitable ore bodies into blocks of predetermined size and undercutting each to induce rock stresses to cave and crush the ore to sizes that can be readily handled. Block caving is applicable to homogeneous and rather weak ore bodies of regular outline with enough horizontal area to cave freely. The method is nonselective in that lean sections of the ore as well as waste will be broken up and drawn with the ore.

Underground mining by supported stopes involves excavating the ore by a series of horizontal, vertical, or inclined workings in veins or large irregular bodies of ore or by rooms in horizontal deposits. It covers breaking ore and removing it from underground workings and timbering, rock bolting, and filling for support. The costs of this type of underground mining vary greatly and are dependent on the method of support of the walls and the roof and the methods of handling the broken ore. This method requires large amounts of skilled labor.

The choice between open pit and underground mining of a given ore deposit is based upon factors such as size, shape, and depth of ore body. Relative costs of mining by open pit or by an underground method are influenced by such factors as the dilution of the ore with waste, topography and surface improvements required, climate, availability of skilled labor, probable continuity of operation, and available capital. An important consideration in choosing the open pit method is preliminary stripping, which must be done before the ore can be produced at plant capacity. At several mines in the U.S., waste equal to about 1/5 of the total estimated ore reserves had to be removed before the planned rate of production could be attained. Advantages of open pit mining include: flexibility and ability to obtain large-scale production, ease with which the rate of production can be increased or decreased once the pit has been developed fully, small shutdown expense and the ability to mine selectively to meet requirements for certain grades of ore, virtually complete extraction of the ore inside the pit limits, the comparatively small labor force required, and elimination of hazards inherent in underground mining operations. On the other hand, there are certain disadvantages which have a direct bearing on the economic considerations of mining. Large open pit operations involve heavy capital outlay for equipment and when the amount of overburden to be removed is extensive, a correspondingly high capital expenditure is required for stripping. This capital is nonproductive until ore mining is begun so that during the stripping period interest charges accumulate. The time elapsed before production begins may itself be a serious disadvantage, especially if exploration is undertaken when ore prices are favorable and the demand for the metal is strong. Serious problems can be encountered in the disposal of waste, especially when the terrain

is flat or dump areas near the mine have a high real estate value, as well as climatic conditions which may limit or necessitate complete closing of operations during certain months.

Nevertheless, the cost of open pit mining has been decreasing steadily because of the use of larger and larger mining and transportation equipment and it is the predominant method for mining copper.

## D. BENEFICIATION

Copper occurs in nature in several different mineral forms (sulfides, carbonates, oxides, native copper, etc.) and each type requires a different processing technique. Many methods have been used to beneficiate the ores but, in general, only the sulfide ores are amenable to concentration procedures such as grinding and froth flotation.

### 1. Milling of Sulfide Ores

These ores are the most important source of copper and are concentrated by using froth flotation techniques. This procedure requires crushing and grinding and classification to about 100 mesh, or finer, to liberate the particles. Grinding is usually the largest single item of cost in the process and, hence, of great importance. After grinding, the ore-water mixture is treated with reagents to condition the sulfide particles so that their surfaces become air avid. The sulfides are then collected with the froth produced in the flotation cells. The final concentrate may contain from 11 to 32 percent copper. Typical selective or differential flotation practices in copper ore beneficiation are separation of copper sulfides from pyrite, recovery of molybdenum from copper concentrate, and recovery of a copper concentrate, from complex lead-zinc-copper ore.

The treatment of mixed ore, containing both sulfide and oxide minerals, depends on the relative proportions of the two types of minerals. If sulfides predominate, flotation is used, employing reagents that favor flotation of oxide minerals. When the ore contains almost equal amounts of sulfide and oxide minerals, combinations of leaching and flotation are used. In one method, the ore is leached with sulfuric acid and the residue is treated in a concentrator where sulfide minerals are recovered by flotation. In another process, the leach-precipitation-float process (LPF), the oxide minerals are dissolved by leaching and the copper is precipitated by sponge iron or sulfide ions which readily respond to flotation thus recovering the reduced copper along with the sulfide minerals.

## 2. Oxide Ores

Oxide ores occurring in the United States are generally not amenable to flotation, but are generally soluble in various leaching solutions.

### a. Acid Leaching

The ore is properly sized, if necessary, and leached with acid which dissolves the copper. Depending on ore grade and characteristics, the ore is leached in vats (by percolation or with agitation) in heaps, or in-place.

Dump leaching is used to extract copper from low-grade waste material resulting from open pit mining of copper ore deposits; the leaching cycle is measured in years. Heap leaching is employed to dissolve copper from oxide ore that has been placed on a prepared surface; the leaching cycle is measured in months. In-place leaching techniques are applicable to shattered, broken, or otherwise porous ore bodies for leaching oxide and sulfide ores of copper and other metals; the leaching cycle is measured in years. Vat leaching is employed to extract copper from crushed and sized oxide or mixed oxide-sulfide ores containing more than about 0.5 percent acid-soluble copper; the leaching cycle is measured in days.

Sulfuric acid is usually the only practical acidic solvent for oxidized copper minerals. The presence of ferric sulfate in the leach solution can solubilize some sulfide minerals such as chalcocite. For dissolution of the oxide minerals, about 1.5 pounds of acid per pound of contained copper are required. However, total consumption is often much greater because of reaction with gangue minerals. The presence of acid-consuming minerals, such as calcite or dolomite, in the ore can make the process prohibitively costly. In the present context, an excess of acid will be available in the Western U.S. after 1976 which will have to be disposed. Acid leaching of oxide ores high in acid consuming ingredients might be a cheaper alternative to limestone neutralization of some of the acid, if such ores are available.

Copper is recovered from dilute leach solutions by precipitation with scrap iron and from concentrated leach solutions by electrowinning. Recently, liquid ion exchange has been successfully used for selectively extracting copper from dilute streams and producing purified concentrated streams of copper sulfate ideally suited for electrowinning.

### b. Other Methods

Ammonia leaching has been used in the past for copper carbonate ores where acid consumption was very high due to carbonate gangue minerals.

Flotation has been practiced successfully on some oxide ores in Africa. Recent work has also indicated some limited success in floating copper silicates (chrysocolla), but it is far from being acceptable commercially.

Cyanide leaching is also a possibility and is currently being promoted. The problems relate to recovery of the cyanide for reuse and reagent consumption associated with the cyanide recovery.

A recent pyrometallurgical process is the segregation process which is based on heating high grade oxide ore with salt and coke. Copper migrates to the reductant surface and forms a massive film around coke particles. This metallic copper can then be separated from the gangue by flotation.

## E. SMELTING PRACTICE

Because most of the U.S. copper is extracted from low-grade sulfide ores that require concentration, current pyrometallurgical practice for recovery of copper from its sulfide concentrates is fairly uniform from smelter to smelter and is adapted to treating fine grained sulfide concentrates consisting mainly of copper and iron sulfides and gangue. The smelter in Michigan smelting native copper ores uses a similar processing scheme. Since it is in compliance with Federal ambient standards for SOx emissions, it will not be discussed further.

Copper's strong affinity for sulfur and its weak affinity for oxygen as compared with that of iron and other base metals in the ore forms the basis for the three major steps in producing copper metal from sulfide concentrates; roasting, smelting and converting.

A detailed description of smelting practice is given below for background prior to a discussion of technological alternatives available for air pollution control.

### 1. Raw Materials

Flotation concentrates containing from 15-30% copper constitute the bulk of the feed to the smelters. In addition, smelters will charge cement copper (produced by acid leaching of oxide ores and precipitation with iron) containing 70-85% copper, siliceous flux and limestone and a quantity of direct smelting ore containing 4-8% copper. This type of ore, when available, functions as a source of both copper as well as flux.

### 2. Drying

The flotation concentrates received by the smelter are a wet filter cake and can contain 10-15% moisture. Cement copper can contain as much as 30% moisture. The charge to a reverberatory furnace can be dried so that its overall moisture content is 4-8% without unduly increasing dusting problems in the reverb. The removal of moisture in drying reduces the fuel requirements in the reverb. Also the drier acts as a blender for homogenizing the charge. Rotary or multiple hearth driers are used for drying the feed materials.

## 3. Roasting

About half the copper smelters in the U.S. roast their charge prior to feeding in the reverberatory furnace. The older smelters use multiple hearth roasters for this purpose while the new smelters used fluidized bed roasters.

The object of roasting copper sulfide ores and concentrates is to regulate the amount of sulfur so that the material can be efficiently melted and to remove certain volatile impurities such as antimony, arsenic, and bismuth. However, in modern practice, the grade of the concentrate produced from some sulfide ores is sufficiently controlled at the concentrator to eliminate roasting prior to reverberatory smelting. In the case of custom or toll smelters, the composition of feed materials can vary widely. Hence, roasting is practiced to blend and control the sulfur content of the charge.

Elimination of some of the sulfur in roasting results in a higher grade matte in the reverberatory furnace and hence decreases the oxidizing load on the converters. Sulfide roasting is autogeneous and additional fuel is not required. The charging of hot roasted calcines into the reverberatory furnace can decrease its fuel consumption per ton of charge by about 40% and consequently increase reverb capacity. In addition, roasting also reduces the emissions of sulfur dioxide from the reverb. The reason for this is as follows: The two major constituents of concentrates utilized by almost all the U.S. smelters are chalcopyrite, $CuFeS_2$, and pyrite, $FeS_2$. These minerals contain sulfur that is loosely held or "labile" which is given off by melting the minerals.

$$2CuFeS_2 = Cu_2S + FeS + S$$

$$FeS_2 = FeS + S$$

$Cu_2S$ and FeS form matte, whereas the labile sulfur reacts with oxygen in the reverb gases to form $SO_2$. Removal of the labile sulfur during roasting can reduce emissions from the reverb. Also the lower fuel requirement per ton of charge when using calcine smelting reduces the volume of reverb off-gases.

Both types of roasters (multiple hearth and fluidized bed) usually operate around 1200°F. Sulfur dioxide concentration in the wet off-gas is usually 5-10% with multiple hearth roasters because of dilution with air. With fluid bed roasters the wet off-gases can run 12-14% sulfur dioxide. Both types of roasters, therefore, can produce a steady stream of relatively rich off-gases suitable for sulfuric acid manufacture after cooling and dust removal. Both types of roasters involve handling and collecting of large quantities of hot abrasive dust which can lead to high maintenance costs.

## 4. Reverberatory Furnace Smelting

Roasted and unroasted materials are melted after mixing with suitable fluxes in reverberatory furnaces. Liquid converter slag is also charged into the reverberatory furnace to recover its copper content. Heating of the charge is accomplished by burning fuel in the furnace cavity, the heat being transmitted to the charge primarily by radiation from the roof, walls and flame.

Almost all the reverbs in the U.S. use natural gas as a fuel and only one plant uses powdered coal. Because of the impending domestic shortage of natural gas, most smelters are now installing facilities to burn alternate fuels. The maximum smelting capacity of a reverb is limited by the amount of fuel that can be burned (a function of reverb shape and size) and the quantity of heat required by a unit weight of charge. Reverb throughput can be increased by drying the charge, preheating the charge by roasting and preheating the combustion air.

In the reverberatory furnace, copper and sulfur form the stable copper sulfide, $Cu_2S$. Excess sulfur unites with iron to form a stable ferrous sulfide, FeS. The combination of the two sulfides, known as matte, collects in the lower area of the furnace and is removed. Such mattes may contain from 15 to 50% copper, with a 40 to 45% copper content being most common, and also contain impurities such as sulfur, antimony, arsenic, iron, and precious metals.

The remainder of the molten mass containing most of the other impurities and known as slag, being of lower specific gravity, floats on top of the matte and is drawn off and discarded. Slags in copper smelting are ideally represented by the composition $2FeO.SiO_2$, but contain alumina from the various charge materials and calcium oxide which is added for fluidity. Since reverb slags are discarded, the copper contained in the reverb slag is a major cause of copper loss in pyrometallurgical practice. The concentration of copper in the slag increases with increasing matte grade. This behavior limits the matte grades normally obtained in conventional reverberatory practice to below 50% Cu.

When using a reverb for green charge smelting, 20% to almost 45% of the sulfur in the feed is oxidized and is removed from the furnace with the off-gases. The wet off-gases can contain 1.5-3% sulfur dioxide. When using calcine smelting, sulfur dioxide evolution is lower and about 10-15% of the sulfur in the unroasted feed material is contained in the reverb off-gases. $SO_2$ concentration in the wet off-gases in this case can vary between 0.5 to 1%.

The hot gases from the reverb are cooled in waste heat boilers which extract up to 50% of the sensible heat in the gases. A considerable amount of dust is removed in the waste heat boiler and the gases are further cleaned in electrostatic precipitators before venting to the atmosphere.

Reverberatory furnaces can vary in width from about 22 feet to 38 feet and in length from about 100 feet to 132 feet. The roofs of the older reverberatory furnaces are sprung arch silica roofs, while almost all the newer furnaces have suspended roofs of basic refractory. Over the years two types of reverberatory furnaces have evolved, each with its specific charging methods. The first and older is the deep bath reverberatory furnace which contains a large quantity of (in excess of 100 tons) molten slag and matte at all times. In modern deep bath reverberatory furnaces, the molten material is held in a refractory crucible with cooling water jackets along the sides which greatly diminishes the danger of a breakout of the liquid material. In deep bath smelting several methods exist for charging. Wet concentrates can be charged using slinger belts (high speed conveyors) that spread the concentrates on the surface of the molten bath. Dry concentrates or calcines from the roaster can be charged through the roof or via a Wagstaff gun, (an inclined tube). Roof charging (side charging) is rarely practiced in conjunction with deep bath smelting because of dusting problems with fine dry calcine and explosion problems with green charge. Wagstaff guns minimize these problems and are commonly used.

The second type of reverberatory furnace is the dry hearth type in which a pool of metal exists only at the tapping end. The dry hearth type furnaces are charged with wet or partially dried concentrates (green feed smelting), or with calcines through the roof. In the latter case the dusting problem can be quite severe for fine concentrates.

5. Converting

Matte produced in the reverberatory furnace is transferred in ladles to the converters using overhead cranes. The converters used in copper smelting are of the cylindrical Pierce-Smith type, the most common size being 13' x 30'. Air is blown from the side through a series of openings called tuyeres. During the initial blowing period (the slag blow) FeS in the matte is preferentially oxidized to FeO and $Fe_3O_4$ and sulfur is removed with the off-gases as $SO_2$. Flux is added to the converter to combine with iron oxide and form a fluid iron silicate slag. When all the iron is oxidized, the slag is skimmed from the furnace leaving behind "white metal" or molten $Cu_2S$. Fresh matte is charged into the converter at this stage and the slag blowing continued until a sufficient quantity of white metal has accumulated. When this happens the white metal is oxidized with air to blister copper during the "copper blow". The blister copper is removed from the converter and cast or subjected to additional fire refining prior to casting. Converter blowing rates can vary between 12,000 to 30,000 scfm of air. Also, the $SO_2$ content of the off-gases is lower during "slag blow" than during "copper blow".

Cooling of the hot converter gases is necessary in order to prevent thermal damage to the dry gas cleaning equipment. Normally, this is accomplished by adding dilution air that can vary in quantity from 1 to 4

times the converter off-gas. With dilution air, $SO_2$ concentrations in the converter off-gases can vary from 1-7%. With close fitting hoods or with Hoboken converters, the off-gases average 5-10% $SO_2$. However, when dilution air is not used, cooling devices such as waste heat boilers, air/gas heat exchangers or water sprays are necessary.

The converter gases pass via a balloon flue or individual high velocity flues to dry gas cleaning equipment such as cyclones or electrostatic precipitators. When these gases are to be used for acid manufacture an electrostatic precipitator for dry gas cleaning is not essential since the wet gas cleaning system (wet scrubber, electrostatic demister, etc.) removes all the particulates from the gas stream. Thus, with proper hooding, the converter off-gas is sufficiently high in sulfur dioxide so as to be suitable for sulfuric acid manufacture, but converting by its very nature is a batch operation and the off-gas flow rates vary widely. In the smaller copper smelters which use two or three converters, the scheduling of converter blows in order to obtain relatively steady flows to the acid plant is a difficult problem.

## F. REFINING

The blister copper produced by smelting is too impure for most applications and requires refining before use. It may contain silver and gold, and other elements such as arsenic, antimony, bismuth, lead, selenium, tellurium, and iron. Two methods are used for refining copper - fire refining and electrolysis.

The fire-refining process employs oxidation, fluxing and reduction. It is based on the weak affinity of copper for oxygen as compared with that of the impurities. The molten metal is agitated with compressed air, sulfur dioxide is liberated and some of the impurities form metallic oxides which combine with added silica to form slag. Sulfur, zinc, tin, and iron are almost entirely eliminated, and many other impurities are partially eliminated by oxidation. Lead, arsenic, and antimony can be removed by fluxing and skimming as a dross. After the impurities have been skimmed off, copper oxide in the melt is reduced to metal by inserting green wood poles below the bath surface (poling). Reducing gases formed by combustion of the pole convert the copper oxide in the bath to copper. In recent years, reducing gases such as natural gas or reformed natural gas have been used. If the original material does not contain sufficient gold or silver to warrant its recovery, or if a special purpose silver-containing copper is desired, the fire-refined copper is cast directly into forms for industrial use. If it is of such a nature as to warrant the recovery of the precious metals, the fire refining is not carried to completion but only far enough to insure homogeneous anodes for subsequent electrolytic refining.

In the electrolytic refining step anodes and cathodes (thin copper starting sheets) are hung alternately in concrete electrolytic cells containing

the electrolyte which is essentially a solution of copper sulfate and sulfuric acid. When current is applied, copper is dissolved from the anode and an equivalent amount of copper plates out of solution on the cathode. Such impurities as gold, silver, platinum-group metals, and the selenides and tellurides fall to the bottom of the tank and form anode slime or mud. Arsenic, antimony, bismuth, and nickel enter the electrolyte. After the plating cycle is finished, the cathodes are removed from the tanks, melted, and cast into commercial refinery shapes. The copper produced has a minimum purity of 99.9%.

## G. HISTORICAL

Until the beginning of this century, only the high-grade deposits of copper could be mined economically and treated for the extraction of copper. The discovery of froth flotation techniques for beneficiation of sulfide minerals early in this century enabled the exploitation of low-grade sulfide deposits. Around this time the market for copper was growing because of the start of the electrical industry and the producers of copper were able to satisfy this demand by relying increasingly on the beneficiation of sulfide ores. The early sulfide concentrates were relatively low in copper and high in sulfur. Hence the early pyrometallurgical practice required roasting in multiple hearth furnaces and converting to produce blister copper. Several of the older smelters incorporated sulfuric acid manufacture. With improvements in differential flotation it was possible to produce a sufficiently high-grade concentrate which did not require roasting. This led to the phasing out of multiple hearth roasters and the use of green charge smelting in which the wet concentrates were charged directly into the reverberatory furnace. Also, as a result of the availability of inexpensive elemental sulfur from Frasch sources, the operation of by-product sulfuric acid plants at smelters was no longer economical and most of them were shut down.

## H. RECENT TRENDS IN COPPER EXTRACTIVE TECHNOLOGY

Because of the framework of raw material, fuel and labor costs that has existed for some time in the U.S., the domestic smelters have used reverberatory furnaces (reverbs) of increasingly larger size and capacity to smelt copper concentrates. Under the present requirements for efficient sulfur oxide recovery, it is possible that the copper reverb like its predecessor, the open hearth furnace in the steel industry, will become obsolete.

Over the past twenty-five years, several alternative smelting approaches have been developed around the world in response to local conditions of raw materials, energy and labor costs and by-product markets. These alternative approaches might be adaptable in the U.S. with minimal research and development efforts. These and other approaches are briefly discussed below, purely from the viewpoint of whether they offer technical solutions to the problems faced by the U.S. copper smelting industry. The discuss-

ion in this section does not address the question of cost-effectiveness of this technology compared to that already in use.

In Japan a blast furnace was developed (the Momoda blast furnace) which would accept a portion of its charge in the form of fine concentrates. This approach can be economical for small sized plants. For many years, Nippon Mining Company has smelted pelletized copper concentrates directly in the converter using an enriched oxygen blast. A similar approach has been tried at the Garfield, Utah smelter of the Kennecott Copper Corporation.

The flash smelting processes for smelting sulfide concentrates utilize the heat of oxidation of the concentrate to form a molten matte and slag. The best known of these are the Outokumpu flash smelting process developed in Finland and the Inco oxygen flash smelting process developed in Canada. In the former, the furnace is kept in heat balance by burning a fuel if necessary and in the latter by oxygen. The steady $SO_2$-rich stream of gas produced by flash smelting is ideal for acid manufacture. The Inco oxygen process produced extremely high concentrations of $SO_2$ and at Inco, the off-gas was utilized for liquid $SO_2$ manufacture. Outokumpu furnaces have been installed in several plants around the world. Recent developments in the Outokumpu process involve producing a matte in the flash furnace that is essentially at the white metal stage. The advantages claimed for this approach are the minimization or elimination of converter slag and removal of a major amount of the sulfur in the concentrate in the flash smelter in the form of a steady stream of off-gases which minimizes the impact of cyclic converter operations on the acid plant operation.

Because flash smelting is autogeneous, the availability of uniform feed is a very important factor when the applicability of this approach is considered. Some of the Japanese flash smelters are custom smelters and operate on concentrates from a variety of sources.

There are two developments which would substantially decrease or eliminate air infiltration and dilution of the converter off-gases. The first is the Hoboken syphon converter. The Inspiration Consolidated Copper Company plans to install five of these converters in their new plant. The second is the use of tight-fitting converter hoods to minimize air infiltration and the use of waste-heat boilers for air cooling as used by Mitsubishi at Onahama in Japan. Most U.S. copper smelters plan on installing various types of tight-fitting hoods and appropriate gas cooling facilities.

Electric arc smelting has been practiced for many years by Boliden in Sweden for smelting copper concentrates and scrap. This processing technique is receiving renewed attention on a world-wide basis because of its potential in reducing and controlling sulfur oxide emissions and its ability to operate with concentrates as well as scrap feed. Electric furnaces are being installed at Inspiration and at Tennessee Copper. The cost and

availability of the required amount of electric energy is a major factor in the economics of electric smelting.

In the pyrometallurgical treatment of copper concentrates, the major portion of the copper lost during processing is that which leaves the smelter in the slag. In conventional smelting, the high copper (about 6% Cu) converter slag is fed into the reverberatory furnace for copper recovery while the reverb slag (about 0.4% copper) is discarded. The copper content of a slag in contact with a matte increases with increasing matte grade, hence if the reverb slag is to be discarded, this behavior imposes an upper limit on the matte grade in the reverb. The commercialization of various slag flotation schemes for recovering copper from converter slags and flash smelter slags offers several advantages.

- If converter slags are to be treated for copper recovery, only the copper recovered has to be recycled to the reverb. This prevents the introduction of magnetite into the reverb from this source and avoids the problems associated with the build-up of magnetite on the bottom of the reverb furnaces.

- The reaction of magnetite in the converter slag with the matte causes evolution of $SO_2$:

  $$3Fe_3O_4 + FeS = 10FeO + SO_2$$

  This can be prevented by not recycling the slag and the $SO_2$ content of the reverb off-gases is decreased.

- If slag from a primary smelting unit (a reverb, a flash smelting furnace or a continuous smelting furnace) can be treated successfully and economically for recovering its copper content, the copper content of the slag no longer limits the matte grade in the primary smelting unit. Thus, high grade mattes up to the white metal stage (containing about 80% copper) could be obtained in the primary unit. For example, this approach is the basis for the improvements in Outokumpu flash smelting.

The treatment of converter slags by slow cooling, crushing, grinding and flotation has been used at Hitachi and Naoshima in Japan, by Outokumpu and has been incorporated in some of the recent continuous smelting methods such as the Noranda process.

All of the developments mentioned above have been tested on a commercial scale for many years and are adaptable to the U.S. conditions with a minimal research and development effort. There are several schemes for processing copper concentrates that are being tested at the present time in a variety of pilot plants or semi-production facilities that produce only concentrated $SO_2$ streams. Over the long term, they offer a potential for

reducing operating costs in comparison to the problems and costs associated with the control of low-level $SO_2$ emissions from the copper reverberatory furnace. Unfortunately, these processes are as yet unproven and could not be used by the U.S. smelters within the short time scale required to implement the air pollution abatement programs, even if they provided the most economical solution to the problems. Prominent amongst these are the Noranda, Worcra, Mitsubishi and other continuous smelting processes, in which copper concentrates are treated up until the blister copper stage in a single reactor. Similarly, there are other schemes for the direct smelting of concentrates in the converter using such equipment as the top blown stationary converter and the top blown rotary converter.

There exist processes for reduction of sulfur dioxide to elemental sulfur in various stages of development. Outokumpu is reportedly working on a modern version of the Orkla process, a process for the reduction of $SO_2$ to elemental sulfur with a solid carbonaceous reductant. We understand that this process has been tried only in a pilot plant. Other sulfur reduction reductants are Allied Chemical and Asarco-Phelps Dodge. However, the reduction of $SO_2$ to elemental sulfur is expensive.

There are several hydrometallurgical approaches that can treat sulfide concentrates. Unfortunately, none of these processes have been developed to the degree where they can be used as a basis for a full-scale commercial operation to replace existing copper smelters within the given time scale for pollution abatement. (Also, the replacement of operating smelters with new unproven processes would cause a major financial impact on the industry.) The more interesting processes convert copper sulfide concentrates to the metal and produce elemental sulfur which would be easier to store and cheaper to transport than sulfuric acid. Examples are: weak acid pressure leaching (Sherritt Gordon-Cominco process), atmospheric pressure leaching with nitric acid, sulfuric acid bake, ferric ion leaching and chlorine water leaching. Of course, there are several other hydrometallurgical processes in which sulfur in the concentrate is oxidized to sulfate, but these are of lesser interest since sulfate values have to be disposed or marketed. Typical of these are the ammoniacal leaching processes which Sherritt Gordon has operated on a large scale for leaching nickel sulfides and bacterial leaching.

There are two trends in the U.S. that would also affect the profitability of domestic smelters in the long term and influence the evolution and adaptation of new technology. The first is the increase in labor cost. Since the smelters have been operating in their current configuration for many years, we would assume that significant increases in productivity

could only be obtained by a change to the continuous smelting processes. Unfortunately, the current timetable for implementation does not permit the consideration of these processes. Also it is doubtful that the potential economics offered by continuous processes can justify the scrapping of operating plants.

The expected shortages of natural gas and concommitant increases in the fuel fuel costs would increase reverb operating costs and increase the attractiveness of autogenous processes in the long term. In general, the rising energy costs in the U.S. would seriously penalize the users of second level pollution abatement technology (such as scrubbing for $SO_2$ recovery, $SO_2$ reduction and scrubbing for $SO_2$ disposal) since this technology generally requires a considerable energy input.

## I. STATUS OF AIR POLLUTION ABATEMENT TECHNOLOGY

### 1. Current Methods

At present there are three methods in use at copper smelters for reducing the sulfur dioxide concentrations in the vicinity of a smelter. These are: the use of a tall stack to disperse and dilute the smelter off-gases; the production of sulfuric acid by the contact process from concentrated gas streams to achieve a degree of reduction in emissions; and production curtailment.

The tall stack discharges sulfur dioxide at such heights that the gas is diluted when dispersed into the lower atmosphere. It is possible to add preheated air into the stack to achieve additional dispersion and dilution. Because tall stacks and preheated air can achieve dispersion and dilution when used in conjunction with other means of limiting emissions, there is no simple relationship which can predict ambient concentrations as a function of percent sulfur recovery. The overall control strategy has to be well defined and local weather patterns have to be considered.

The contact sulfuric acid process is well established for treating $SO_2$-containing off-gases from metallurgical plants. Modern contact acid plants require at least 3.5-4% sulfur dioxide in the feed gas in order to operate autogenously. For handling lower concentrations of $SO_2$ an additional fuel input is required. The acid plant size is primarily a function of the volume of gas handled. Hence, for a constant acid output, an acid plant operating on more dilute gases is much larger (and more expensive) than an acid plant operating on more concentrated gases. With the currently used vanadium pentoxide catalysts the upper level of $SO_2$ concentration in the feed gas to an acid plant is between 7 and 9%. Gas streams more concentrated than this require dilution. At present, some of the copper smelters in the western U.S. make sufficient acid for the local needs and a tall stack is used to disperse the remaining emissions.

The third method for controlling sulfur dioxide concentrations at ground level is production curtailment when adverse weather conditions prevail. This method has been referred to as "closed loop control" when it is based on the monitoring of sulfur dioxide concentrations at ground level at various sites in the areas surrounding the smelter and using this information to control the smelter operating rate. When ground level concentrations increase as a result of adverse weather conditions, the smelter operation is curtailed to reduce the emission rate.

## 2. Technological Approaches

There are several technological approaches that can be used by copper smelters to reduce their sulfur oxide emissions. There are two major factors that influence and limit the options available to the operating plants. The first is the relatively short timetable required for implementation which means that prudent business practice would limit the choice of alternatives only to well-established technology, the so-called first level technology. The second factor is the manner in which the pollution control laws are written. For example, an emission control law can require a different approach than a law that limits ambient concentrations.

There is general agreement that only the production of sulfuric acid has been developed to a point where its performance as a sulfur dioxide removal process can be guaranteed. Various schemes for scrubbing off-gases have been considered as second level technologies, because they have not yet developed to the point that they could be built in three years and their performance and operability guaranteed within a smelter. We believe that scrubber technology is "second level" but regardless of whether a particular scrubbing scheme is considered first level or second level, any SOx removal process has to be considered primarily in the context of copper smelting technology and has to be properly interfaced with the sources of SOx.

### a. First Level Technology

There are four ways in which first level technology (acid plants) can be interfaced with a copper smelter:

- Acid plants coupled to converter off-gases
- Acid plants coupled to roaster off-gases
- Acid plants coupled to reverb off-gases but first requiring an $SO_2$ concentration step (considered second level technology)
- Acid plants coupled with new smelting units (flash furnaces or electric furnaces)

During conventional copper smelting, between 40 to 60% of the sulfur in the feed materials is eliminated from the converters and the capturing of these emissions is a logical starting point to consider for emission abatement and the other three methods mentioned above could operate in addition to the conversion of $SO_2$ in converter off-gases to acid. At present, the converter gases are cooled by three to four times their volume of dilution air, and this air infiltration has to be stopped in order to maintain high concentrations appropriate for autogenous conversion to sulfuric acid. The general approach to accomplish this includes the installation of tight-fitting hoods to prevent air infiltration, the cooling of hot off-gases with waste-heat boilers or water sprays, dry gas cleaning with electrostatic precipitators and finally wet gas cleaning in Peabody-type scrubbers, and acid mist elimination prior to treatment in a contact acid plant. The only other technical alternative is the use of Hoboken syphon converters which eliminate entirely the leakage of dilution air, but still requires the same gas treatment facilities downstream. All the copper smelters in the west are now preparing to install these changes which are essential for pollution abatement. Of these changes, the flue modifications necessary to capture converter off-gases without excessive dilution can be quite expensive because the construction work has to be completed in an operating plant with minimal interference with plant production. Also, the addition of an acid plant substantially increases the power demand at a smelter. Currently, most smelters generate more than adequate power for their internal needs from the waste-heat boilers on the reverberatory furnaces and power generation can be increased by installing waste-heat boilers to cool the hot converter gases. This increase in the power generation capacity is obtained at considerably higher capital cost as compared to the use of water sprays for converter gas cooling. Because there is considerable variation in the heat load at smaller smelters, the use of water sprays would be preferred.

The second approach for further reduction in emissions would be the one that would require the abandonment of green feed smelting and a reversion to concentrate roasting in conjunction with deep-bath smelting.

New multiple-hearth roasters as well as fluid bed roasters can produce off-gases sufficiently high in $SO_2$ for autogenous acid manufacture. Of the three fluid bed roasters installed at copper smelters, the smallest unit has operated trouble-free for several years. The intermediate sized fluid bed unit has encountered considerable operating difficulty in the past but these problems have been successfully overcome, and the management believes that they have sufficent in-house experience to properly design a new fluid bed roaster should they choose to do so. The largest fluid bed roaster has also had considerable operating difficulties in the past but these seem to have been successfully overcome since the management of this particular company will rely on the fluid bed roaster as a part of its strategy to reduce sulfur oxide emissions at that particular smelter. The advantage of partial roasting is that the loosely held sulfur in the concentrates is removed and a steady stream of off-gases rich

in sulfur oxides and ideal for sulfuric acid manufacture is obtained. In cases where the degree of sulfur elimination and iron oxidation in fluid bed roasting is not sufficient to substain an autogenous reaction, supplemental fuel can be burned in the roaster. This technology of burning supplemental fuel has never been used in the operation of fluid bed roasters treating sulfide concentrates but only for the partial reduction of iron ore by Montecatini in Italy. An alternative would be the utilization of multiple hearth roasters using supplemental fuel.

The usual way to charge hot calcines produced by roasting is by using Wagstaff guns. This method minimizes dusting problems when compared to roof charging of calcines and reduces the oxidation of calcines in the reverberatory furnace atmosphere. At plants currently using green feed smelting, the addition of roasters could be accomplished relatively easily, assuming that space restrictions are not very stringent within the plant. However, the change from green feed smelting using side charging to calcine smelting would require major modifications on the reverb. These would be related to the change from dry hearth smelting to deep bath smelting and require, for example, the installation of cooling water jackets all around the crucible of the furnace. One copper producer undertook changes of this type several years ago, hence this approach appears to be technically feasible, though the costs would be highly variable since they would depend on the exact configuration of each reverb. The use of properly designed new roasters along with the facilities for capturing converter off-gases described previously and the conversion of both the roaster and converter off-gases to sulfuric acid in a contact acid plant would theoretically achieve sulfur recoveries as acid in the range of over 80% and perhaps approaching 90%. (See an example of this, based on data from the McKee report, in Section J of this chapter.)

The advantages of roasting and calcine smelting are: reduction in fuel consumption in reverb and potential increase in plant throughput. The disadvantages are: introduction of large amounts of magnetite into the reverb and an increase in copper losses in slag resulting from higher matte grade. In addition, for smelters equipped for roof charging of green concentrates, this would require essentially the rebuilding of the entire reverb complex and this might not be the most inexpensive strategy with respect to meeting the Federal ambient standards.

The third approach (which is being tested at present) is based on the use of green feed smelting in closed-in reverbs and concentration of reverb off-gases using dimethylaniline (DMA). The advantages of this approach are the use of the green feed smelting concept which is easier from an operational viewpoint. The disadvantages are: DMA scrubbers have not operated on as large a scale previously and DMA scrubbing is a higher cost process when compared to roasting. In view of predicted increases in energy and fuel costs, the operating costs for this approach can also be expected to increase significantly in the future.

The fourth approach would require abandoning the reverbs entirely and the adoption of alternate smelting approaches which would be utilized in conjunction with properly hooded converters. Of the approaches described in the previous section, electric furnace smelting has already been adapted and flash smelting is under serious consideration.

b. Second Level Technology

One of the major issues involved in the control of sulfur oxide emissions from non-ferrous smelters is the operational applicability of removal technologies to the smelters. For example, Arthur G. McKee and Company, in a 1969 report on the National Air Pollution Control Administration (PB184884) stated that "only five control processes have been sufficiently tested and enough data made available so that costs can be estimated for their applicability to a range of smelter conditions." The five control processes selected by McKee were:

Contact Sulfuric Acid
Cominco Absorption (Ammonium Sulfate production)
Reduction to elemental sulfur (Asarco Process)
Lime Wet Scrubbing
Limestone Wet Scrubbing

In a subsequent study by Fluor-Utah in 1971, under the sponsorship of Kennecott Copper, the same general process technologies were considered with only acid manufacture defined as first level technology. However, the Cominco absorption process was replaced by an Asarco developed absorption process utilizing dimethylaniline (DMA). The major reason for the selection of DMA was the high sulfur dioxide recovery characteristics. Although there was some disagreement between Fluor-Utah and McKee on the sulfur oxide removal capabilities of the Cominco ammonium sulfate process, there was no disagreement that both processes (Cominco and DMA) are high in capital and operating costs. Both Fluor-Utah and McKee considered the possibility of producing elemental sulfur by a process piloted by the American Smelting and Refining Company. Again, the two agreed that the capital and operating costs for sulfur production would be high.

Each of the aforementioned processes results in a by-product which can be an item of commerce, i.e. sulfuric acid, ammonium sulfate, liquid sulfur dioxide or solid sulfur. The other sulfur oxides removal processes considered, i.e. lime and limestone scrubbing are not capable of producing a product of commercial interest since the gypsum from natural sources is far superior.

In regard to lime-limestone scrubbing, our assessment is in agreement with that of Slack, Falkenberry and Harrington* who stated "Lime-limestone scrubbing is being adopted as a basic method of controlling $SO_2$ emissions from power plants. Use in other industries that emit $SO_2$ is limited but is likely to increase. At the present time technology is only in the beginning of development, perhaps usable as a means of controlling emissions but crude and far from being optimized."

The operational status of lime-limestone scrubbing has been characterized by the aforementioned authors as "Scale Formation on scrubbing surfaces has been the main operating problem throughout the history of lime-limestone scrubbing---. At the present level of development, it appears that to use lime at reasonable circulation rates it is necessary to operate at low pH or to dilute the system with water. Both are undesirable, the latter particularly so because scrubber liquor must be drained to a water course, with accompanying water pollution, to make room for the water." Furthermore, as these authors note, in many sections of the country calcitic limestones are not readily available and if dolomitic limestones are used, the highly soluble magnesium sulfate that is produced would present a difficult containment and long term disposal problem. Consequently, the lime or limestone scrubbing process as well as the use of sodium hydroxide or sodium carbonate for scrubbing results in waste streams of solids or concentrated salt solutions which must be disposed of in a manner which will not pollute ground and surface waters. The problem of disposing of waste solids generated from scrubbing sulfur dioxide from gas streams or from neutralization of excess acid has been recognized by both the industries and regulatory agencies and is a problem which must be considered for each individual plant location. In general, where smelters are located near mines, the problem of disposal of solids generated in sulfur oxides removal is minimal because of the large amounts of solids already being disposed of in tailing piles. Furthermore, in the case of the copper industry particularly, and to some extent in the lead and zinc industries, the problem of disposal of these solids is further decreased because of the aridity of the areas where the mines and smelters are located.

Within the present time constraints, the optimum strategy for the copper, lead and zinc industries is therefore based, in general, on minimizing the volumes of dilution air historically used or allowed to enter, increasing SOx concentrations and using the well established contact sulfuric acid plant for its removal. Since it is often possible to achieve

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* Sulfur oxide removal from waste gases: Lime-limestone scrubbing technology - A.V. Slack and H.L. Falkenberry, Tennessee Valley Authority and R.E. Harrington, Environmental Protection Agency. Journal Air Pollution Control Assoc. Vol. 22, No. 3, March 1972.

this concentration by better ducting, hooding, and replacement of equipment, the control of sulfur oxide emissions from these industries involves considerations other than those of direct treatment of an off-gas which cannot be altered in composition, as in the fossil fuel electric power industry. This approach is based not only on the known operational difficulties inherent in lime-limestone scrubbing but also on the fact that the lowest concentrations of sulfur oxides present in the major gas streams (such as reverb off-gases) are considerably greater than those that occur in, for example, the flue gases from fossil fuel power generating plants. Some preliminary evidence indicates that scrubber efficiencies for these higher concentrated gases may be less than demonstrated on power plant flue gases. Also, the variable flows that occur in smelters have caused some of the preliminary designs to be limited to less than 100,000 SCFM units; however, single train scrubbing units of larger capacity are available which would probably result in lower capital investments than often estimated. However, because these scrubbers have not been installed and operated for long periods of time, it is not surprising to find a reluctance to consider them when confronted with a relatively short time period for installation of equipment for compliance with emission regulations. Therefore, the principal control methods being considered by the industries are toward the removal of sulfur oxides as sulfuric acid; liquid sulfur dioxide with scrubbing being considered principally for those gas streams of low sulfur oxides concentration, i.e. where the concentration levels have been reduced to the levels characteristic of the electric power generating industry but are still too high to attain compliance with emission standards.

An additional aspect of second level technology is that it consumes considerable energy--more than can be generated at smelters by utilizing waste heat.

As higher and higher degrees of sulfur recovery are considered, "converter aisle losses" become increasingly important. "Converter aisle losses" refer to low level SOx emissions that occur either during normal operations of a copper smelter (for example, tapping of matte, charging converter slag into the reverb, several converters blowing into a balloon flue at the same time resulting in inadequate draft, and so on) or during short-time transients (for example, SOx leakage while converter is being turned, draft reversal in the reverbs resulting in reverb gas leakage from all openings, and so on).

These low level emissions are difficult to quantify since they would have to be calculated by difference and their magnitude is not known at the present time with any degree of certainty.

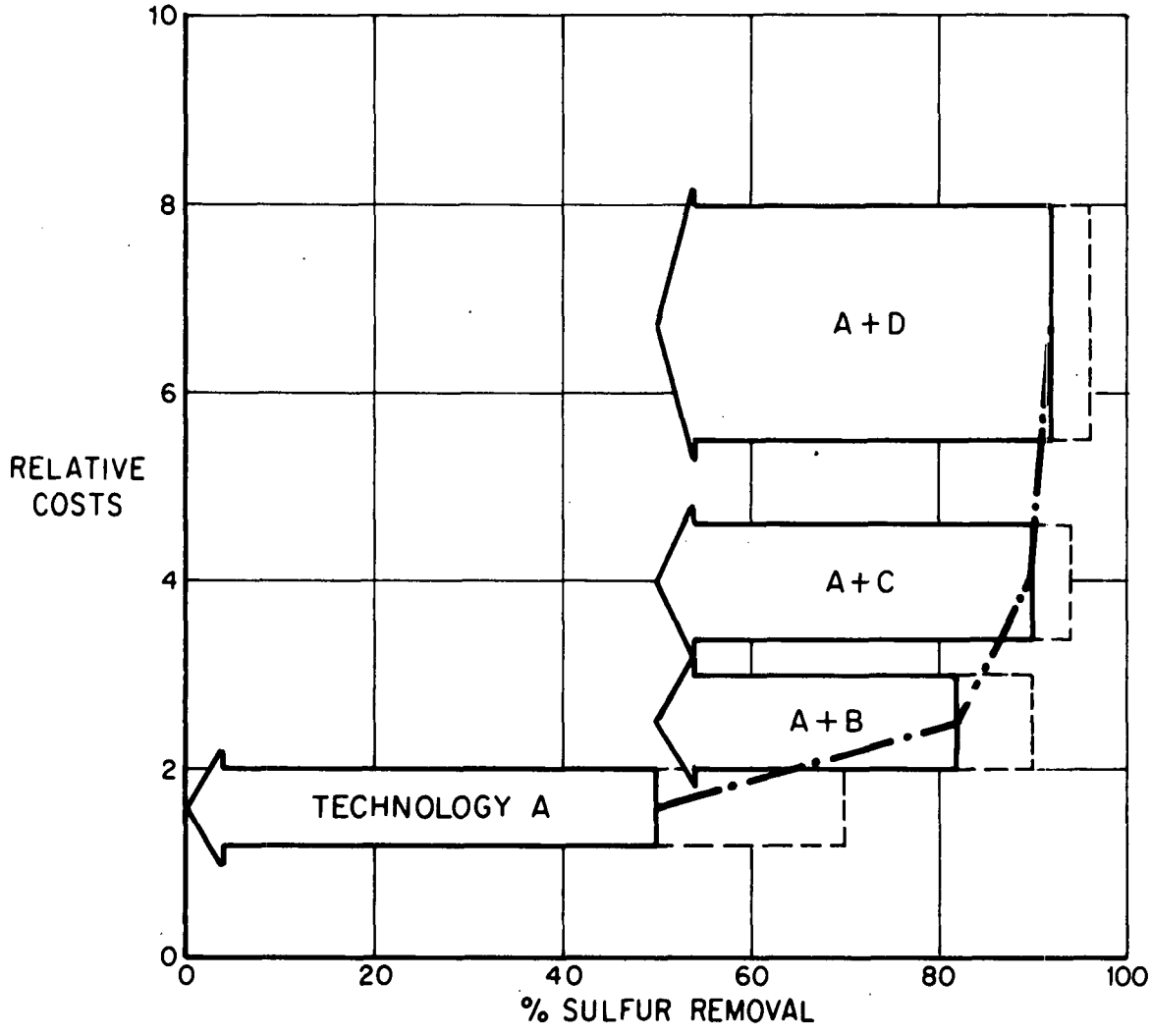
## J. GENERALIZED COSTS OF EMISSION CONTROL

As noted earlier, a copper smelter has a variety of options available to meet a required set of standards. Because the ambient SOx concentrations are affected by local weather patterns, tall stacks, use of dilution air, etc., it is not possible to express in a simple generalized relationship the percent sulfur recovery (i.e. the degree of emission control) necessary to produce a predetermined ambient concentration.

It is however possible to calculate the costs associated with different degrees of emission control since each type of technology can be the optimum within a particular range of emission control objectives. We have prepared Figure III-1 in order to show the costs associated with different degrees of emission control. The figure is based on the sequential selection of emission control strategy. We have selected collection of converter gases and acid manufacture as the basic strategy (Technology A) since these gases are a major source of SOx emissions that can be obtained in adequate concentrations for acid manufacture. Also, all the western copper smelters have pollution abatement plans that include this approach. This strategy can recover from about 45% to perhaps 70% of the sulfur in the feed materials, the exact recovery depending on the nature of the concentrate and type of reverb operations. The vertical axis in Figure III-1 has been labelled "relative costs"; however, these costs are approximately in ¢/lb. of copper incurred in direct operating costs plus 20% per year of capital costs for amortization, debt maintenance, taxes and administration when using a particular technology. For example, the horizontal bar for Technology A extends from 0% to 50% and indicates the range of emission control assured by this technology. Its dotted extension to 70% denotes the area where it might be applicable but where its performance could not be guaranteed. The cost range denoted by this bar is the range of total costs (i.e. direct operating plus fixed costs) expected when this technology is used to obtain the maximum recovery it is capable of or about 50% sulfur removal. It can be argued that when this technology is used of only 20% sulfur removal, the costs could be lower than shown in the figure. However, since the purpose of this exercise is to show what level of emission control can be obtained at what cost, each technology would logically be utilized to its limit and we believe that the use of horizontal bar representation of cost vs. technical capability for emission control is justified.

We have selected roasting of concentrates (Technology B) as the second strategy.

We believe that the use of this approach in conjunction with the converter gas collection--acid manufacture approach will recover over 80% of the sulfur and might approach 90% sulfur recovery, though the latter could probably not be guaranteed. (For example, Model B in the McKee report was based on this approach but incorporated the use of dilution air for cooling of converter gases. The sulfur emitted from roaster, reverb and




**Note:** Technology A — Acid manufacture from converter gases
Technology B — Roasting and acid manufacture in addition
Technology C — Scrubber technology such as lime-limestone or DMA scrubbing plus acid plant
Technology D — Scrubber technology such as caustic or DMA scrubbing plus elemental sulfur production

**FIGURE III–1 GENERALIZED COST FOR DIFFERENT DEGREES OF EMISSION CONTROL**

converter was 50%, 6.7%, and 38.5% or a total of 95.2% of the sulfur in the plant feed. The acid plant utilized roaster and converter gases at 94% efficiency and captured 83.2% of the sulfur in the plant feed. The McKee numbers can be manipulated to show a "sulfur recovery" of over 90% by assuming a double absorption acid plant and assuming "sulfur recovery" to include sulfur leaving the plant with reverb slag.)

Removal of over 83% of the sulfur requires the application of a variety of technologies in both the smelting operations and the sulfur oxide removal processes. A variety of decision paths are possible and we have chosen such removal technologies as lime-limestone scrubbing or DMA absorption with recovery of liquid sulfur dioxide for sale or for additional acid production as representative of Technology C. These technologies are considered to be those which could be applied when necessary to achieve 90% sulfur removal at minimum cost and where 90% removal would insure meeting ambient air quality standards at all times. Since these technologies do not as yet have a firm basis for detailed engineering and operating costs, their application to any specific smelter would result in a wide variation of costs as shown by the bar for Technology A plus C.

In the case of certain smelters--where local acid markets are non-existent, where disposal of calcium sulfate from acid neutralization or scrubbing might create potential water pollution problems, or where greater than 90% removal might be required to insure meeting ambient air quality standards--the use of caustic scrubbing, DMA absorption and elemental sulfur production and so on might be required. This technology, labelled D, would be expected to have even higher costs and variability from smelter to smelter and the total cost is shown as Technology A plus D.

To show approximately the rapid increase in costs of sulfur removal as higher and higher percentage recoveries are required, the dotted line of Figure III-1 connecting the mid-points of the estimated ranges has been drawn. This line is characteristic of operating processes as higher and higher recovery efficiencies are required while reflecting the variability that exists between smelter locations.

## K. TECHNOLOGY OF WATER POLLUTION CONTROL

The primary copper, lead and zinc industries must control water emissions from three major sources, the mines, the smelters and the refineries. In controlling water pollution it is often necessary to remember that in controlling the air pollution problems, a water pollution problem can be created since some of the most effective air pollution technologies are based on the use of water in scrubbing. Furthermore, the water drainage problem from mines and tailings disposal areas is of considerable concern to the industries, but, of course, much less than in the coal mining industry. Although air and water pollution control have been considered separately, it is mandatory that in arriving at solutions to one problem, another one of equal or greater magnitude is not created.

Wastewater treatment in the copper, lead and zinc industries is principally based on physical separations and physico-chemical removal techniques since there is little biologically active material other than from the sanitary facilities of the plant. However, in certain instances the chemical additives used in ore beneficiation can contribute to nutrient enrichment of receiving waters so that algal growth, for example, is accelerated in holding ponds. Nevertheless, the technology required for wastewater treatment is principally that required for removal of suspended solids and the removal of soluble metals since many of the latter have known toxic effects in the aquatic environment. Since the industries must deal with complex minerals containing many minor metals in addition to the major ones of copper, lead and zinc, the wastewater treatment problems become increasingly significant and difficult to treat as the concentrations of metals such as cadmium, mercury, chromium, arsenic, nickel and so on increase. In general the present wastewater treatment technology is based on separation of suspended solids followed by lime treatment to a pH sufficiently on the alkaline side to precipitate metallic elements as hydroxides which have generally low solubilities. The precipitated solids are removed in settling tanks or allowed to settle out in ponds. The metal values in the precipitated solids may be recovered if in high concentrations or the solids are buried or placed in holding ponds or tailing piles. The alkaline waters can then be neutralized to a pH acceptable for discharge or reuse. At this point the treated waters will still contain metals equal to or greater than the solubilities of the precipitated forms. In general these concentrations are greater than theoretical due generally to incomplete reactions, carryover of colloidal particulates, pH fluctuations and the effects of other ions in solution. Consequently, precipitation-type treatment systems, while effective, are limited by a number of physico-chemical laws and if the permissible concentrations of heavy metals are established at values lower than these limits, other and more costly treatment methods would be required. Among the latter are ion-exchange, evaporation, electrodialysis, and reverse osmosis.

The water pollution control problems within the industries are especially dependent upon plant, and mine location, i.e., in arid regions the water treatment, reuse and conservation is high out of necessity, whereas in areas blessed with a greater abundance of water, the water usage practices are less well optimized. In EPA Contract No. 14-12-870 "Water Pollution Control in the Non-Ferrous Metal Industry" it has been indicated that the industries are beginning to take or seriously considering taking a number of measures to improve the quality of the wastewater discharged. These procedures are well known throughout the field of wastewater treatment; however, the major considerations will revolve, undoubtedly, around the questions of water availability, value of materials, and the currently undefined water discharge standards.

# IV. INDUSTRY CHARACTERISTICS

## A. INDUSTRY STRUCTURE AND LOCATION ASPECTS

### 1. Domestic

#### a. Introduction

The United States has been the largest copper producing country in the world since before the turn of the century. The domestic primary copper industry is composed of approximately 200 firms engaged in producing and selling copper. The major producers are vertically integrated and have mining, smelting, refining, fabricating, and marketing interests. Other large producers mine and have processing facilities through the smelting or refining stages, and many companies mine and concentrate their ores and ship the product to custom plants for smelting and refining. The principal domestic producers are shown in Table IV-1. Of these, Anaconda, Inspiration, Kennecott, Magma, Phelps Dodge and White Pine are integrated from mining through primary metal production; Duval, Pima and the Miami Copper Division of the Tennessee Corp. are involved only in mining and milling and Asarco is the major custom smelter and refiner who purchases ores or concentrates from other producers (custom smelting) or will treat them for a fee and return the metal to the mining company for marketing (toll smelting).

#### b. Mining and Milling

In the United States, over 300 mines produce copper. Copper ore was the principal product of almost 200 mines, and the others, mostly lead and zinc mines, produced copper as a byproduct and coproduct. The top five mines each produced more than 100,000 tons of contained metal, amounting to 45% of the total. The ore is beneficiated (crushed, ground and metal sulfides recovered by flotation) in mills that are located near the mines.

Most of the copper is mined in five western states--Arizona, Montana, Nevada, New Mexico, and Utah--(93.5% in 1970) and essentially all of the remainder came from Michigan, Tennessee, and Missouri, as shown in Table IV-2 for the years 1968, 1969, and 1970.

The major copper mines are shown in Table IV-3. Also included in the table is mine employment (when available). On the basis of published data we have estimated the cost of mining and milling and divided the mines into three relative cost categories: high, medium and low. This table has been used later in Volume III in isolating the major mines that would suffer an impact from increased pollution control costs at smelters and refineries.

#### c. Smelting

Traditionally the smelters have been situated near the mines in order to minimize transportation charges for concentrates. With the major copper mines centered in the Western States, most of the smelting capacity is in

TABLE IV-1

PRINCIPAL COPPER-PRODUCING COMPANIES
IN THE UNITED STATES, 1970

| Company | Mine Production, Short Tons |
|---|---|
| American Smelting and Refining Company | 72,500 |
| The Anaconda Company | 242,000 |
| Bagdad Copper Corporation | 17,000 |
| Duval Corporation | 97,000 |
| Inspiration Consolidated Copper Company | 66,000 |
| Kennecott Copper Corporation | 519,000 |
| Magma Copper Company | 112,000 |
| Phelps Dodge Corporation | 313,500 |
| Pima Mining Company | 66,000 |
| Tennessee Corporation - Miami Copper Division | 43,500 |
| White Pine Copper Company | 68,000 |

SOURCE: American Bureau of Metal Statistics, Yearbook 1970

TABLE IV-2

UNITED STATES MINE PRODUCTION OF RECOVERABLE COPPER BY MAJOR PRODUCING STATES: 1968, 1969, 1970

(Short Tons)

| State | 1968 | | | 1969 | | | 1970 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Amount | Rank | Per-cent | Amount | Rank | Per-cent | Amount | Rank | Per-cent |
| Arizona | 631,300 | 1 | 53 | 801,363 | 1 | 52 | 910,000 | 1 | 53 |
| Michigan | 74,590 | 4 | 6 | 75,226 | 6 | 5 | 69,500 | 6 | 4 |
| Montana | 64,862 | 6 | 5 | 103,314 | 5 | 7 | 123,031 | 4 | 7 |
| Nevada | 72,870 | 5 | 6 | 104,924 | 4 | 7 | 101,000 | 5 | 6 |
| New Mexico | 92,300 | 3 | 8 | 119,956 | 3 | 8 | 165,260 | 3 | 10 |
| Utah | 228,300 | 2 | 19 | 296,699 | 2 | 19 | 295,000 | 2 | 17 |
| Other | 34,708 | - | 3 | 43,097 | - | 3 | 42,059 | - | 3 |
| Total | 1,199,290 | | 100 | 1,544,579 | | | 1,705,850 | | |

SOURCE: United States Department of Interior, Bureau of Mines

TABLE IV-3

ESTIMATED MINING COSTS - MAJOR COPPER MINES AND MILLS

| Company | Location | Tons Ore in 1970 | Mining Cost | Employment |
|---|---|---|---|---|
| Kennecott: | | | | |
| Utah Copper Div. | Utah | 40,147,500 | L | 7,900* |
| Ray Mines Div. | Arizona | 12,432,192 | L | 2,100* |
| Chino | New Mexico | 8,276,276 | L | 1,500* |
| Nevada Mines | Nevada | 7,698,883 | H | 1,480* |
| Phelps Dodge: | | | | |
| Morenci | Arizona | 19,172,647 | L | 2,300* |
| New Cornelia | Arizona | 10,560,000 | L | 1,250* |
| Copper Queen | Arizona | 4,800,000 | H | 1,700 |
| Tyrone | New Mexico | 9,147,500 | L | 490 |
| Magma Copper Co.: | | | | |
| San Manuel | Arizona | 14,000,000 | L | 2,200* |
| Superior Div. | Arizona | 450,000 | L | 1,100* |
| Anaconda Co.: | | | | |
| Twin Buttes | Arizona | 8,762,000 | H | 1,000 |
| Berkeley Pit | Montana | 18,850,800 | M | {3,000 |
| Butte - U.G. | Montana | 543,125 | L | |
| Yerington | Nevada | 9,122,000 | L | 450 |
| White Pine Copper: | Michigan | 7,635,192 | M | 2,885* |
| Pima Mining Co.: | Arizona | 14,597,803 | L | 834 |
| Inspiration: | Arizona | 9,377,000 | L | 1,750* |
| Christmas | Arizona | 1,829,000 | H | 275 |
| American Smelting: | | | | |
| Mission | Arizona | 8,038,900 | L | 675 |
| Silver Bell | Arizona | 3,787,700 | L | 385 |
| Duval: | | | | |
| Mineral Park | Arizona | 5,871,721 | L | 411 |
| Esperanza | Arizona | 5,508,742 | L | 492 |
| Sierrita | Arizona | 14,318,125 | M | 1,205 |
| Battle Mtn. | Nevada | 1,636,457 | H | 294 |
| Bagdad: | Arizona | 2,100,000 | M | 525 |
| Cities Service: | | | | |
| Copper Cities | Arizona | 4,970,196 | L | - |
| Copperhill | Tennessee | 1,677,142 | H | 1,900* |

*Includes smelter employment.

SOURCE: ADL Estimates - E/MJ Directory, 1971

that area. The number of smelters has declined from 20 in 1960 to 15 today, 13 of them west of the Mississippi. The thirteen western smelters are operated by six companies--Kennecott, Phelps Dodge, Anaconda, Inspiration and Newmont--who mine a major portion of their respective smelter input, and by Asarco--a major portion of whose input comes from ores mined by other companies.

The ownership of the primary copper smelters, and the approximate capacity of each plant (in tons of charge) in 1970 are shown in Table IV-4. Of these only the White Pine smelter in Michigan treats low sulfur native copper ore.

Of the remaining smelters, Magma will substantially increase its charge handling capacity to about 1 million tons. Should the emission control regulations in Montana require 90% emission control, Anaconda might build a new smelter with a capacity of 300,000 tons of copper per year. The capacity at Douglas will decrease substantially (as a part of an emission abatement program), while the capacity at other smelters is not expected to change by more than ± 20%.

In addition to these smelters, Phelps Dodge's new smelter in New Mexico is the only smelter that will definitely be built in the next few years.

The approximate flow of sulfide flotation concentrates between mines and smelters is shown in Table IV-5, based on information available in 1971-1972. The flow of concentrates can vary from year to year in the case of custom smelters, since the mine can change from one smelter to another when a better contract is obtained. For example, Pima has switched from Asarco to Phelps Dodge's Douglas smelter in recent years.

d. Refining

The major portion of the smelter output of blister copper is electrorefined. Copper electrolytic refineries have traditionally been located near the consumers on the Atlantic Coast, but several refineries have been built in the west. The east coast refineries still account for a major portion--about half--of electrorefining capacity. A smaller portion of smelter output is fire refined--principally in New Mexico and Michigan. The primary copper refineries, their ownership and the location, type and capacity of each refinery are shown in Table IV-6. Figure IV-1 shows the location of the smelters and refineries.

e. Fabrication

Fabricating companies are the principal consumers of refined copper. They work the metal into semi-finished form such as sheet, strip, rod, tube, wire and extruded or rolled shapes which are the raw materials for the manufacturing industries. About 35 companies in the United States are recognized as the important fabricators and users of copper. The larger fabricators,

TABLE IV-4

COPPER SMELTING WORKS OF UNITED STATES

| Company | Location | Approximate Capacity Tons of Copper Per Year (4) | Annual Capacity Tons of Material (1) | Number of Employees |
|---|---|---|---|---|
| American Smelting & Refining Co. | El Paso, Texas | 100,000 | 576,000 | 975 |
| American Smelting & Refining Co. | Hayden, Ariz. | 180,000 | 960,000 | 450 |
| American Smelting & Refining Co. | Tacoma, Wash. | 110,000 | 600,000 | 1,000 |
| Anaconda Company | Anaconda, Mont. | 210,000 | 1,000,000 | 2,000 |
| Cities Service Company | | | | |
| Copperhill Operations | Copperhill, Tenn. | 15,000 | 90,000 | * |
| Inspiration Consolidated Copper Co. | Miami, Ariz. | 140,000 | 450,000 | * |
| Magma Copper Company | | | | |
| San Manuel Division | San Manuel, Ariz. | 100,000 | 403,000 | * |
| Kennecott Copper Corporation: | | | | |
| Nevada Mines Division | McGill, Nev. | 70,000 | 400,000 | * |
| Chino Mines Division | Hurley, N.M. (2) | 90,000 | 400,000 | * |
| Ray Mines Division | Hayden, Ariz. | 80,000 | 420,000 | * |
| Utah Copper Division | Garfield, Utah | 300,000 | 1,000,000 | * |
| Phelps Dodge Corporation: | | | | |
| Douglas Smelter | Douglas, Ariz. | 110,000 | 875,000 | 650 |
| Morenci Branch | Morenci, Ariz. | 190,000 | 900,000 | * |
| New Cornelia Branch | Ajo, Ariz. | 70,000 | 300,000 | * |
| White Pine Copper Company | White Pine, Mich. | 90,000 | 90,000 (3) | * |

(1) At end of 1970. In tons of 2,000 lb.

(2) Produces fire-refined copper as well as blister.

(3) Tons of product.

(4) ADL estimates.

*Not available separately; included in Table IV-3

SOURCE: American Bureau of Metal Statistics Yearbook, 1970
ADL estimates



Arthur D Little, Inc

TABLE IV-5

APPROXIMATE FLOW OF CONCENTRATES BETWEEN COPPER MINES AND SMELTERS

| MINES | | SMELTERS: Kennecott, Utah | Kennecott, Hayden, Ariz. | Kennecott, Hurley, N.M. | Kennecott, McGill, Nev. | Asarco* El Paso, Texas | Asarco* Hayden, Arizona | Asarco* Tacoma, Wash. | P-D, Morenci | P-D, Ajo | P-D, Douglas | P-D, New, N.M. | Anaconda | Inspiration | Newmont | Cities Service |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kennecott------ | Utah Copper | 1 | | | | | | | | | | | | | | |
| | Ray, Ariz. | | 1 | | | | | | | | | | | | | |
| | Chino, N.M. | | | 1 | | | | | | | | | | | | |
| | Veteran, Tripp, Nev. | | | | 1 | | | | | | | | | | | |
| Phelps Dodge--- | Morenci, Ariz. | | | | | | | | 1 | | | | | | | |
| | New Cornelia, Ariz. | | | | | | | | | 1 | | | | | | |
| | Lavender Pit, Ariz. | | | | | | | | | | 1 | | | | | |
| | Tyrone, N.M. | | | | | | | | 1 | | 1 | | | | | |
| Magma---------- | San Manuel, Ariz. | | | | | | | | | | | | | | 1 | |
| | Magma, Ariz. | | | | | | | | | | | | | | 1 | |
| Anaconda------- | Twin Buttes, Ariz. | | | | | | 1 | | | | | | | 1 | | |
| | Berkeley, Mont. | | | | | | | | | | | | 1 | | | |
| | Yerington, Nev. | | | | | | | | | | | | 1 | 2 | | |
| | Butte Hill, Mont. | | | | | | | | | | | | 1 | | | |
| Pima---------- | Pima, Ariz. | | | | | 1 | 1 | | | | 1 | | | | | |
| Inspiration---- | Inspiration, Ariz. | | | | | | | | | | | | | 1 | | |
| | Christmas, Ariz. | | | | | | | | | | | | | 1 | | |
| Asarco--------- | Mission, Ariz. | | | | | 2 | 1 | | | | | | | | | |
| | Silver Bell, Ariz. | | | | | 2 | 1 | | | | | | | | | |
| Duval---------- | Sierrita | | | | | | 2 | 1 | | | | | | | | |
| | Mineral Park | | | | | | 2 | 1 | | | | | | | | |
| | Esperanza | | | | | 1 | 2 | | | | | | | | | |
| | Battle Mtn., Nev. | | | | | 1 | | 1 | | | | | | | | |
| Cities Service - | Copper Cities, Ariz. | | | | | | | | | | | | | 1 | | |
| | Copper Hill, Tenn. | | | | | | | | | | | | | | | 1 |
| Bagdad Cu------ | Bagdad, Ariz. | | | | | | 1 | | | | 2 | | | | | |
| Others | | | | | | 1 | 1 | 1 | | | | | | 1 | 1 | |

1 - major flow

2 - minor flow

* Flows to Asarco Smelters can vary month to month

SOURCE: ADL Estimates based on data in ABMS Yearbook 1970 and Annual Reports.

TABLE IV-6

UNITED STATES COPPER REFINERY CAPACITY

[Annual Capacity At End Of 1970 In Tons Of 2,000 lb.]

| Company | Situation | Annual Capacity, Tons of Material |
|---|---|---|
| Electrolytic: | | |
| The Anaconda Company | Great Falls, MT | 190,000 |
| Asarco | Baltimore, MD | 318,000 |
| Asarco | Perth Amboy, NJ | 168,000 |
| Asarco | Tacoma, Wash. | 156,000 |
| Cerro Copper & Brass Div. of Cerro Corp. | St. Louis, MO | 44,000 |
| Inspiration Consolidated Copper | Inspiration, AZ | 70,000 |
| International Smelting & Refining Co. | Raritan, Perth Amboy, NJ | 150,000 |
| Kennecott Copper Corp. | Garfield, UT | 186,000 |
| Kennecott Refining Corp. | Anne Arundel County, MD | 276,000 |
| Newmont Corporation | San Manuel, AZ | 200,000 |
| Phelps Dodge Refining Corp. | El Paso, TX | 420,000 |
| Phelps Dodge Refining Corp. | Laurel Hill, Maspath, NY | 74,000 |
| United States Metals Refining Co. (Subsidiary of AMAX, Inc.) | Carteret, NJ | 175,000 |
| Lake and Fire Refining: | | |
| Kennecott Copper Corp. | Hurley, NM | 103,000 |
| Phelps Dodge Refining Corp. | El Paso, TX (a) | 23,000 |
| United States Metals Refining Co. (Subsidiary of AMAX, Inc.) | Carteret, NJ | 85,000 |
| White Pine Copper Co. | White Pine, MI | 90,000 |

(a) From Morenci ores

SOURCE: ABMS Yearbook, 1970 - ADL Estimates

FIGURE IV-1

WHERE THE SMELTERS AND REFINERIES ARE LOCATED

SOURCE: METALS WEEK



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representing more than 50 percent of the total volume of business, are affiliated with the major copper producers, who thus have production facilities from the mines to the finished copper and brass products.

The primary brass mills make up that part of the industry engaged in initial forming or alloying and forming refinery shapes and scrap into standard semifabricated forms of copper and copper alloys such as plate, sheet, strip tube, rod, and wire. Subsequent operations involve further rolling, drawing, and shaping so that the products will meet specification dimension and design.

The primary wire mills roll refined copper wirebars or extrude refined copper billets into rod that are drawn in stages to finished wire. Wire is also produced by redraw mills that obtain rod from the primary wire mills. There are other types of mills designed for singular operation such as insulation and stranding.

We estimate that about two-thirds of the brass mill sales in the United States are accounted for by companies integrated back through mining while only one-third of the wire mill sales are so integrated. One major reason for this difference is the nature of the products. Most brass mill products are relatively standard, high volume items. On the other hand, wire products comprise of a large number of high-value-added specialty items that are sophisticated and low in volume. The standard high-volume items are produced by integrated companies, while the specialities are produced by small independent operations.

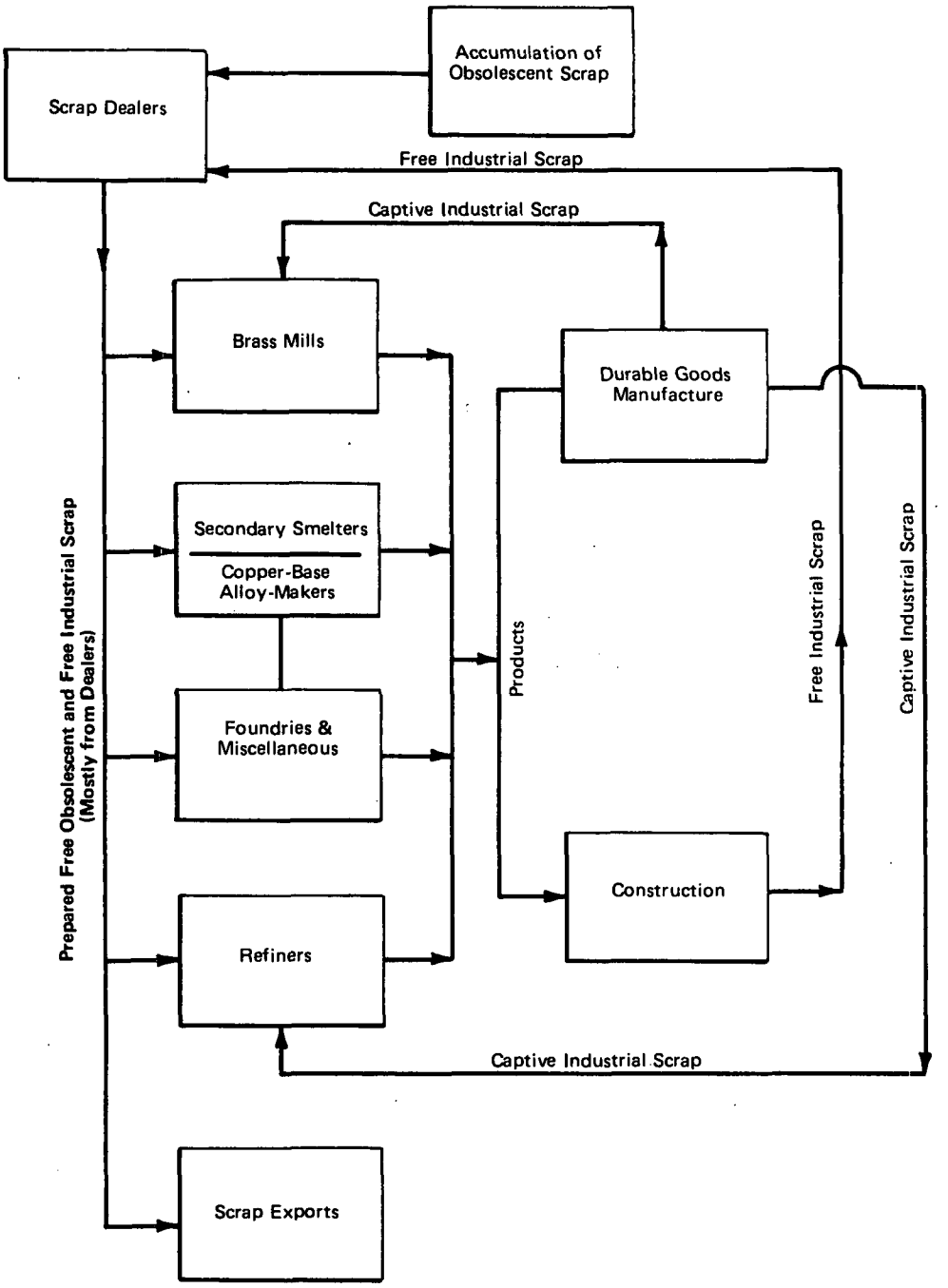
f. Secondary Copper

Copper recovered from copper scrap as metal, as alloys without separation of the copper or as compounds, is known as secondary copper. There are two major classifications of secondary copper. New scrap is generated in the fabrication or manufacture of copper articles, and includes defective finished or semifinished articles that must be reworked. Copper produced from old scrap consists of articles that have been discarded after serving a useful purpose.

The flow of copper scrap is shown in Figure IV-2 which indicates the channels through which much of the reclaimed copper returns to industry from scrap dealers and fabricators. The principal source of copper scrap is in heavily populated industrial areas and most of the plants that treat secondary materials are located nearby.

2. International

The United States has been the largest copper-producing country in the world since 1883, except for 1934 when economic conditions adversely affected domestic production. In 1970, the United States produced about 25% of the total world mine production. Other principal copper-producing countries are the U.S.S.R., Zambia, Chile, Canada, the Congo (Kinshasa), Peru, and Southwest Pacific. The four developing countries--Chile, Peru, Zambia and Kinshasa (the so-called CIPEC countries)--account for over 50% of the free world mine




**Source:** U. S. Bureau of Mines

**FIGURE IV–2 FLOW OF COPPER SCRAP IN UNITED STATES (Excluding Industrial Homescrap)**

production outside the U.S. The production at mine, smelter and refinery, and consumption of copper in the Free World are shown in Table IV-7. It can be seen that the major consumers are the developed countries, while the CIPEC countries are major producers. Production and consumption in U.S. and Australia are more or less in equilibrium, while Canada is a major exporter of domestic production amongst the developed countries.

Tables IV-8, IV-9 and IV-10 show, respectively, the principal foreign producers and the disposition of their copper, copper smelter capacity and copper refinery capacity. Many large domestic producers through subsidiaries or stockholdings operate foreign copper producing properties abroad, and are also involved domestically in the production of other non-ferrous metals such as aluminum, lead and zinc. The financial posture of some of the companies has been changed by expropriation of foreign properties and nationalization in other countries continues to be a threat.

## TABLE IV-7

## 1969 FREE WORLD PRINCIPAL COPPER PRODUCING AND CONSUMING COUNTRIES

| | Mine production * | | | Smelter production | | | Refined production | | | Refined consumption | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rank | Amount | Per-cent | Rank | Amount | Per-cent | Rank | Amount | Per-cent | Rank | Amount | Per-cent |
| Australia | 8 | 144,512 | 3 | 10 | 137,126 | 2 | 10 | 152,779 | 2 | 8 | 109,348 | 2 |
| Belgium | ... | ..... | .. | ... | 61,508 | 1 | 7 | 316,029 | 5 | 7 | 123,678 | 2 |
| Canada | 4 | 551,370 | 10 | 5 | 428,023 | 8 | 5 | 450,620 | 7 | 6 | 258,489 | 4 |
| Chile | 3 | 758,493 | 14 | 3 | 712,857 | 13 | 4 | 499,232 | 8 | ... | 21,715 | .. |
| Congo (Kinshasa) | 5 | 401,237 | 8 | 6 | 401,017 | 7 | 9 | 200,949 | 3 | ... | ..... | .. |
| France | ... | 441 | .. | ... | 10,472 | ... | ... | 40,785 | .. | 5 | 369,050 | 6 |
| Japan | 10 | 132,607 | 3 | 4 | 552,363 | 10 | 2 | 693,567 | 11 | 2 | 889,446 | 14 |
| Peru | 6 | 219,358 | 4 | 8 | 137,722 | 3 | ... | 34,722 | .. | ... | 4,189 | .. |
| Philippines | 7 | 144,842 | 3 | ... | ..... | ... | ... | ..... | .. | ... | ..... | .. |
| South Africa | 9 | 140,102 | 3 | 9 | 140,323 | 2 | ... | 67,461 | 1 | ... | 38,250 | .. |
| United Kingdom | ... | ..... | .. | ... | ..... | ... | 8 | 218,476 | 3 | 4 | 602,738 | 10 |
| United States | 1 | 1,544,579 | 29 | 1 | 1,585,491 | 28 | 1 | 2,208,000 | 34 | 1 | 2,142,210 | 34 |
| West Germany | ... | 1,543 | .. | 7 | 203,374 | 4 | 6 | 443,235 | 7 | 3 | 722,778 | 12 |
| Zambia | 2 | 793,105 | 15 | 2 | 775,689 | 14 | 3 | 664,907 | 10 | ... | ..... | .. |
| Total | | 5,314,114 | .. | ... | 5,655,623 | ... | ... | 6,452,075 | .. | ... | 6,289,062 | .. |

| | Refined exports | | | Refined imports | | | Unrefined exports | | | Unrefined imports | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rank | Amount | Per-cent | Rank | Amount | Per-cent | Rank | Amount | Per-cent | Rank | Amount | Per-cent |
| Australia | 10 | 36,045 | 2 | ... | ..... | ... | 8 | 21,164 | 2 | ... | ..... | .... |
| Belgium | 3 | 280,315 | 11 | 5 | 205,579 | 9 | ... | ..... | ... | 4 | 177,249 | 14 |
| Canada | 5 | 209,988 | 9 | ... | 18,188 | 1 | 4 | 157,849 | 12 | ... | ..... | .... |
| Chile | 2 | 472,115 | 19 | ... | ..... | ... | 1 | 251,545 | 19 | ... | ..... | .... |
| Congo (Kinshasa) | 6 | 202,052 | 8 | ... | ..... | ... | 2 | 200,067 | 15 | ... | ..... | .... |
| France | ... | 6,834 | .. | 3 | 356,153 | 15 | 9 | 11,023 | 1 | 6 | 17,416 | 1 |
| Japan | ... | ..... | .. | 4 | 219,688 | 9 | ... | ..... | ... | 1 | 463,738 | 35 |
| Peru | 9 | 37,368 | 2 | ... | ..... | ... | 3 | 180,777 | 14 | ... | ..... | .... |
| Philippines | ... | ..... | .. | ... | ..... | ... | 6 | 144,842 | 11 | ... | ..... | .... |
| South Africa | ... | 29,101 | 1 | ... | ..... | ... | 7 | 104,608 | 8 | ... | ..... | .... |
| United Kingdom | 8 | 78,153 | 3 | 1 | 459,769 | 19 | ... | ..... | ... | 5 | 49,163 | 4 |
| United States | 4 | 214,987 | 9 | 6 | 131,063 | 5 | ... | 5,300 | ... | 2 | 277,124 | 21 |
| West Germany | 7 | 105,270 | 4 | 2 | 392,309 | 16 | ... | 1,323 | ... | 3 | 260,473 | 20 |
| Zambia | 1 | 677,915 | 28 | .. | ..... | ... | 5 | 153,220 | 12 | ... | ..... | .... |
| Total | ... | 2,459,159 | .. | ... | 2,350,006 | ... | ... | 1,315,273 | ... | ... | 1,317,313 | .... |

*Rank indicates position among ten top countries – no rank number indicates country not among top ten.
Amount in short tons.
% indicates percent of total.

SOURCE: WORLD METAL STATISTICS, BDC

## TABLE IV-8

## PRINCIPAL COPPER PRODUCERS AND THE DISPOSITION OF THEIR COPPER

### CANADA

| | | | |
|---|---|---|---|
| Anaconda American Brass Ltd. | Asarco, Tacoma, Wash. | Asarco, Tacoma, Wash. | Anaconda Sales Co. |
| Anaconda American Brass Ltd. | Boliden Aktiebolag, Stockholm, Sweden | Boliden Aktiebolag, Stockholm, Sweden | Boliden Aktiebolag, Stockholm, Sweden |
| Asarco, Buchans Unit | Norddeutsche Affinerie, Germany | Norddeutsche Affinerie, Germany | Norddeutsche Affinerie, Germany |
| Atlantic Coast Copper Corp. | Gaspe Copper Mines, Ltd. | Canadian Copper Refiners, Ltd. | Noranda Sales Corp., Ltd. |
| Bethlehem Copper Corp. | Sumitomo Metal Mining Co., Ltd., Shisakajima Island, Japan | Sumitomo Metal Mining Co., Ltd., Niihama, Japan | Sumitomo Shoji Kaisha Ltd., Tokyo, Japan |
| Campbell Chibougamau Mines, Ltd. | Noranda, Noranda, Quebec. | Canadian Copper Refiners, Ltd. | Noranda Sales Corp., Ltd. |
| Copperfields Mining Corp., Ltd. | Japan | Japan | Philipp Brothers |
| Craigmont Mines, Ltd. | Japan | Japan | The Company |
| Ecstall Mining, Ltd., Div. of Texas Gulf Sulphur Co. | Noranda, Noranda, Quebec. | Canadian Copper Refiners, Ltd. | Texas Gulf Sulphur Company |
| Falconbridge Nickel Mines, Ltd. | Own plant, Falconbridge, Ont. | Falconbridge Nikkelverk A/S, Norway | The Company, Brandeis, Goldschmidt & Co., Ltd. (London), Huetten Metal G.m.b.H., (Frankfurt), and Victoria S.p.A. (Genoa), Metaux Bruts Belges S.p.r.l., Antwerp, AB Ferrolegeringar, Sweden, Francomet, Paris, Mitsubishi Shoji Kaisha Ltd., Tokyo, Jorge Pascual S.A., Barcelona, Voegeli & Co., Metalle, Zurich. |
| Gaspe Copper Mines, Ltd. | Own plant, Murdochville, Que. | Canadian Copper Refiners, Ltd. | Noranda Sales Corp., Ltd. |
| Gullbridge Mines, Ltd. | Gaspe Copper Mines, Ltd. | Canadian Copper Refiners, Ltd. | Noranda Sales Corp., Ltd. |
| Hudson Bay Mining and Smelting Co., Limited | Own plant, Flin Flon, Manitoba | Canadian Copper Refiners, Ltd. | Hudson Bay Mining and Smelting Co., Limited |
| International Nickel Co. of Canada, Ltd. | Own plants, Copper Cliff, and Coniston, Ont. | International Nickel Co. of Canada, Ltd., Copper Cliff | The Company and Ametalco (Toronto) Ltd. |
| Lake Dufault Mines, Ltd. | Noranda, Noranda, Quebec. | Canadian Copper Refiners, Ltd. | Noranda Sales Corp., Ltd. |
| Mattagami Lake | Noranda, Noranda, Quebec. | Canadian Copper Refiners, Ltd. | Noranda Sales Corp., Ltd. |
| McIntyre Porcupine Mines, Ltd. | Japan | Japan | Philipp Brothers |
| Noranda Mines Ltd. | Own plant, Noranda, Quebec. | Canadian Copper Refiners, Ltd. | Noranda Sales Corp., Ltd. |
| Normetal Mines Limited | Noranda, Noranda, Quebec. | Canadian Copper Refiners, Ltd. | Noranda Sales Corp., Ltd. |
| Opemiska Copper Mines, Ltd. | Noranda, Noranda, Quebec. | Canadian Copper Refiners, Ltd. | Noranda Sales Corp., Ltd. |
| Patino Mining Corp. | Noranda, Noranda, Quebec. | Canadian Copper Refiners, Ltd. | Noranda Sales Corp., Ltd. |
| Quemont Mines Limited | Noranda, Noranda, Quebec. | Canadian Copper Refiners, Ltd. | Noranda Sales Corp., Ltd. |
| Sherritt Gordon Mines, Ltd. | Hudson Bay Sm. & Ref. Co., Ltd., Flin Flon, Manitoba, Japan. | Canadian Copper Refiners, Ltd. Japan. | Noranda Sales Corp., Ltd. |
| Solbec/Cupra Mines | Japan | Japan | Philipp Brothers |
| Tribag Mining Co., Ltd. | Noranda, Noranda, Quebec | Noranda, Noranda, Quebec | Noranda Sales Corp., Ltd. |
| Western Mines, Ltd. | Japan | Japan | Philipp Brothers |

### OTHERS

| | | | |
|---|---|---|---|
| Asarco Mexicana, S.A. | Own plant, San Luis Potosi, S.L.P. | Cobre de Mexico, S.A. | Various |
| Compania Minera de Cananea, S.A. de C.V. | Own plant, Cananea, Sonora | Cobre de Mexico, S.A. | Cobre de Mexico S.A. |
| Macocozac, S.A. | Asarco Mexicana, S.A. San Luis Potosi, S.L.P. | Asarco, Perth Amboy, New Jersey | Ametalco, Inc. |
| Met-Mex Penoles, S.A. | Asarco Mexicana, S.A. San Luis Potosi, S.L.P. | Cobre de Mexico, S.A. | Various |
| Compania de Cobre, Salvador, S.A. | Own plant, Potrerillos, Chile. | Own plant, Potrerillos and Raritan Copper Wks. | Anaconda Sales Co. |
| Atlas Cons. Mng. & Dev. Corp. | Mitsubishi Metal Mining Co., Japan | Mitsubishi Metal Mining Co., Japan | MMM & Ansor Corp. |
| Cerro de Pasco Corpn. | Own plant, Oroya, Peru. | Own plant, Oroya, Peru. | Cerro Sales Corp. |
| Compania de Cobre, Chuquicamata, S.A. | Own plant, Chuquicamata, Chile | Own plant, Chuquicamata and Raritan Copper Wks. | Anaconda Sales Co. |
| Compania Minera Exotica, S.A. | Compania de Cobre, Chuquicamata, Chile | Compania de Cobre, Chuquicamata, Chile | Anaconda Sales Co. |
| Cyprus Mines Corpn. | Norddeutsche Affinerie, Germany | Norddeutsche Affinerie, Germany | Ametalco, Inc. |
| Generale Congolaise des Minerais | Own plants, Congo | Own plants, Congo, and Olen (Belgium) Refinery of Metallurgie Hoboken S.A. | Soc. Gen. des Minerais |
| Kilembe Mines Ltd. | Own plant, Uganda | Nippon Mining Co. Ltd., Japan | Falconbridge Nickel Mines Ltd. |
| Lepanto Consolidated | Asarco, Tacoma, Wash. and various smelters in Japan and Korea | Asarco, Tacoma, Wash. and various refineries in Peru, Japan and Korea | Various |
| Mantos Blancos | Own plant, Mantos Blancos, Chile | Shipped as high conductivity fire refined | Sudamin, Brussels, Belgium & Associates |
| Mount Isa Mines Limited | Own plant, Mount Isa, Australia | Copper Refineries Pty. Ltd., Townsville, Australia | Mount Isa Mines Ltd. |
| Nchanga Consolidated Copper Mines Ltd. | Own plant Nkana, Zambia | Shipped as blister, or refined at own plants Chingola and Nkana | Anmercosa Sales Ltd. |
| O'Okiep Copper Co., Ltd. | Own plant, Republic of South Africa | Various | Ametalco, Ltd. |
| Palabora Mining Co., Ltd. | Own plant, Phalaborwa, Republic of S. Africa | Own plant, Phalaborwa and Norddeutsche Affinerie, Germany | Rio Tinto-Zinc Corp. |
| Peko Mines, N.L. | Sumitomo's Kunitomi, Japan plant | Shipped as concentrates to Sumitomo Shoji Kaisha Ltd., Tokyo | Duval & Co. Ltd., Tokyo, Japan |
| Roan Consolidated Mines Limited—Chambishi Division(b) | Mufulira and Luanshya smelters | Mufulira Division and NCR Division refineries of Roan Consolidated Mines Limited | Ametalco Limited |
| Chibuluma Division(b) | Mufulira smelter | Mufulira Division and NCR Division refineries of Roan Consolidated Mines Limited | Ametalco Limited |
| Luanshya Division(a) | Own plant, Luanshya, Zambia | Electro-refined at Ndola Copper Refinery—NCR Division of Roan Consolidated Mines Limited | Ametalco Limited |
| Mufulira Division(b) | Own plant, Mufulira, Zambia | Mufulira Division and NCR Division refineries of Roan Consolidated Mines Limited | Ametalco Limited |
| Sociedad Minera Pudahuel | Enami, Las Ventanas, Chile | Enami, Las Ventanas, Chile | Ametalco Limited |
| Sociedad Minera El Teniente S.A. | Own plant, Caletones, Chile | Part fire-refined at own plant in Chile; part shipped as blister; part electro-refined at Enami, Las Ventanas, Chile | Sociedad Minera El Teniente S.A. |
| Southern Peru Copper Corp. | Own plant, Ilo, Peru | Various | Various |
| Tsumeb Corp. Ltd. | Own plant, Tsumeb, S.W.A. | Various | Ametalco, Inc. |

SOURCE: ABMS Yearbook, 1970

TABLE IV-9

COPPER SMELTING WORKS OF THE WORLD

AT END OF 1970 (IN TONS OF 2,000 LB.)

## CANADA

| | | |
|---|---|---|
| Falconbridge Nickel Mines, Ltd.... | Falconbridge, Ont. | 600,000 |
| Gaspe Copper Mines, Ltd..... | Murdochville, Que. | 260,000 |
| Hudson Bay Min & Smg. Co., Ltd.. | Flin Flon, Manitoba | 575,000 |
| International Nickel Co. of Canada, Ltd..... | Copper Cliff, Ont. | 5,600,000 |
| International Nickel Co. of Canada, Ltd..... | Coniston, Ont. | 1,000,000 |
| Noranda Mines, Ltd..... | Noranda, Que. | 1,700,000 |
| Total..... | ..... | 9,735,000 |

## MEXICO

| | | |
|---|---|---|
| Asarco Mexicana, S.A..... ..... | San Luis Potosi | 300,000 |
| Cia. Minera de Santa Rosalia, S.A... | Santa Rosalia, Baja, Calif. | 100,000 |
| Compania Minera de Cananea, S.A. de C.V..... ..... | Cananea, Son. | 290,000 |
| Total..... | ..... | 690,000 |

SOURCE: ABMS Yearbook, 1970

## TABLE IV-9 (Cont'd)

The listing of copper smelting works is according to latest available information. The annual capacity is estimated on the basis of dry tons of materials smelted that yield a product. A blank space has been left in the capacity column, where data was not obtainable.

| Company | Situation of Works | Annual Capacity at End of 1970 | Tons |
|---|---|---|---|
| **SOUTH AMERICA** | | | |
| **Chile:** | | | |
| Compania de Cobre, Salvador, S.A | Potrerillos | 250,000 | s.t |
| Compania de Cobre, Chuquicamata, S.A | Chuquicamata | 600,000 | s.t. |
| Cia. Minera Disputada de las Condes S. A | Chagres | 85,000 | s.t. |
| Empresa Nacional de Mineria (ENAMI) | Las Ventanas | 165,000 | s.t. |
| Empresa National de Minera—Enami | Paipote | 150,000 | s.t. |
| Mantos Blancos | Mantos Blancos | 80,000 | m.t. |
| Sociedad Minera El Teniente S.A | Caletones | 986,000 | s.t. |
| **Peru:** | | | |
| Cerro de Pasco Corporation | Oroya | 400,000 | s.t. |
| Southern Peru Copper Corp | Ilo | 500,000 | s.t. |
| **EUROPE (a)** | | | |
| **Belgium:** | | | |
| Metallurgie Hoboken-Overpelt S.A | Hoboken | 45,000 | m.t. |
| La Métallo-Chimique S.A | Beerse | 100,000 | m.t. |
| **Finland:** | | | |
| Outokumpu Oy | Harjavalta | 50,000 | m.t. |
| **Germany, Federal Republic:** | | | |
| Duisburger Kupferhütte | Duisburg | 30,000 | m.t. |
| Hüttenwerke Kayser A.G | Lünen | 75,000 | m.t. |
| Norddeutsche Affinerie | Hamburg | | |
| **Norway:** | | | |
| A/S Sulitjelma Gruber | Sulitjelma | 6,600 | m.t. |
| **Spain:** | | | |
| Cia. Espanola de Minas de Rio Tinto S.A | Rio Tinto, Huelva | 22,000 | m.t. |
| Industrias Reunidas Minero-Metalurgicas S.A | Asua (Vizcaya) | 18,000 | m.t. |
| **Sweden:** | | | |
| Boliden Aktiebolag | Rönnskär | 65,000 | m.t. |
| **Yugoslavia:** | | | |
| Rudnici Bakra i Topionice | Bor | 360,000 | m.t. |
| **ASIA** | | | |
| **India:** | | | |
| Indian Copper Corporation | Moubhandar, Bihar | 38,000 | m.t. |
| **Japan:** | | | |
| Dowa Mining Co. Ltd | Kosaka, Akita-ken | 39,600 | m.t. |
| Furukawa Mining Co. Ltd | Ashio, Tochigi-ken | 38,400 | m.t. |
| Mitsui Mining & Smelting Co. Ltd | Hibi, Okayama-ken | 48,000 | m.t. |
| Mitsubishi Metal Mining Co. Ltd | (Closed) | | m.t. |
| | Naoshima, Kagawa-ken | 148,400 | m.t. |
| Nippon Mining Co. Ltd | Hitachi, Ibaragi-ken | 60,000 | m.t. |
| | Saganoseki, Oita-ken | 12,000 | m.t. |
| Onahama Smelting & Refining Co., Ltd | Onahama, Fukushima-ken | 90,000 | m.t. |
| Rasa Industry Co. Ltd | Miyako, Iwate-ken | 24,000 | m.t. |
| Sumitomo Metal Mining Co. Ltd | Kunitomi, Hokkaido | 15,600 | m.t. |
| | Bessgi, Ehime-ken | 72,000 | m.t. |
| Toho Zinc Co., Ltd | Onahama, Fukushima-ken | 18,600 | m.t. |
| **Korea:** | | | |
| Korea Mining & Smelting Corp | Chang Hang | 66,000 | m.t. |
| **Turkey:** | | | |
| Ergani Bakir Isletmesi Müessesesi Müdürlüğü | Elazig-Maden | 18,000 | m.t. |
| Murgul Bakir Isletmesi Müessesesi Müdürlüğü | Artvin-Murgul | 12,000 | m.t. |
| **AFRICA** | | | |
| **Congo:** | | | |
| Generale Congolaise des Minerais | Lubumbashi | 130,000 | m.t. |
| **Republic of South Africa:** | | | |
| Messina (Transvaal) Dev. Co., Ltd | Messina, Zoutpansberg Dist., Transvaal | 13,000 | l.t. |
| O'Okiep Copper Co., Ltd | Nababeep | 150,000 | s.t. |
| Palabora Mining Co., Ltd | Phalaborwa, Transvaal | 300,000 | m.t. |
| **Rhodesia:** | | | |
| Messina Rhodesia Smelting & Refining Co., Ltd | Alaska, near Sinoia | 25,000 | l.t. |
| **South West Africa:** | | | |
| Tsumeb Corporation, Ltd | Tsumeb | 80,000 | s.t. |
| **Uganda:** | | | |
| Kilembe Mines Ltd | Jinja, on north shore of Lake Victoria, at the Nile River headwaters | 20,000 | l.t. |
| **Zambia:** | | | |
| Roan Consolidated Mines Limited | | | |
| Luanshya Division (b) | Luanshya | 450,000 | m.t. |
| Mufulira Division | Mufulira | 660,000 | m.t. |
| Nchanga Consolidated Copper Mines Ltd | Nkana | 1,200,000 | m.t. |
| **AUSTRALIA** | | | |
| Electrolytic Ref. & Sm. Co. of Australia | Port Kembla, N. S. W | 30,000 | l.t. |
| Mount Lyell Mining & Ry. Co., Ltd | Queenstown, Tasmania | 15,000 | l.t. |
| Mount Isa Mines, Ltd | Mount Isa, Queensland | 470,000 | l.t. |
| Mount Morgan, Ltd | Mount Morgan, Queensland | 80,000 | l.t. |

(a) Copper smelters in U.S.S.R. and other Iron Curtain countries are omitted owing to absence of accurate data. (b) Formerly Luanshya Mines Limited.

SOURCE: ABMS Yearbook, 1970

TABLE IV-10

COPPER REFINERY CAPACITY

Annual Capacity at End of 1970 in tons of 2,000 lb.

| CANADA | MEXICO |
|---|---|
| Canadian Copper Refiners | Cobre de Mexico, S.A. |
| Montreal, East, Quebec.....342,000 | Atzoapotzalco, D.F....79,000 |
| International Nickel Co. of Canada, Ltd. | |
| Copper Cliff, Ontario.....198,000 | |

SOURCE: ABMS Yearbook, 1970

TABLE IV-10 (Cont'd)

## COPPER REFINERIES—FREE WORLD—(EXCEPT CANADA AND MEXICO)

(Electrolytic except as otherwise stated; so far as possible plants treating only secondary material have been omitted.)

| Company | Situation of Works | Annual Capacity at End of 1970 | Tons |
|---|---|---|---|
| **SOUTH AMERICA** | | | |
| **Chile:** | | | |
| Compania de Cobre, Salvador, S.A. | Potrerillos | 72,000 | s.t. |
| Compania de Cobre, Chuquicamata, S.A. (c) | Chuquicamata | 405,000 | s.t. |
| Empresa Nacional de Mineria (ENAMI) | Las Ventanas | 84,750 | m.t. |
| Mantos Blancos (l) | Mantos Blancos | 27,800 | m.t. |
| Sociedad Minera El Teniente S.A. (a) | Caletones | 280,000 | s.t. |
| **Peru:** | | | |
| Cerro de Pasco Corpn. | Oroya, Peru | 45,000 | s.t. |
| **EUROPE (b)** | | | |
| **Austria:** | | | |
| Montanwerke Brixlegg G.m.b.H. | Brixlegg/Tirol | 20,000 | m.t. |
| **Belgium:** | | | |
| Metallurgie Hoboken-Overpelt, S.A. | Olen | 450,000(f) | m.t. |
| La Métallo-Chimique, S.A. | Beerse | 36,000 | m.t. |
| **Finland:** | | | |
| Outokumpu Oy | Pori | 48,000 | m.t. |
| **France:** | | | |
| Cie. Gen. d'Electrolyse du Palais | Le Palais | 30,000 | m.t. |
| **Germany, Federal Republic:** | | | |
| Hüttenwerke Kayser Aktiengesellschaft | Lünen | 75,000 | m.t. |
| Metallhüttenwerke Lübeck GmbH | Lübeck-Herrenwyk | 16,000 | m.t. |
| Norddeutsche Affinerie (d) | Hamburg | 220,000 | m.t. |
| Zinnwerke Wilhelmsburg | Hamburg | (k) | m.t. |
| **Norway:** | | | |
| Falconbridge Nikkelverk A/S | Kristiansand | 28,000 | s.t. |
| **Spain:** | | | |
| Electrolisis del Cobre S.A. | Palencia | 20,000 | m.t. |
| Industrias Reunidas Minero-Metalurgicas S.A. | Asua (Vizcaya) | 18,000 | m.t. |
| Soc. Española de Construcciones Electro-Mecánicas, S.A. | Cordoba | 60,000 | m.t. |
| Sociedad Industrial Asturiana "Santa Barbara" | Lugones (Oviedo) | 19,500 | m.t. |
| **Sweden:** | | | |
| Boliden Aktiebolag | Rönnskar | 53,000 | m.t. |
| **United Kingdom:** | | | |
| British Copper Refiners, Ltd. (a) | Prescot and Widnes, Lancashire | 170,000 | l.t. |
| Elkington Copper Refiners, Ltd. | Walsall, Staffs | 26,000 | l.t. |
| Enfield Copper Refining Co., Ltd. (a) | Brimsdown | 60,000 | l.t. |
| **Yugoslavia:** | | | |
| Rudarsko Topionicarski Bazen, Bor | Bor | 70,000 | m.t. |

SOURCE: ABMS Yearbook, 1970

TABLE IV-10 (Cont'd)

## COPPER REFINERIES—FREE WORLD—(EXCEPT CANADA AND MEXICO)

(Electrolytic except as otherwise stated; so far as possible plants treating only secondary material have been omitted.) (*Continued*)

| Company | Situation of Works | Annual Capacity at End of 1970 | Tons |
|---|---|---|---|
| **AFRICA** | | | |
| **Congo:** | | | |
| Generale Congolaise des Minerais (*o*) | Likasi-Shituru | 185,000 | m.t. |
| Generale Congolaise des Minerais (*o*) | Luilu, near Kolwezi | 125,000 | m.t. |
| **Zambia:** | | | |
| Roan Consolidated Mines Limited NCR Division (*m*) | Ndola | 135,000 | l.t. |
| Mufulira Division (*i*) | Mufulira | 185,000 | l.t. |
| Nchanga Consolidated Copper Mines Ltd. (*h*) | Chingola | 105,000(*g*) | m.t. |
| Nchanga Consolidated Copper Mines Ltd | Chingola and Nkana | 300,000(*j*) | m.t. |
| **Republic of South Africa:** | | | |
| Messina (Transvaal) Dev. Co. (*a*) | Messina, Transvaal | 13,000 | l.t. |
| Palabora Mining Co., Ltd. | Palabora Transvaal | 59,000 | m.t. |
| **Rhodesia:** | | | |
| The Messina Rhodesia Smelting & Ref. Co., Ltd. (*a*) | Alaska, near Sinoia | 25,000 | l.t. |
| **ASIA** | | | |
| **India:** | | | |
| Indian Copper Corp. (*a*) | Moubhandar, Bihar | 9,600 | m.t. |
| **Japan:** | | | |
| Dowa Mining Co. Ltd | Kosaka, Akita-ken | 42,000 | m.t. |
| | Okayama, Okayama-ken | 10,800 | m.t. |
| Furukawa Electric Co., Ltd | Nikko, Tochigi-ken | 42,000 | m.t. |
| Mitsubishi Metal Mining Co., Ltd | Osaka | 84,000 | m.t. |
| Mitsubishi Metal Mining Co., Ltd | Naoshima, Kagawa-ken | 84,000 | m.t. |
| Mitsui Mining & Smelting Co. Ltd | Takehara, Hiroshima-ken | 75,600 | m.t. |
| Nippon Mining Co. Ltd | Hitachi, Ibaragi-ken | 72,000 | m.t. |
| | Saganoseki, Oita-ken | 168,000 | m.t. |
| Onahama Smelting & Refining Co., Ltd | Onahama, Fukushima-ken | 120,000 | m.t. |
| Sumitomo Metal Mining Co. Ltd | Besshi, Ehime-ken | 120,000 | m.t. |
| Toho Zinc Co., Ltd | Onahama, Fukushima-ken | 14,400 | m.t. |
| **Korea, South:** | | | |
| Korea Mining & Smelting Corp | Chang Hang | 5,400 | m.t. |
| **Turkey:** | | | |
| Makina ve Kimya Endustrisi Kurumu | Kirikkale | 3,600 | m.t. |
| Rabak Elektrolitik Bakir Fabrikasi | Istanbul | 10,000 | m.t. |
| **AUSTRALIA** | | | |
| Copper Refineries Pty. Ltd. (*n*) | Townsville, Queensland | 100,000 | l.t. |
| Electrolytic Ref. & Sm. Co. (*d*) | Port Kembla, N.S.W. | 120,000 | l.t. |

In this table, data with respect to most companies has been directly reported to ABMS; in a few instances supplementary sources of information have been used.

(*a*) Furnace refining. (*b*) Copper refineries in U.S.S.R. and other Iron Curtain countries are omitted owing to absence of accurate data. (*c*) Includes electrowinning facilities. (*d*) Tankhouse. (*f*) Electrolytic copper products, of which 240,000 tons from the refinery's own tankhouse. (*g*) Cathode produced at Chingola are cast into wirebars at Nkana. (*h*) Type of plant: Leaching—Electrowinning. Quality: Electrolytic. (*i*) Formerly Mufulira Copper Mines Limited. (*j*) The annual capacity of refinery Tankhouse for producing cathode copper. The furnacing capacity for Electrolytic shapes is 325,000 short tons. (*k*) Taken over by Norddeutsche Affinerie. (*l*) High conductivity fire refined (in ingot bars or cakes) conforming to the specifications of ASTM designation for electrolytic copper, B 5-43, except that it is not produced by electrolytic process. (*m*) Formerly Luanshya Mines Limited, Ndola Copper Refinery. (*n*) Includes semi-continuous cast cakes, billets and special alloys. (*o*) Cathodes produced at Luilu near Kolwezi are cast into wirebars partly at Shituru-Likasi (Gecomin-Congo) and Olen (METALLURGIE-HOBOKEN—Belgium).

SOURCE: ABMS Yearbook, 1970

## B. THE INTERDEPENDENCE OF THE COPPER, LEAD AND ZINC INDUSTRIES*

The copper, lead and zinc industries, located in western U.S. are mutually interdependent and the existence of one industry depends to a certain extent on the existence of the other because the economics of any particular mine, mill or smelter are dependent on obtaining co-product and/or by-product credits for their other outputs. The overall crossflow of materials between these industries is shown in Table IV-11 and described in detail below.

Several copper mills produce a small tonnage of lead or lead-zinc concentrates. Similarly, several lead mines and mills in Missouri produce a copper concentrate which is shipped to a copper smelter. Lead and zinc occur almost invariably together in the same deposit in the Western U.S. and the mining and exploitation of these deposits is based on obtaining adequate co-product credits for both lead and zinc and associated precious metals.

On the smelter side there is also a flow of materials between copper, lead and zinc industries which enables each plant to obtain by-product credit for small quantities of residues that cannot be processed in an economical fashion internally within a particular smelter. An example of this flow is the El Paso smelter of Asarco where a copper smelter, a lead smelter and slag fuming facilities for zinc extraction are integrated in the same plant. Lead, zinc and other by-products in the copper circuit are eliminated as fume and dust during roasting and converting. These high lead/zinc fumes are an input into the lead circuit. The existence of this and other Western smelters also provides an outlet for the lead containing copper converter dusts from the Arizona copper smelters. If this dust were recycled, a deleterious buildup of lead would occur. In the lead circuit, copper in the lead is eliminated during drossing as a matte and this matte is transferred back to the copper circuit. Zinc in the lead circuit is slagged in the blast furnace and this slag is treated by slag fuming to produce zinc oxide which is then shipped to an electrolytic zinc plant. Several by-products are recovered from the fume and from impure lead bullion during refining.

The interrelationship beweeen western lead and zinc production is even closer because the western ores differ from the Missouri ores or those in the eastern U.S. in having a more intimate association of copper, iron, lead and zinc sulfides and usually having a higher impurity and/or precious metal content. As a result, the three western lead smelters (Asarco in El Paso, Texas and East Helena, Montana; and Bunker Hill in Kellogg, Idaho) include slag fuming facilities to recover zinc from the lead blast furnace slag and very extensive refining and by-product recovery facilities. The value of the by-products passing through a

*This section is identical in the copper, lead and zinc reports.

TABLE IV-11

CROSS-FLOW OF MATERIALS BETWEEN PRIMARY COPPER, LEAD AND ZINC INDUSTRIES

| | Source | Material Produced By Source | Industries Where Treated |
|---|---|---|---|
| A) Mining and Milling | Cu mills | Pb-Zn concentrate | Western Pb smelter; Zn smelter |
| | Pb-Zn mills | Cu concentrate | Cu smelters |
| | Pb mills | Cu concentrate | Cu smelters |
| | Pb-Zn mills | Pb conc.; Zn conc. | Pb smelter; Zn smelter |
| B) Smelting | Cu smelter | Pb-Zn converter dust | Western Pb smelter |
| | Pb smelter | ZnO fume from slag | Electrolytic Zn plant |
| | Pb smelter | Pb-Cu dross | Pb smelter |
| | Pb smelter | Au, Ag Cu matte | Cu smelter |
| | Zn-Pb smelter | Cd fume | Cd refinery |
| | Zn Horizontal retorts | Pb-Zn residue | Western Pb smelter |
| | Zn electrolytic | Pb-Zn residue | Western Pb smelter |
| | Cu smelter | Cu-As-Sb converter dust | Cu smelter (Tacoma) |
| | Pb smelter | Cu-As-Sb speiss | Cu smelter (Tacoma) |
| | Ag-Pb-Sb-Cu conc. | Cu-As-Sb speiss | Cu smelter (Tacoma) |
| C) Refining | Pb refinery | Bi dross | Bismuth refinery |
| | Pb refinery | Au-Ag skimmings | Au,Ag refinery |
| | Pb refinery | Pb-Cu dross | Pb smelter |
| | Cu refinery | Slag fume & residues | Cu &/or Pb smelter |
| | Cu refinery | anode slimes | By-product refinery (Au, Ag, Pt, Se, Te, Ni) |

SOURCE: ADL



Arthur D Little, Inc

western lead smelter is of the same magnitude as the value of the lead recovered. Thus, the western lead smelters are called "lead" smelters for convenience but, in reality, handle, process and collect several other metals such as silver, cadmium, bismuth, antimony, and others as discussed in detail in the next section. In Missouri, the lead blast furnace slag is sufficiently low in zinc and can be discarded. The lead bullion is quite pure and can be refined adequately by a smaller number of refining steps than necessary for western bullion. Should the western lead smelters close for one reason or another, the Missouri smelters would require major modifications in their flowsheets in order to treat western lead-zinc ores. These modifications would have to include slag fuming facilities and much more extensive lead purification and by-product recovery facilities. In other words, even if the western lead-zinc mines could absorb the additional freight for sending the concentrates to Missouri, major changes would have to occur at the smelters before the concentrates are acceptible.

The western type lead smelters also provide an essential service to the primary zinc industry. All the processes producing primary zinc also produce a residue that is high in lead and other inert materials such as zinc ferrite. The amount of residue, containing zinc, associated copper, lead and precious metals is generally higher for the marmatitic type western zinc ores. Up to 15% of the zinc in feed materials can be tied up in this fashion. The zinc smelter economics depend to a considerable extent on being able to realize a value for this residue. We understand that the value of this residue is related to its copper, lead, and precious metal content and contained zinc is not accounted for. Several alternative technologies exist for treating these residues for zinc recovery but the existence of the western type lead smelters has enabled several zinc smelters to realize a value for the other metal content of the residue. For example the residues from Bunker Hill's zinc plant in Kellogg, Idaho are treated in the adjoining lead plant, and the residues from the Oklahoma and Texas zinc plants are treated at the El Paso lead plant. The two remaining eastern zinc smelters (New Jersey Zinc and St. Joe Minerals), treat purer zinc ores and because of the processing conditions, produce residues much lower in zinc or other by-products than either the electrolytic or the horizontal retort processes used in Oklahoma and Texas. Both these eastern plants treat their residues internally for zinc recovery.

The western lead smelters also act as collectors of silver that is associated with the copper concentrates obtained in several mills in Northern Idaho. If anodes high in silver are electrorefined in a copper refinery, silver carry-over to the purified cathodes cannot be prevented. By charging the high silver copper concentrates into a lead smelter, silver and copper are separated. Silver collects in the lead bullion while copper is recovered as a sulfide dross and can then be shipped to a copper smelter.

The copper and lead ores in Idaho and Montana contain significant amounts of arsenic and antimony. The lead smelters produce a mixture of complex copper arsenides and antimonides termed "speiss" which requires separate handling. Arsenic in copper concentrates can be eliminated as fume from roasters or converters and arsenic trioxide obtained by repeated distillation. The Tacoma smelter of Asarco is the only smelter in the U.S. that accepts arsenical ores and concentrates or arsenical residues from other smelting operations (for example flue dust from Anaconda and speiss from the western primary lead and silver smelters and high arsenic concentrates from abroad).

Because arsenic is undesirable in the copper product, Tacoma produces $As_2O_3$ as a by-product and is the only domestic producer. The closing of the Tacoma smelter for any reason would affect several northwestern producers who require both East Helena and Tacoma to process their complex arsenic and antimony containing products and residues. Even more important, these residues are not disposable since the arsenic in it is in soluble form and could be leached out by groundwater. Hence, the only realistic alternative for them would be to set up their own arsenic treatment facilities similar to Tacoma's and in this sense Tacoma's arsenic handling capability is irreplacable.

## C. BY-PRODUCTS OF THE WESTERN MINING INDUSTRY*

The nonferrous mining industry involved in the production of copper, lead and zinc produces substantial quantities of by-products and/or co-products that are a major portion of the domestic production of these respective metals.

About 98% of the U.S. mine production of copper is recovered from ores mined primarily for their copper content, the remainder being recovered from complex or base metal ores. In addition to copper, important quantities of gold, silver, molybdenum, nickel, selenium, tellurium, arsenic, rhenium, iron, lead, zinc, sulfur, and platinum-group metals were recovered as by-products.

Ores containing lead also contain other valuable and recoverable commodities including antimony, arsenic, cadmium, copper, fluorspar, gallium, germanium, gold, indium, selenium, silver, and zinc. Lead ranges from the major product, as in the Missouri ores, to a co-product, as in the complex western ores, to a by-product in the eastern ores. When treating mixed ores, a division in contained metals is initiated during beneficiation with certain amounts of other metals remaining in the lead concentrate. Smelter further separates the various metals, and refining completes the dissociation. Copper, gold, silver, and zinc are the major

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*This section is identical in the copper, lead and zinc reports.

co-products or by-products associated with western lead ores, and minor by-products consist of antimony, bismuth, sulfur, and tellurium.

Zinc production affects, and in turn is affected by, the demand for and the economic aspects of a variety of co-products and by-products. Ores containing zinc also contain a varying amount of other valuable and recoverable materials including cadmium, copper, fluorspar, gallium, germanium, gold, indium, lead, manganese, silver, sulfur, and thallium. Zinc ranges from the major product as in the Tennessee, New York, New Jersey deposits, to a co-product as in the complex western ores and the Missouri lead belt. In concentration of the ore, a division of metals is initiated with certain metals remaining in the zinc concentrate. Metallurgical treatment to recover the zinc by roasting, followed by distillation, or electrolytic process further separates the metals and permits commercial recovery. The major products associated with zinc and recovered at zinc plants in stack gases, flue dusts, and residues are sulfur, cadmium, germanium, thallium, indium and gallium. Manganese is a co-product of zinc-lead manganese-silver ores at Butte, Montana, and zinc-manganese ores at Ogdensburg, New Jersey.

According to the U.S. Bureau of Mines, the smelting segment of the zinc industry realizes about 89 percent of its revenue from production of zinc. The two principal by-products are cadmium and sulfuric acid, representing about 7% and 3%, respectively, of total revenue. Other by-product metals including germanium, indium, thallium, and gallium are very minor contributors to total revenue, accounting for a combined total of about 1%.

Each individual by-product is discussed briefly below and available production statistics for 1968 (the latest year for which a consistent set of statistics were available from a single source) are presented in Table IV-12. The Table shows the quantity of by-products and co-products produced and their gross value based on projected average prices indicated by the Bureau of Mines and in line with current prices. The gross value is shown mainly to indicate the relative dollar-volume represented by these commodities. It should be realized that several of these commodities fluctuate widely in price and that their value at the stage they are separated from the primary product is considerably below the value shown since additional processing is necessary. The table also puts the by-product production in the perspective of the domestic mine production, smelter or refinery production and the domestic demand for each of these metals. Sulfur is a potential by-product that will be recovered (mainly as sulfuric acid) from the copper-lead-zinc industries in quantities amounting to about 2 million tons per year. As indicated in subsequent chapters, it will have a negative value in most cases.

### Antimony

Three mines located in Idaho account for the bulk of the domestic primary production of antimony, all of which is derived incidental to

TABLE IV-12

1968 STATISTICS REGARDING BY-PRODUCTS AND CO-PRODUCTS FROM U.S. Cu-Pb-Zn INDUSTRY

| By-Product or Co-Product | Source | Estimated Quantity of By-Product in Short Tons | Gross Value Million $ | Quantity of By-Product as % of Domestic Mine Production[1] | Quantity of By-Product as % of Smelter/ Refinery Production[2] | Quantity of By-Product as % of Domestic Demand[3] |
|---|---|---|---|---|---|---|
| Antimony | lead-silver | 1,019 | 1.1 | 58 | 8 | 2 |
| Arsenic | copper-lead | 2,900 | 0.4 | 100 | 47 | 12 |
| Bismuth | lead-zinc | 350 | 2.8 | 100 | 88 | 30 |
| Cadmium | zinc-lead | 1,890 | 11.3 | 100 | 35 | 28 |
| Gallium | zinc | NA | NA | NA | NA | NA |
| Germanium | zinc | 10 | 1.8 | 100 | 84 | 25 |
| Gold | copper | 510* | 30.6 | 34 | 30 | 6 |
| Indium | zinc | 230* | 0.7 | 100 | 49 | 42 |
| Manganese | zinc | 8,000 | 5.3 | NA | NA | NA |
| Molybdenum | copper | 11,700 | 46.8 | 25 | 25 | 42 |
| Nickel | copper | 2,000 | 5.0 | 13 | 13 | 1 |
| Platinum | copper | 5* | 0.6 | 100 | 8 | 1 |
| Rhenium | copper | 1.2 | 2.9 | 100 | 100 | 310 |
| Selenium | copper | 316 | 5.7 | 100 | 100 | 29 |
| Silver | lead-zinc-copper | 19,260* | 34.7 | 59 | 31 | 11 |
| Tellurium | copper | 60 | 0.7 | 100 | 100 | 55 |
| Thallium | zinc | 1.3 | -- | 100 | 49 | 40 |

*Thousand Troy Ounces

1. 100% indicates all of domestic production is a by-product; less than 100% indicates other production from a primary source or a source other than Cu-Pb-Zn mining.
2. 100% indicates absence of ore imports; less than 100% (and less than column 5) indicates ore or concentrate imports.
3. Greater than 100% (or greater than column 6) indicates exports.
4. NA: not available.

SOURCE: Adapted from Mineral Facts and Problems, U.S. Department of Interior, Bureau of Mines, Bulletin 650 (1970).

the production of lead-silver ores. Primary production of antimony at smelters was 12,500 tons in 1969. Only about 15% of this production was supplied by domestic sources chiefly as a co-product from silver ores or a by-product of lead ores. By-product antimonial lead produced at primary lead refineries was 1174 tons.

Arsenic

The only producer of arsenic in the U.S. is the Tacoma, Washington smelter of Asarco. Their current output is around 12,000 tons per year of arsenic oxide of which about 4-5000 tons is refined or white arsenic. We understand from Asarco that Tacoma's arsenic production is currently about 60% of the domestic demand.

Bismuth

Virtually all domestic production of bismuth results from the treatment of lead smelter products. The major bismuth producers are the Omaha refinery of Asarco and the U.S. Smelting Refining and Mining Company in East Chicago, Illinois (now shut down). Almost all domestic bismuth production is a by-product of the processing of complex western base metal ores. The bismuth normally enters primary and secondary lead smelters in varying quantities through the inputs and follows lead in the production sequence finally reporting to the lead refinery in lead bullion. Other sources are electrolytic sludges from copper and zinc refineries which are sent to a lead smelter for separation and refining.

Cadmium

Cadmium is a by-product mainly of zinc smelting and to a lesser extent of lead smelting. As such it provides income of about 4-10% of the value of slab zinc produced. The domestic production in 1969 amounted to about 6,300 tons based on domestic as well as imported flue dust, and imported zinc concentrates. Of these, 5,400 tons were produced at zinc plants, about 2,000 tons at electrolytic zinc plants and the remainder from retort and electrothermic plants. Until recently the domestic production and consumption of cadmium have been more or less in equilibrium but is a cyclical commodity and is rarely in balance for very long.

Gallium

Gallium is a by-product derived entirely from the processing of certain aluminum and zinc ores. Gallium is recovered by just one zinc producer, Eagle-Picher Industries, Incorporated.

Germanium

Germanium is a by-product of zinc production. One domestic refinery produces germanium by refining residues from zinc concentrates,

from domestic mines and from residues from other zinc refineries. Germanium is a minor aspect of this producer's base metal or manufacturing activities.

Gold

In the U.S., by-product and co-product production of gold accounted for 34% of the 1968 output. The major by-product gold producer was Kennecott who recovers gold as a by-product of copper production from the anode slimes obtained during copper electrorefining. Lead smelters and refineries are also important collectors and processors of gold (and silver).

Indium

Indium is a by-product of zinc production. The domestic indium industry is composed of two producers--Asarco and Anaconda--both of whom began production about 1940. Indium metal is produced mainly as an integral part of zinc operations or by processing indium-containing residues generated by other zinc producers. Indium is collected in western type lead smelters for subsequent recovery.

Manganese

Manganese is a co-product of lead-zinc manganese silver ores in Montana and in New Jersey.

Molybdenum

About one-third of the domestic production of molybdenum is obtained as a by-product or co-product during the processing of copper, tungsten and uranium ores. Kennecott is the largest producer of by-product molybdenum and recovers molybdenum from copper ores at its mines near Salt Lake City, Utah; Hurley, New Mexico; McGill, Nevada; and Ray, Arizona. Other large producers from copper ores are Duval and Magma. Six other companies recover molybdenum from copper ores. Most of these companies sell their production as molybdenite (molybdenum sulfide concentrate or molybdic oxide).

Nickel

Nickel is produced as a co-product of copper mined in a number of localities outside the U.S., but is not found in significant amounts in association with U.S. copper deposits. Nickel in anode copper can cause problems in electrolytic refining and is extracted from the electrolyte. Nickel in lead ores follows copper and is obtained in the sulfide skimmings.

Platinum

The major part of the U.S. output is recovered as a by-product of copper refining in the form of anode mud.

Rhenium

Rhenium occurs in small percentages with molybdenum, copper, manganese and non-metallics, from which it might be recovered during roasting or smelting. Currently, rhenium supply is wholly dependent upon recovery of molybdenite from porphyry copper ores. Molybdenite concentrates from Kennecott mines in the western U.S. and flue dust and gas at Garfield, Utah, are a primary source of rhenium.

Selenium

Selenium is derived domestically as a by-product of electrolytic copper refining. Five plants account for all the selenium production in the U.S. These are the large electrolytic refineries of Amax, Asarco, International Smelting and Refining and Kennecott Copper.

Silver

About 60% of the domestic silver output in 1968 came from ores mined chiefly for copper, lead and zinc. These ores occur in the western U.S. and the high silver concentrates (even when they are copper concentrates, or antimony concentrates) are treated in western lead smelters where the silver collects in the lead and is extracted from lead bullion during refining.

Tellurium

Tellurium is a minor by-product of electrolytic refining of copper and lead and the producers of these commodities are producers of tellurium.

Thallium

Thallium metals and compounds are produced by Asarco which maintains thallium producing facilities as an integral part of its cadmium operations. Production of thallium is derived mainly from lead smelter flue dusts, residues and other products. The value of thallium output is negligible.

## D. ECONOMIC ASPECTS*

An important aspect of the primary copper, lead and zinc industries is that traditionally the smelters and refineries have been operated at a fixed and relatively low profit margin which is not very sensitive to the price of the finished product. As a result, the value of the contained metal in a typical concentrate is a high proportion of the value of the primary metal product. This, in turn , means that the smelting and refining plants are operated mainly as service operations in the conversion of these concentrates to usable metal and alloys. Hence, any changes in price of the primary metal have to be reflected back to the mine and affect directly the value of the concentrate.

We illustrate this mechanism based on data from the copper industry but a similar mechanism occurs in the lead and zinc industries. In the 60's, the traditional rule-of-thumb in determining concentrate value in the copper industry has been to assume 4¢/lb. for smelting charges and 5¢ for refining charges so that the value of copper contained in the concentrate is very approximately 9¢/lb. below the cathode or wire-bar market price. (The current smelter and refinery operating margin is closer to 10¢/lb.) Most of the U.S. smelters are old and therefore the operating margin comprises mainly of direct costs with only a small percentage being the fixed costs and profit. Because of this mechanism, any increase in smelting or refining costs cannot be "absorbed" by the smelter or refinery but can only be passed backward to the mine and the net-back to the mine (the net concentrate value realized at the mine, e.g. smelter payment minus transportation costs) would be decreased. Should the market supply/demand constraints permit an upward adjustment in primary metal price, this increase would then be reflected back to the mine.

The mechanism described above is of primary importance to custom and toll smelters such as Asarco, since the custom smelter has to compete in an international market for concentrates. When treatment charges at a particular smelter increase, the mines have the option of shipping their concentrates to other smelters that offer them better net-backs. For example, Asarco in Tacoma, Washington, does not treat copper concentrates out of British Columbia because the Japanese smelters are able to offer better terms to the Canadian mines. Thus, a custom smelter saddled with increased costs can suffer from a loss of smelter feed. Smelting costs per unit of product increase rapidly when smelters operate below capacity; hence a custom smelter can suffer a major impact if an

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*This section is identical in the copper, lead and zinc reports.

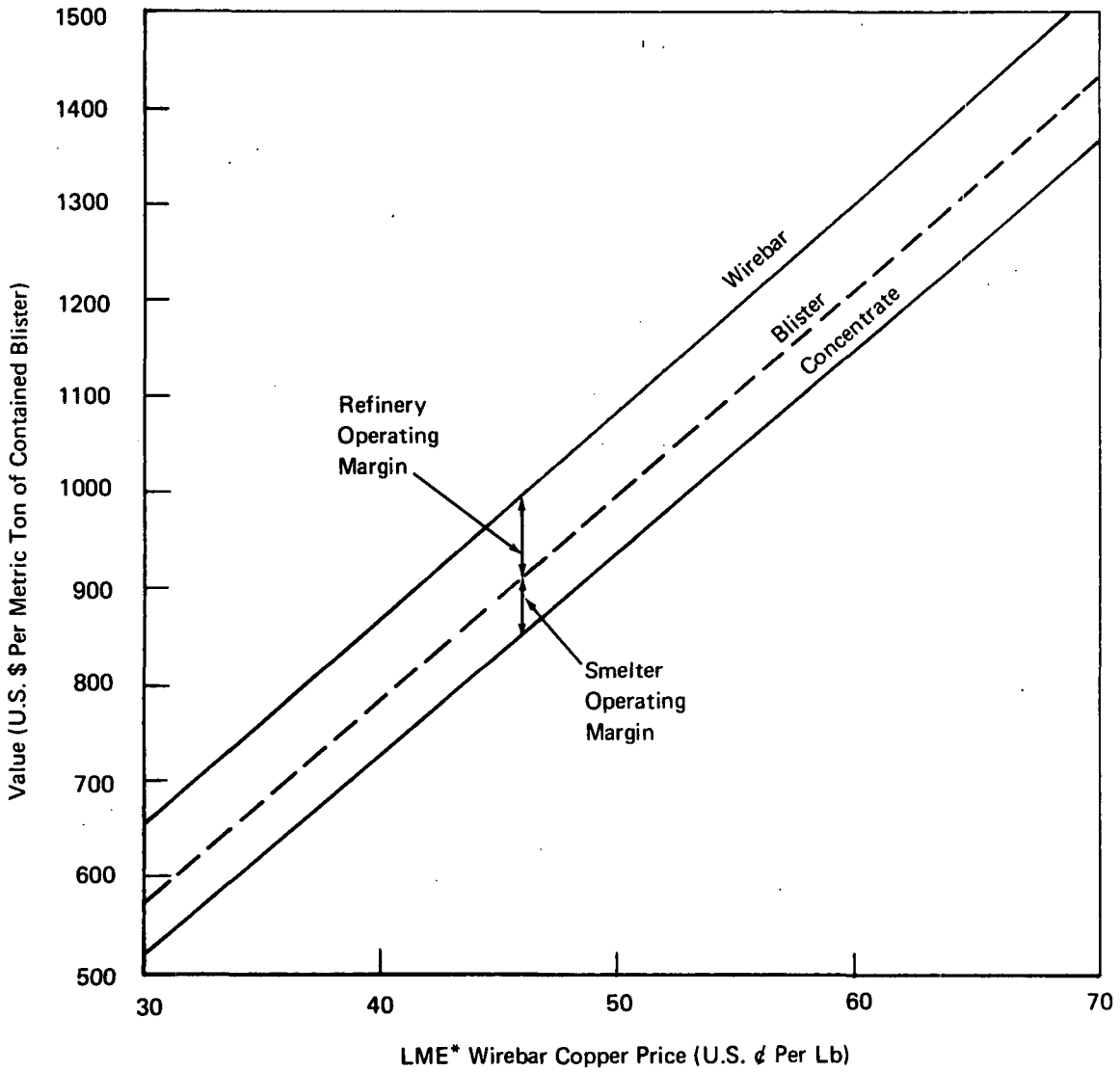
adequate supply of concentrates is not available. Alternately, if a particular mine does not have other outlets for its concentrates, it has to close if the additional smelting costs cannot be absorbed.

In the case of producers integrated from mining through smelting and refining, a cathode or wirebar is the first product that is actually sold. However, the internal transfer price of the concentrates is calculated on the basis of the primary metal price. Thus, any fluctuations in the primary metal price are again reflected back to the mine and have a major influence on mine profitability.

Figure IV-3 illustrates this mechanism qualitatively. The figure is based on actual custom smelting contracts that were in effect several years ago. It can be seen that any change in wirebar price affects the concentrate value directly and the smelter and refinery margins remain unchanged.

Identical mechanisms operate in the lead-zinc industries and any increases in smelting costs would bave to be reflected back to the mines. The smelter operating margin in the lead industry varies greatly because of the significant by-product values passing through the western lead smelters and is very approximately 4-6¢/lb of lead and that in the zinc industry is about 8-10¢/lb. Custom smelters in the lead industry account for a much larger portion of domestic smelter production as compared to the copper industry and a significant portion of the smelter feed is imported. Hence, factors increasing the smelting costs would affect the competitive position of U.S. custom lead smelters for purchasing concentrates in an international market.

In the domestic zinc industry, a cost-price squeeze and prospects for increasing operating costs in the future have already led to smelter shutdowns and an almost 60% decrease in domestic smelter capacity. Before 1964, the U.S. smelters operated on about half domestic, half imported concentrates and exported zinc. Between 1964 and 1970, while concentrate imports did not change significantly, the domestic demand increased to about the same level as smelter production. The smelter shutdowns since 1970 mean that the U.S. smelter capacity is barely adequate for smelting domestic mine production and that the U.S. will have to import a large portion of its demand for zinc in the higher value forms such as primary metal or finished products.




* (London Metal Exchange)

**Source:** Arthur D. Little, Inc.

**FIGURE IV–3 DIAGRAMMATIC REPRESENTATION OF VARIATION IN CONCENTRATE VALUE WITH CHANGES IN WIREBAR PRICE**

# V. MARKET CHARACTERISTICS

## A. SUPPLY AND DEMAND

### 1. The World Situation

Over the past twenty years, world consumption of copper has increased at an average annual rate of 4-4 1/2% to its present level of 7.9 million tons per year of the refined metal. Of this total, about 6.3 million tons are consumed by the Free World countries.

Although copper is used in myriad applications, most of these fall into five broad categories:

| | | |
|---|---|---|
| Electrical/electronic equipment | - | 49% |
| Building construction | - | 16% |
| Transportation | - | 12% |
| Non-electrical industrial equipment | - | 10% |
| Ordnance | - | 6% |

The remaining 7% is divided among such applications as chemicals, inorganic pigments, jewelry, and coinage.

Copper is facing increasing competition in a number of these applications. Plastics, for example, have made some inroads into tubing markets; stainless steel is making inroads into some building construction markets. The most serious threat, however, has come from aluminum--a commodity product that has a relatively stable price, is produced in many areas, and is much less subject to political and economic pressures than is copper. Aluminum is used for virtually all high-voltage, overhead power-transmission lines; it has replaced copper in some building construction uses; and it is being pushed as a replacement for brass in automobile radiators.

Despite these competitive forces, consumption of copper is expected to continue to increase worldwide at an average annual rate of about 4 1/2% over the next decade with a lower growth rate in the industrialized countries. Some of this increase will be the result of copper's gaining a larger share of certain markets (e.g. coinage). Some will simply be the result of the anticipated 5%-per-year increase in industrial production throughout the world.

To keep pace with this mounting demand, the industry has explored for new deposits, added capacity, and improved mining, metallurgical, and fabricating technologies. Despite occasional setbacks--for example,

from strikes, political upheavals and natural disasters--world mine production has increased about in line with demand, rising from 5.4 million tons in 1965 to 6.9 million tons in 1970. The bulk of Free World production comes from just 11 countries (Table V-1). Four of these--the so-called CIPEC countries of Chile, Peru, Republic of Congo, and Zambia--account for more than half the Free World's mining production outside the United States.

At present, copper concentrates and electrolytic refined copper are available from most of the major producing countries. Blister copper (copper that has been smelted but not refined) is available in quantity only from the CIPEC countries.

Primary copper capacity is expected to increase throughout the world (Table V-2). Overall, another 1.2 million short tons of mining capacity is expected to be added by 1975, an increase of about 6.2% per year. Barring serious upheavals, future demand may not be strong enough to absorb all of the additional output that is planned.

2. The Situation in the United States

The United States is both the leading producer and leading consumer of copper, accounting for about one-third of Free World Production and consumption. In 1970, for example, the figures were:

| | Free World | U.S.A. | U.S. Share |
|---|---|---|---|
| | (million short tons) | | |
| Mine Production | 5.66 | 1.7 | 30.2% |
| Refined Production | 6.80 | 2.3 | 33.5% |
| Refined Consumption | 6.32 | 2.0 | 32.3% |

SOURCE: S.D. Strauss, Trans., Inst. Min. Met. (London) 80, A169 - A174 (1971).

Despite its position as the leading producer of copper and a heavy user of scrap copper, the United States has been in a position of undersupply since the early 1960's. Thus it has had to make up a considerable portion of its needs with imports of refined and blister copper (Table V-3). Most of the imported refined metal has come from Canada; essentially all of the imported blister copper has come from foreign sources that are tied financially to U.S. refiners. However, recently U.S. copper mine production has been increasing at an adjusted rate of 3.5% per year, whereas consumption has yet to regain the 1966 level.

TABLE V-1

WORLD COPPER MINE PRODUCTION BY COUNTRY

(Thousands of Short Tons)

| Country | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 |
|---|---|---|---|---|---|---|
| U.S.A. | 1,356 | 1,408 | 950 | 1,203 | 1,535 | 1,706 |
| Chile | 645 | 701 | 728 | 726 | 758 | 747 |
| Zambia | 767 | 687 | 731 | 755 | 793 | 765 |
| Canada | 510 | 508 | 603 | 633 | 573 | 674 |
| Republic of the Congo | 318 | 349 | 353 | 358 | 399 | 425 |
| Peru | 199 | 194 | 212 | 223 | 219 | 234 |
| Republic of South Africa | 67 | 137 | 141 | 141 | 139 | 164 |
| Japan | 118 | 123 | 130 | 132 | 134 | 132 |
| Australia | 96 | 116 | 94 | 112 | 135 | 152 |
| Philippines | 70 | 81 | 95 | 122 | 145 | 177 |
| Mexico | 76 | 82 | 69 | 67 | 73 | 67 |
| Other Free World | 343 | 365 | 343 | 371 | 397 | 404 |
| Sino-Soviet Bloc | 867 | 927 | 1,009 | 1,077 | 1,160 | 1,207 |
| TOTAL WORLD | 5,433 | 5,678 | 5,458 | 5,920 | 6,460 | 6,854 |

SOURCE: Yearbook of the American Bureau of Metal Statistics - 1970

## TABLE V-2

## NET INCREASE IN FREE WORLD PRIMARY COPPER PRODUCTIVE CAPACITY - 1973-1975

## IN SHORT TONS, ANNUAL RATE

(Estimated as of March 16, 1972)

| Area or Country | Estimated Capacity 1971 | Free World Share (%) | Total Planned 1972-74 | Estimated Capacity 1975 | Free World Share (%) |
|---|---|---|---|---|---|
| **North America:** | | | | | |
| United States | 1,820,000 | 28.8 | 197,000 | 2,017,000 | 26.6 |
| Canada | 825,000 | 13.1 | 202,000 | 1,027,000 | 13.6 |
| Other | 95,000 | 1.5 | 38,000 | 133,000 | 1.8 |
| Total | 2,740,000 | 43.4 | 437,000 | 3,177,000 | 42.0 |
| **South America:** | | | | | |
| Chile | 840,000 | 13.3 | 28,000 | 868,000 | 11.5 |
| Peru | 240,000 | 3.8 | - | 240,000 | 3.2 |
| Other | 15,000 | 0.2 | 35,000 | 50,000 | 0.7 |
| Total | 1,095,000 | 17.3 | 63,000 | 1,158,000 | 15.3 |
| **Africa:** | | | | | |
| Zambia | 850,000 | 13.5 | 104,000 | 954,000 | 12.6 |
| Zaire | 450,000 | 7.1 | 115,000 | 565,000 | 7.5 |
| South Africa | 165,000 | 2.6 | 45,000 | 210,000 | 2.8 |
| South West Africa | 40,000 | 0.6 | (1,000) | 39,000 | 0.5 |
| Other | 50,000 | 0.8 | 52,000 | 102,000 | 1.3 |
| Total | 1,555,000 | 24.6 | 315,000 | 1,870,000 | 24.7 |
| **Asia:** | | | | | |
| Japan | 140,000 | 2.2 | 10,000 | 150,000 | 2.0 |
| Philippines | 220,000 | 3.5 | 7,000 | 227,000 | 3.0 |
| Bougainville | - | - | 180,000 | 180,000 | 2.4 |
| West Irian | - | - | 65,000 | 65,000 | 0.9 |
| Other | 85,000 | 1.3 | 67,000 | 152,000 | 2.0 |
| Total | 445,000 | 7.0 | 329,000 | 774,000 | 10.2 |
| **Australia:** | 205,000 | 3.2 | 75,000 | 280,000 | 3.7 |
| **Europe:** | | | | | |
| Yugoslavia | 110,000 | 1.7 | 15,000 | 125,000 | 1.7 |
| Finland | 35,000 | 0.6 | 7,000 | 42,000 | 0.6 |
| Other | 130,000 | 2.1 | 18,000 | 148,000 | 2.0 |
| Total | 275,000 | 4.4 | 40,000 | 315,000 | 4.2 |
| (CIPEC) | 2,380,000 | 37.6 | 247,000 | 2,627,000 | 34.6 |
| Total Net Increases | - | | 1,259,000 | 7,574,000 | |
| TOTAL FREE WORLD CAPACITY | 6,315,000 | | - | | |
| Percent Increases | | | | 6.2% (Per Year) | |

SOURCE: American Metal Market

TABLE V-3

U. S. IMPORTS OF REFINED AND BLISTER COPPER

(Thousands of Short Tons)

| Year | Refined Copper | Blister Copper |
|---|---|---|
| 1965 | 137 | 333 |
| 1966 | 163 | 350 |
| 1967 | 330 | 269 |
| 1968 | 400 | 271 |
| 1969 | 131 | 238 |
| 1970 (est.) | 132 | 224 |

SOURCE: Copper Supply and Consumption, 1951-1970, CDA, Inc.

## B. PRICES

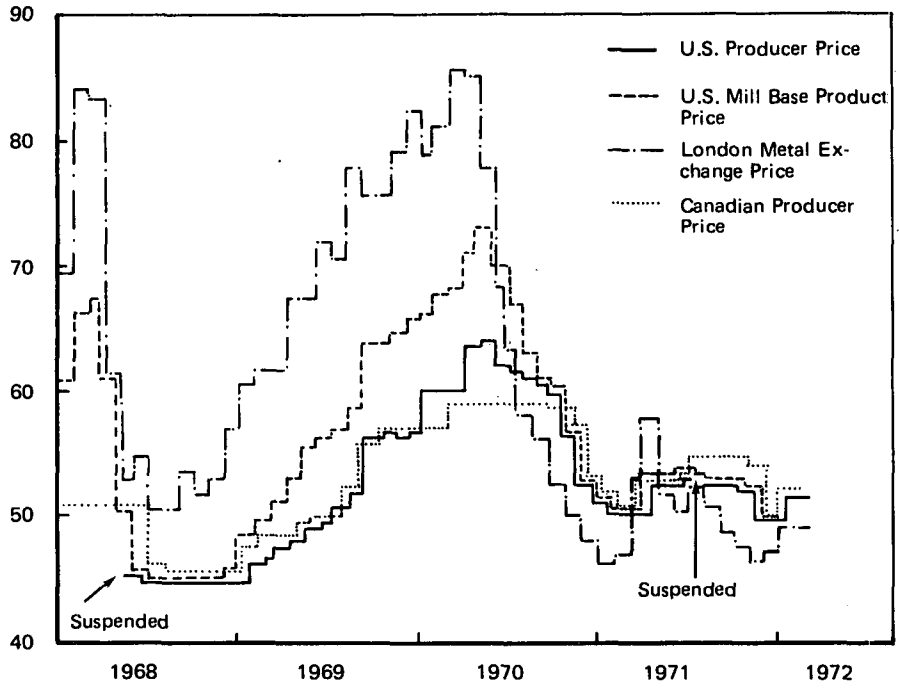
Currently, refined copper in the United States is consumed at an annual rate of about 2 million short tons. About two-thirds of this metal is derived from domestic ores and sold by the major producers at the so-called producer price. The remainder comes essentially from four sources: 1) refined imports of copper; 2) imports of blister for processing in U.S. refineries; 3) toll refining of concentrate from some of the smaller domestic mines; and 4) scrap.

The imports depend on foreign sellers being able to realize a netback at least equal to that available outside the United States; i.e., to remain in the United States, it must be sold at the world price. In practice, much of the refined copper produced from such imported material is subsequently re-exported. Thus, although the domestic producer price does not apply to all sales of refined metal in the domestic market, it does cover the greater part.

Shortly after World War II, the practice of having a uniform delivered price to all consuming destinations within the continental United States came into being. Until recently, the quoted price applied to wire bars, ingots and ingot bars, with cathodes available at a modest discount, indicating the absence of melting and casting costs. Cakes and billets sell at premiums to cover additional casting costs. However, two major producers now refer to their cathode price as representing the standard quotation for copper; they also quote a price for wire bars, but as yet the differential over cathodes has not been standardized and some time will probably elapse before a uniform procedure is adopted by most sellers.

Typically, U.S. copper producers sell on the basis of the price prevailing on the date of shipment, regardless of when the buyer placed his order. However, not all producers follow this practice; some sell at the average for the month of shipment as quoted in Engineering and Mining Journal or some other publication. In addition, some sales are made at a firm price (usually that prevailing at the time of sale), particularly to fabricators who prefer this method of fixing the cost of raw material rather than to operate in the hedge market, to protect their profit margin.

The basic reason behind the use of the domestic producer price is to minimize price changes which are considered undesirable because users want to know what their raw material costs will be. The wide fluctuations in copper price in markets outside the United States and on commodity exchanges (see Figure V-1) are believed to have encouraged the substitution of other materials for copper - notably the use of aluminum, plastics, and stainless steel. At times the U.S. government has interceded in copper pricing - notably during World War II and the Korean war when price ceilings were placed on copper as well as other metals and again during the Vietnam war when President Johnson, in the fall of 1965, virtually forced domestic




**Source:** Noranda Mines Limited, Annual Report, 1971.

**FIGURE V–1 COPPER PRICES (Canadian Funds)**

producers to rescind a 2¢ price advance to 38¢/lb., even though prices on the London Metal Exchange at the time were over 60¢/lb.

The outside market (accounting for about one-third of refined sales) is, of course, not bound by price ceilings such as those imposed during World War II and the Korean war. If the ceilings are too restrictive, imports decline and scrap flow to the refineries declines. During the Korean war, therefore, the government sanctioned a higher price ceiling for copper of foreign origin than for metal of domestic origin.

Under reasonably balanced conditions, the outside market tends to follow closely the London Metal Exchange price. However, if business is expanding in Europe and slow in the United States, the outside market in the United States tends to be lower than London. When there is a severe shortage in the United States - for instance, during the 1967-68 strike - the outside market in the United States typically moves to a premium over the L.M.E. price sufficient to attract increased imports.

The outside market can be at a discount from the producer price as well as at a premium. From early 1964 through mid-1970 the outside market was consistently at a premium, but in the summer of 1970 the L.M.E. price dropped below the U.S. producer price. During most of the last half of 1970 and the first few months of 1971, sellers in the outside market in the United States offered copper at substantial discounts from the producer price. A similar situation prevailed from 1961 through 1963. The discounts available during such periods were far smaller than the premiums asked during periods of extreme shortage. Consequently, even though there may be an immediate saving by purchasing on the outside market, most U.S. consumers maintain their purchases from the large domestic producers in order to ensure future availability of copper in times of scarcity.

The recent devaluation and readjustment of the currencies has also had an effect on the worldwide pricing structure of copper.

## VI. GOVERNMENT POLICIES*

The U.S. Government affects the copper, lead and zinc mining industries not only by its general economic policy actions but also by specific programs and regulations for these industries and the mining industry in general. Some of the major government policies affecting these industries are discussed below.

### A. STOCKPILE PROGRAM

For national security and defense reasons the U.S. Government maintains a stockpile of so-called strategic meterials both metallic and non-metallic. In 1965 some 95 items were in the stockpile but about 18 items carry quotas of zero so only about 77 are actively stockpiled. Among these are copper, lead and zinc.

As of September 30, 1971, the General Services Administration had 251,615 short tons of copper in government stockpiles, which represents about 14 percent of total 1970 domestic consumption. This is considerably less than the desired stockpile objective of 775,000 tons. At times, in the past, stocks have been considerably above the objective. Large quantities have been released in the past decade, at first to bring stocks more closely in line with the objective and more recently to assist in stabilizing the market in periods of excess demand.

On December 31, 1964, inventories of copper in government stockpiles totaled 1,095,483 tons. From 1965 through 1968 the government released 760,000 tons from its stockpile and 62,000 tons from Defense Product Act Inventories. During 1969 only about 8,000 tons of copper were released.

During World War II and in 1951-1952 the government regulated the lead industry to provide adequate supplies for all essential purposes. Lead was recommended for stockpile in 1941 and by 1943, 260,000 tons had been purchased. Withdrawals during the war reduced stocks to 65,000 tons. Stockpiling was resumed in 1950, expanded in 1954 and by the end of 1962 about 1,386,000 tons of lead were in the stockpile. Disposals for government and commerical use had reduced the stockpile to 1,149,251 at the end of 1969 as compared to a stockpile objective of 530,000 tons. The surplus lead in the stockpile amounts to about a one year's supply.

Zinc stockpiling followed a similar pattern to lead discussed above and at the end of 1969, 1,140,060 short tons of slab zinc were in the stockpile. This is in excess of the stockpile objective of 560,000 tons set in December 3, 1969 by the U.S. Government.

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* This section is identical in the copper, lead and zinc reports.

## B. HEALTH AND SAFETY LEGISLATION

The health and safety of workers in the mining industry in the U.S. is protected and regulated by the U.S. Government, who has passed various laws on the subject. The health and safety of coal miners is regulated by the new Federal Coal Mine Health and Safety Act passed in 1969, while all other mines are regulated by the Federal Metal and Non-Metallic Mine Safety Act of 1966. The U.S. Bureau of Mines is charged with the enforcement of these acts. Copper, lead and zinc mines of all types (underground and open pit) are covered by the Metal and Non-Metallic Act.

The Metal and Non-Metallic Act consists of a total of 1,806 standards covering all the aspects of health and safety in mines, such as roof control, equipment design and operation, respirable dust hazards, radiation hazards in uranium mines, noise hazards, and many others.

All copper, lead and zinc mines must meet the required standards and are regularly inspected. If violations of mandatory standards for health and safety are found by inspectors, withdrawal orders can be issued and the mines closed. The record has been however that mines promptly correct violations and operate within the requirements.

It is anticipated that an increasingly active effort will be made by the U.S. Government to enforce health and safety laws and make them even stricter in specific areas if this appears to be necessary.

As a result of the Williams-Steiger Occupational Safety and Health Act of 1970, the Occupational Safety and Health Administration (OSHA) of the Department of Labor has been setting standards for control of in-plant emissions which affect plant employees. In general, we understand that the setting of these standards will be based on a cost-effectiveness approach that will take into account the economic impact, the safety impact, the social impact and other such criteria.

## C. ENVIRONMENTAL IMPACT ON STRIP AND OPEN PIT MINING

Increased public concern about the environmental impact of mining operations (particularly strip mining) has resulted in government and state regulatory bodies planning and taking actions that will have a considerable impact on many parts of the mineral industry.

At the present time Federal legislation is being considered to control strip mining and require complete land restoration. Some 15 bills are

in Congress proposing various regulations for strip mining. The major bills are listed in Table VI-1. They cover the entire range from complete abolishment of strip mining to the "Administration Bills" which are industry oriented and "do nothing" bills. These bills cover coal mining and in some cases the mining of minerals in general which would include copper, lead and zinc.

It is our belief that the 92nd Congress will pass legislation before its adjournment in January 1973 to regulate the strip mining industry. We believe these regulations will be limited to surface mined coal only and that no form of strip mining will be abolished totally. However, contour coal stripping will be effectively halted by outlawing stripping "when the disturbed land cannot be reclaimed." We anticipate that reclamation will be defined to require soil profile restoration which would require segregation of overburden during stripping.

The copper, lead and zinc mining industries will probably not be severely effected by the Federal strip mining legislation discussed above.

## D. LAND MANAGEMENT - EXPLORATION

In recent years there has been increased governmental participation and control and restrictions placed on the mining use of public lands. The principal Federal acts that effect the industry are the Classification and Multiple Use Act of 1964 and the Wilderness Act also of 1964. The main effect of these laws on the mineral industry is that they allow for the withdrawal of public lands from exploration and from location and development of mineral deposits. Many areas promising for mineral discoveries have been withdrawn. This action is of concern to an industry charged with supplying the present and future basic mineral needs of this country. The rate of land withdrawal under the acts has been increasing. For example, from 1968 to 1970, land was withdrawn from mineral entry at the rate of about 2.4 square miles per day.

As a part of the mining industry, the copper, lead and zinc industries are effected by the above laws and will probably find it increasingly difficult to discover and develop U.S. copper, lead and zinc mines in the future. These metals will definitely be effected since they are known to occur in areas that will probably be withdrawn from mined entry.

The mining industry views the question of being able to explore and develop ore bodies and the hampering of that effort by unrealistic government regulations as being probably the most serious problem facing the industry.

# TABLE VI-1

## MAJOR PENDING FEDERAL LEGISLATION ON STRIP MINING

| RANKING[1] | BILL NUMBERS | SPONSOR | TYPE OF CONTROL OVER STRIP MINING | COVERAGE | AGENCY CHARGED WITH ENFORCEMENT | DESCRIPTION | REMARKS |
|---|---|---|---|---|---|---|---|
| 1a | H.R. 4556<br>S. 1498 | Ken Hechler (D-W.Va.)<br>Gaylord Nelson (D-Wis.) | Abolishment | Coal | EPA | No new strip mining permitted following enactment; existing operations to terminate within 6 months; existing operations to submit to EPA within 60 days plans for reclaiming disturbed land; where operator fails to reclaim, EPA could do work and bill operator. Provides civil and criminal penalties; provides class action citizen suits. H.R. 4556 establishes a reclamation fund providing 90% federal support for reclamation of previously strip-mined lands owned by government bodies, or for reclamation of lands intended for use by the public.<br><br>H.R. 4556 also establishes an EPA regulatory structure for underground mining; prohibits underground mining in wilderness areas; limits underground mining in national forests. | Co-sponsored by 6 Senators and 88 Representatives (including 3 from Illinois); extremely strong legislation; gathered much public support; probably will not be passed in present form. |
| 1b | H.R. 8174 | John Sieberling (D-Ohio) | Abolishment | Coal | EPA | Identical to Hechler Bill; provides for salary compensation to workers laid off by mine shutdown; provides relocation allowance for workers able to find work outside specified commuting distance. | |
| 2 | S. 3000[2] | Howard Baker (R-Tenn.)<br>John Cooper (R-Ky.) | Regulatory | Coal | EPA | Calls for 270 day freeze period on new strip mines after enactment; present operators to be investigated; allows some state supervision; institutes 5 year liability period for strip-mine reclamation projects. | Does not define "reclamation"; does not ban contour stripping but places moritorium on area stripping. |
| 3 | S. 2777<br>H.R. 10758 | Mike Gravel (D-Ala.)<br>Wayne Aspinall (D-Colo.) | Regulatory | General Minerals | Department of Interior | Defines reclamation; calls for restoration to "original use or original potential use" of land; requires soil profile be restored; institutes 5 year liability period but permits operators to be released from responsibility as early as 2 yrs.; calls for public hearings on license application. | Most stringent definition of "reclamation"; would require segregation of overburden--expensive; public hearings section weak. |
| 4 | H.R. 9736[2,3] | Wayne Hays (D-Ohio) | Abolishment & Regulatory | Coal | Independent Commission | Ban on strip-mining in areas where reclamation is impossible or where stream pollution, landslides, stream dislocation, or destruction of recreational areas is threatened.<br><br>Sets up 3 man Strip Mine Reclamation Commission (appointed by the president) for enforcement; calls for submitted plan of reclamation and public liability insurance policy prior to licensing; authorizes Commission to set rules governing stripping on steep slopes. | Good definition of "reclamation"; includes few opportunities for public involvement; no public hearings specified. |
| 5 | "THE ADMINISTRATION BILLS" | | | | | | |
| | H.R. 4704 | William Broomfield (R-Mich.) | Discretionary | General Minerals | Department of Interior | States given two years to conduct public hearings, after which time they may set plans for strip mining regulation; enforcement would remain within the states; sets up Federal advisory committee; inspections of operators left to discretion of DOI. | State oriented; very favorable to industry; doesn't define "reclamation"; essentially a "do nothing" bill. |
| | H.R. 4967<br>H.R. 5689<br>H.R. 6580<br>H.R. 7422 | William Harsha (R-Ohio)<br>Craig Hosmer (R-Calif.)<br>Charles Chamberlain (R-Mich.)<br>Carl Perkins (D-Ky.) | | | | | |

1 Ranking in terms of amount of control placed on strip-mining operations.
2 No House (or Senate) sister bill as of 1 March, 1972.
3 Rep. Clarence Miller (R-Ohio) has introduced a bill identical to H.R. 9736, but giving regulatory powers to EPA.

With regard to exploration programs themselves, the Government does provide for some exploration assistance. For copper exploration, the Office of Mineral Exploration provides for government participation of 50% of approved exploration costs. This program was terminated in 1962 but was reinstated in 1966 so it is currently in force. However, exploration for lead and zinc is not eligible for exploration assistance.

## E. TRADE POLICIES

The domestic tariff on primary copper products has generally been low, and in the past refined copper entered the U.S. duty-free. In 1958 the U.S. tariff on ore concentrate, matte, blister, refined copper, scrap and many semifabricated products became $0.017 per pound (copper content). In accordance with the Kennedy Round tariff reductions this tariff was reduced by stages to $0.008 per pound in January 1972. Since February 1966, however, tariffs have been suspended on copper-bearing ores and materials, blister copper, anode copper, all other unwrought copper (except that containing nickel and silver), as well as copper waste and scrap; the most recent suspension expired in June 30, 1972, and to date the suspension has not been reimposed although bills to do so are pending in Congress.

The tariffs on various forms of refined copper and fabricated copper products are still in effect, and vary according to type. Since the 1970 tariffs on these products are usually less than the present tariff plus the 10 percent surcharge, the former will be the effective tariff as long as the 10 percent surcharge continues.

The U.S. Government has also effected severe quota limitations on the export of refined copper and scrap. In 1969 exports of refined copper from domestic primary sources and scrap were limited to 50,000 and 60,000 short tons of contained copper, respectively. Export controls may be part of the explanation of why prices in Europe can sometimes remain at levels far higher than domestic copper prices. As the LME price has declined and even fallen below the domestic producers' price, these restrictions have been modified, and in September 1970 the United States lifted its copper short-supply Export-Control Restrictions.

Foreign tariffs on primary copper products are also generally low. In 1964, the Scandinavian countries, Austria, Switzerland, and the EEC admitted unwrought copper duty-free. The British tariff ranged from zero to 10 percent ad valorem.

Trade in fabricated products is to some extent limited by tariffs. The domestic tariff on fabricated products is generally modest, but some European tariffs are substantial. In 1962, for example, the EEC duties, were in the range of 13-15 percent ad valorem, and the British tariff on some copper semis was 20 percent.

Lead was excluded from the "Kennedy Round" on the General Agreements on Tariffs and Trade. The present import duty is 0.75 cents per pound on lead in ore and 1.0625 cents per pound of lead metal. This duty applies to all free world areas and is one half the statutory rate which applies to certain designated Communist countries.

Zinc similarly was excluded. The present duty on zinc in ores or fumes is 0.67¢ per pound and 0.7¢ per pound on zinc metal. This duty applies to all free world areas and compares with the 1.67 cents per pound for metal statutory rates applying to certain designated Communist countries.

## F. PRICE CONTROL

The U.S. government has directly intervened on several occasions to influence or control copper prices. The best known occasion was in November 1965 after Anaconda and Kennecott had agreed to Chile's demand that they raise their prices in the U.S. from $0.36 to $0.39 per pound. The government persuaded the producers to rescind the increase so as to conform to Guidepost policy. Three months later, in officially separate actions, Chile agreed to sell 100,000 tons in the United States at the producers' price of $0.36 and the U.S. government, through the Alliance for Progress, agreed to lend Chile $20 million for forty years for use in copper development. In addition, Anaconda, the importing company, was to pay a $3.5 million export surtax to Chile.

Another instance occurred in March 1966, when government agencies were directed to use acceptable substitutes for copper whenever possible. This order was made in light of the excess demand for copper, and at the same time the government made $100,000,000 available for the Copper Production Expansion Program. The Copper Substitution Order was subsequently rescinded in August 1968.

The recent price freeze has not affected refined copper prices because a provision in the Economic Stablization Act of 1970 states that prices cannot be frozen at levels less than those prevailing on May 25, 1970. On that date U.S. producer copper sold at $0.60 per pound and the COMEX

price was quoted at $0.658. As a result, copper producers presently have a price ceiling considerably above the prices now prevailing.

## G. DEPLETION

"Depletion is to the owner of a mineral property what depreciation is to the owner of a depreciable asset. A manufacturer, for example, may recover the cost of a plant by means of depreciation deductions over the period of its useful life. Similarly, the owner of a mine may recover the cost of the mineral deposit during the period in which the mineral is extracted." [1]

The U.S. copper producers receive a 15% depletion allowance, calculated on the value of the first marketable product (concentrate), from their domestic as well as foreign operations.

The lead and zinc industries receive a 23% depletion allowance on domestic production and 15% on foreign production.

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[1] 724CCH, Standard Federal Tax Reports, Commerce Clearing House, Inc. 1971, p. 45,007

## VII. THE OUTLOOK FOR SULFURIC ACID, AND BY-PRODUCT SULFUR*

### A. PRODUCTION

The United States produced about 30 million tons of sulfuric acid (100% acid basis) in 1969 and this is expected to grow at an annual average rate of 4% during the next decade. About 51% of this quantity was used in the fertilizer industry, primarily for the production of phosphate fertilizers. Twenty-five percent went to the production of a wide variety of chemicals, and the remainder was used in the petroleum and refining industry, in the iron and steel industry and in miscellaneous uses.

The sources of this acid are given in Table VII-1. Some 22 million tons of sulfuric acid were produced from elemental sulfur, or about 75% of total acid production. This was equivalent to about 7.4 million tons of sulfur. Most of this was Frasch sulfur recovered from deposits along the Gulf Coast but a substantial portion - close to 2 million tons - was sulfur recovered from the production of natural gas and from refinery desulfurization.

With the preponderance of sulfuric acid produced from elemental sulfur, acid prices follow sulfur prices very closely. Sulfur prices have dropped sharply in recent years, from a high of close to $40.00 per long ton in 1969, to an average of $18.00 per long ton in 1971, on an FOB Gulf Coast basis. The principal reason for this sharp decline was a major increase in production of recovered sulfur from Canadian natural gas production. Sulfur production from this source is expected to continue to increase at a substantial rate since the demand for natural gas continues strong, and production from sour gas fields in Alberta continues to increase.

It is important to note the increasing extent to which by-product sources of sulfur, or sulfur values, will represent an increasing and preponderant portion of the total raw material for the manufacture of sulfuric acid. The increase in availability of such by-product sources of sulfur recovered from natural gas and oil desulfurization, and sulfur dioxide recovered during stack gas cleaning, will be more than adequate to meet the normal increases in demand for sulfuric acid. The discretionary sources of sulfur - principally Frasch sulfur, and pyrites - will show little if any increase in total consumption volume and may actually decrease. For example, we estimate that in 1970 approximately 7.1 million tons of discretionary sulfur were produced in North America (almost entirely Gulf Coast Frasch sulfur) out of a total of 15.0 million

* This section is identical in the copper, lead and zinc reports.

TABLE VII-1

SOURCES OF U.S. SULFURIC ACID, 1969
(millions of short tons of 100% acid)

| | |
|---|---|
| New Sulfur | |
| Elemental | 22.19 |
| Hydrogen Sulfide | 1.03 |
| Smelter Gases | 1.77 |
| Pyrites | 1.10 |
| Subtotal | 26.09 |
| Sludge Acid | 2.15 |
| Fortified Acid | 1.30 |
| Total Production | 29.54 |

SOURCE: ADL Estimates

tons of sulfur values. By 1975 we estimate that Frasch sulfur production will decrease slightly to 7.0 million tons production while total North American sulfur production will increase to 20.1 million tons. Thus, the non-byproduct sulfur will have dropped from 47% to 32% of total North American production. These volumes are substantially in excess of North American needs and the remainder goes into export markets.

## B. TRENDS

The outlook for sulfuric acid at least during the first part of the next decade is for continued surpluses and low prices, corresponding to the expected continued surplus and depressed prices for sulfur. In addition to a continued oversupply of elemental sulfur, the situation will be further aggravated by an increase in the secondary sources of sulfuric acid. A major such secondary source (which will represent an increasingly large volume of sulfuric acid to be marketed) will be the stack gas cleaning in the smelting industry, and to a lesser extent in electric generating plants.

It is clear that a substantial cleanup of stack gas emissions of sulfur dioxide will be enforced by regulation during the 1970's. Sulfur dioxide may be recovered in potentially saleable form, i.e., as sulfur or sulfuric acid, may be removed by processes which produce a nonsaleable product such as gypsum, or may be reduced through the use of low-sulfur fuels.

The total sulfur dioxide emissions into the air over the United States have been estimated and summarized in Table VII-2. While only a portion of these total emissions will be recovered, and only a portion of the recovered sulfur dioxide will be in saleable form, the total magnitude of the emissions indicates the potential for adding substantial volumes of sulfuric acid to the national market.

While it is likely that there will be a significant amount of sulfuric acid produced from smelter stack cleanup, current indications are that the amount of saleable product from powerplant emission control will not be significant during the 70's. Major emission reduction in power plants will probably take place either through the use of low sulfur fuels or through stack gas cleaning processes producing nonsaleable product such as gypsum. Also, the much lower sulfur dioxide content of fuel combustion gases as compared to smelter gases makes recovery as acid difficult.

The recovered sulfur from Canada will probably be the most important factor in maintaining an excess supply of sulfur and therefore of sulfuric acid. Production in Canada is estimated to increase from an estimated 4.4 million long tons of sulfur in 1970 to approximately 8 million tons

TABLE VII-2

ESTIMATED POTENTIAL SULFUR DIOXIDE EMISSIONS

(without abatement)

| Source | Annual Emissions of $SO_2$ (millions of tons) | |
|---|---|---|
| | 1970 | 1980 |
| Power plant operation | 20.0 | 41.1 |
| Other coal combustion | 4.8 | 4.0 |
| Other petroleum product combustion | 3.4 | 3.9 |
| Smelting | 4.0 | 5.3 |
| Refinery Operation | 2.4 | 4.0 |
| Miscellaneous | 2.0 | 2.6 |
| Total | 36.6 | 60.9 |

Source: "Abatement of Sulfur Dioxide Emissions from Stationary Combustion Sources" - National Academy of Engineering, National Research Council, 1970.

by 1975. While a substantial portion of this would be exported outside of North America, a significant volume will be coming into the U.S.

In addition, significant quantities of sulfur recovered from natural gas can be expected from fields being developed in Mississippi, Alabama, and Florida where much of the gas is turning out to be sour. There will also be significant quantities of sulfur produced from crude oil desulfurization.

On the basis of a 4% annual growth rate for sulfuric acid demand, the 1969 demand of about 30 million tons of sulfuric acid will increase to 44 million tons by 1979. Thus, an additional 14 million tons of sulfuric acid will be needed. This is equivalent to about 4.7 million tons of additional sulfur required annually by 1979. When we see that an increase in available supply from Alberta alone will be about 3.6 million tons per year by 1975, there seems little question that this additional quantity of sulfuric acid will be readily available, and excess supplies will continue.

The outlook for sulfuric acid pricing will continue to reflect an excess capacity, and there seems no reason to believe that a significant increase in prices can be expected. Therefore, that quantity of acid which will be marketed from smelter stack gas cleanup will be entering a highly competitive market, where acid prices are expected to remain low, and in most areas of the country, substantially below $20 per ton on a delivered basis.

# VIII. FINANCIAL STRUCTURE

## A. INTRODUCTION

As developed earlier in Chapter IV of Part II, the primary copper, lead and zinc industries are mutually interdependent to a considerable extent. Also, several major companies are involved in the production of all three metals. Because of this, these non-ferrous industries have been treated as a group in this chapter. However, Section D, "Selected Company Profiles" discusses only the major copper producers.

The primary copper, lead and zinc industries are rather concentrated industries. For example, the top three producers in copper--Kennecott, Phelps Dodge, and Anaconda--account for well over half of mine output and smelting capacity, are vertically integrated, and also account for a substantial share of fabricated product sales.* Similarly, in lead and zinc, St. Joe Minerals is a major factor in both metals. Because of the raw material characteristics, substantial by-product, or co-product metal recovery occurring in these industries, the major producers all tend to have significant production of all three metals as well as by-product recovery of silver and other valuable metals. Another feature is their extensive holdings in foreign mining ventures (including diversification into other minerals), their participation in joint ventures with each other, and their equity holdings in other companies which complement their degree of participation in the primary non-ferrous metal industry. Due to major differences in end-product market characteristics--between copper, on the one hand, and lead and zinc, on the other--as well as to the historical development of these industries; the lead and zinc companies are not integrated forward into fabricated products or end-products--e.g., storage batteries, tetraethyl lead, galvanized steel products or zinc die castings.

From the companies' viewpoints, the major influences on earnings are operating rate and metal prices. These fluctuate much more than annual consumption or demand and prices tend to be sensitive to small imbalances between supply and demand. Although the non-ferrous metal market is not a classic commodity market in the sense of a very large number of small independent producers, the non-differentiated nature of primary metal products and supply-demand characteristics in the industry including the foreign sources, indeed result in a commodity market in copper, lead and

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* In June 1970, Triangle Industries, Inc., filed suit against several domestic copper producers and fabricators, alleging various violations of the Federal antitrust laws and seeking treble damages and divestiture by the producers of their fabricating subsidiaries. Reading Industries, Inc., filed a similar suit in October. The proceedings are in the pre-trial stage and the outcome would clarify the status of vertical integration in this industry.

zinc. At the same time, the nature of the cost and marketing structure, as well as tax laws result in the commodity of commerce being the refined metal. Under these conditions, smelting and refining are equivalent to toll services on a relatively fixed margin even for companies integrated from mining to refining and more, if not most, profits come from mining operations. The upshot is that profitability of all companies is sensitive to changes in refined metal prices--and since metal prices are influenced by traditionally cyclical forces, the non-ferrous metals companies' revenues and earnings are highly cyclical.

## B. FINANCIAL PERFORMANCE

Fifteen or so firms dominate the U.S. primary copper, lead and zinc industries (excluding secondary producers, independent fabricators, etc.). It is difficult to generalize about profitability and financial conditions on an industry-wide basis because each company has some unusual features. We present in Table VIII-1 an estimated breakdown of revenues and earnings, by source and geographic area, as well as other information, to illustrate this point. Table VIII-2 presents financial performance data for the four years 1968-1971 (two relatively good years and two relatively poor years for most of the companies). The highest rates of return on equity are shown by Inspiration and St. Joe Minerals. Newmont Mining, a holding company which owns Magma Copper, has the highest consolidated operating margin. Newmont earns substantial income from its large investment holdings, as do Amax and Asarco. Anaconda and Gulf Resources and Chemicals have shown the lowest rates of return on equity recently. Anaconda's valuable Chilean properties which were expropriated were written off in 1971, leaving the company with relatively low margin domestic mining operations. Gulf Resources has had heavy expenses and low offsetting volume at the Bunker Hill lead-zinc operations recently; but, more significantly, has had substantial write-offs associated with its other minerals and chemicals projects, i.e., Mexican Sulphur (1969), and the Great Salt Lake project (1971).

The aggregated average annual net after-tax income of the eleven companies in Table VIII-2 exceeds $500 million.

## C. CAPITAL SPENDING AND FUNDING

Annual new plant and equipment expenditures for the companies in Table VIII-2 averaged about 10% of their gross plant, as stated on the balance sheets. In 1971, which was a relatively poor year for most of the companies, aggregate cash flow was about $650 million, or very roughly equal to aggregate capital expenditures. The debt-to-equity ratio of the non-ferrous metals companies has been increasing of late as the pace of their expansion and diversification programs has increased. For example, Kennecott, Phelps Dodge and Amax, combined, raised $500 million in long-term financing in 1971. In the face of cost-cutting moves and weaker earnings in 1971, several companies cut their dividends. The requirement for pollution abatement expenditures, which was acknowledged by

# TABLE VIII-1

## REFERENCE DATA

## NON-FERROUS METALS COMPANIES*

| | Asarco | Anaconda Co. | Copper Range | Inspiration Consolidated | Kennecott Copper | Newmont Mining | Phelps Dodge | St. Joe Minerals | Amax | Gulf Resources (Bunker Hill) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Percent Change in Earnings** | | | | | | | | | | |
| Due to 1¢ copper price change: | (low) | (high) | (high) | (med-high) | (low) | (low-med) | (low) | | | |
| Due to Pb-Zn metals price change: | (low) | (high) | (high) | (med.) | (low) | | (low) | (high) | (low) | (med. - high) |
| Due to aluminum price change: | | (low) | | | | | (low) | | (med.) | |
| **Reported Income Tax Rate, Percent** | | | | | | | | | | |
| 1971 | 11.0% | $440 MM U.S. tax loss carry forward 1971-81 (and $190 MM foreign tax credits) | (credit) | 27.7% | 15% | 19.3% | 35.07% | 29.8% | 17% } excludes dividend income | nil |
| 1970 | 22.3% | | 29.4% | 33.1% | 30% | 32.2% | 37.6% | 29.6% | 22% } | 27% |
| **Mine Production-U.S.A.** | | | | | | | | | | |
| Copper (thous. short tons) | | | | | | | | | Note: Also 20% Equity in Copper Range Co. | |
| 1971 | 75.8 | 182.0 | 58.6 | 54.4 | 456.1 | 101 } | 281.2 | | 182.0 } custom smelter refined | |
| 1970 | 83.4 | 242.1 | 67.8 | 67.1 | 518.9 | 112 } | 313.5 | | 215.0 } | |
| Lead (thous. short tons) | | | | | | | | | | |
| 1971 | 18.7 | 16.4 } Toole Smelter Closed '71 | | | 68.6 | Joint venture with Asarco. Also holds 8.1% of St. Joe Minerals | Note: P-D owns 772,500 shares Amax stock | 303.2 | N.A. | 44-own 85-others |
| 1970 | 28.4 | 18.1 } | | | 83.7 | | | 318.4 | 75.0 | 40-own 83-others |
| Zinc (thous. short tons) | | | | | | | | | | |
| 1971 | 43.1 | 0.7 } Great Falls Closing '72 | | | 17.4 | | | 144.0 (conc. produced) | N.A. | 67-own 53-others |
| 1970 | 63.3 | 0.1 } | | | 21.7 | | | 66.4 mine | 32.0 | 50-own 64-others |
| Silver (million troy ounces) | | | | | | | | | | |
| 1971 | 6.66 | 3.87 | | | 3.7 | | | | 20.0 | 9.6 } refined |
| 1970 | 6.84 | 5.02 | | | 4.3 | | | | 40.0 | 7.8 } |
| **Aluminum Production (thous. short tons)** | | | | | | | | | | |
| 1971 | 33.6% interest in Revere Copper and Brass | 171.7 | | | owns 925,000 shares Kaiser Aluminum | | 40% interest in Consolidated Aluminum Corp. (Conalco) | | 260.0 | |
| 1970 | | 177.3 | | | | | | | 247.0 | |

The information presented above has been obtained from company annual reports and SEC filings, statistical services, financial manuals, and other sources *believed to be reliable, but its accuracy and completeness are not guaranteed.*

*For a discussion of New Jersey Zinc Company, a subsidiary of Gulf and Western Industries, see text.

# TABLE VIII-1 (Cont'd)

| | Asarco | Anaconda Co. | Copper Range | Inspiration Consolidated | Kennecott Copper | Newmont Mining | Phelps Dodge | St. Joe Minerals | Amax | Gulf Resources | Cyprus Mines |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Estimated Revenue Breakdown** | | | | | | | | | | | |
| Copper | | | | | | | | | | | |
| Mining | 13-17% | 5-10% | 75-85% | 94-98% | 50-55% | 85% | 40-45% | | | | 25-30% |
| Fabrication | | 60-65% | 15-20% | 2-06% | 10-15% | | 40-45% | | | | |
| Custom Smelting | 13-17% | nom. | | | nom. | nom. | 5-10% | | | | |
| subtotal | 26-34% | 65-75% | 95+% | 100% | 60-70% | 85-90% | 90-93% | | 30% | | 25-30% |
| Zinc | | | | | | | | 44% | | 76%, includes silver | 10-15% |
| Lead | | | | | | | | 35% | | | |
| Coal | | | | | 25% | | | | | 13% | |
| Aluminum | | 15-17% | | | | | 7-10% | | 35% | | |
| Primary | | | | | | | | | | | |
| Fabrication | | | | | | | | | | | |
| Other Sales | | | | | | | | | | | |
| All Other, n.e.c. | 66-74% | 8-20% | nom. | | 8-11% | 10-15% | | 21% | 35% | 11% | 55-60% |
| | 100% | 100% | 100% | | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| **Approximate Earnings Distribution** | | | | | | | | | | | |
| Copper | | | | | | | | | | | |
| Mining-U.S. | 20-25% | 60-70% | 95-105% | 92+% | 68-72% | 40-45% | 79-83% | | | | |
| Mining-Foreign | 40-45% | 15-20% | | | 10% | 30-35% | 5% | | | | |
| subtotal | 60-70% | 80-85% | 95-105% | 92+% | 78-82% | 70-80% | 85±% | | | | 45-55% |
| Fabrication | 2% | 2- 4% | (nil) | nom. | nom. | | 5-10% | | | | |
| Custom Smelting | 5% | 1- 2% | | | nom. | | nom. | | 7-10% | [Lead, zinc and silver account for 41% of profit in 1970, and a loss in 1971] | |
| Total, Copper | 70-75% | 84-88% | 95-100% | 95% | 85±% | 70-80% | 95±% | | | | 50-60% |
| Zinc | | | | | | | | 30±% | | | 10-15% |
| Lead | | | | | | | | 65±% | | | |
| Coal | | | | | 10-12% | | | | | | |
| Aluminum | | nil | | | | | nom. | | 10-15% | | |
| Primary | | | | | | | | | | | |
| Fabrication | | | | | | | | | | | |
| Other Sales | | | | | | | | | | | |
| All Other, n.e.c. including interest and dividends | 25-30% | 10-15% | ≤5% | ≤5% | 3- 5% | 20-30% | 5±% | 5±% | 80±% | | 25-35% |
| | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | | 100% |
| **Approximate Source of Pre-tax Profits** | | | | | | | | | | | |
| U.S.A. | 40-50% | 70-80% | 100% | 100% | 95±% | 70% | 95% | 80-90% | | | 40-50% |
| Canada | 5±% | 2±% | | | | | 1% | 5±% | | | 10-15% |
| Mexico | 5-10% | 15-20% | | | | | | | | | --- |
| South America | 15-20% | | | | | 57 (nom.) | 5% | 10-15% | | | 10-20% |
| Australia | 25-30% | (nom.) | | | nil | | (1%) | | | | 10-20% |
| Africa | | | | | | 20-30 | | | | | --- |
| Other | (nom.) | | | | nil | | | | | | 15-20% |
| | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

## TABLE VIII-1 (Cont'd)

## SELECTED FINANCIAL DATA: MAJOR U. S. NON-FERROUS METALS COMPANIES

| 1971 | Asarco | Anaconda | Copper Range | Inspiration | Kennecott | Newmont | Phelps Dodge | St. Joe | Amax | Gulf Resources | Cyprus Mines |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sales (in millions of dollars) | 656.8 | 946.5 | 88.6 | 66.2 | 1,066.9[o] | 240.5[o] | 703.6 | 194.4 | 756.9 | 116.2[o] | 203.2 |
| Pre-tax Profit (in millions of dollars) | 51.7 | (5.2) | (6.1) | 12.1 | 102.9 | 67.5 | 113.7 | 27.9 | 65.8 | (3.5) | 58.6 |
| Net Income (in millions of dollars) | 46.0 | (8.7)[a] | (3.5) | 8.7 | 87.2 | 54.5 | 73.8 | 19.6 | 55.4 | (3.9) | 27.8 |
| Cash Flow from Operations and Holdings (in millions of dollars) | 60.0 | 84.5 | 4.9 | 14.6 | 180.0 | 86.0 | 110.3 | 29.1 | 86.5 | 1.2[d] | 32.5 |
| Increase (Decrease) in Debt | 14.4 | 25.0 | 12.0 | (0.1) | 52.0 | 93.2 | 78.7 | (1.0) | 130.6 | 4.6 | (5.5) |
| Dividends Paid | 46.2 | 10.9 | 0.6 | 4.8 | 58.0 | 28.2 | 42.9 | 13.7 | 36.5 | 1.1 | 9.1 |
| Current Ratio: Assets/Liabilities | 2.1 | 3.1 | 3.2 | 3.7 | 2.4 | 3.5 | 3.4 | 3.0 | 3.3 | 1.9 | 1.8 |
| Net Working Capital | 174.0 | 265.0 | 30.3 | 19.0 | 269.0 | 79.3 | 209.0 | 46.5 | 302.0 | 18.3 | 35.8 |
| Capital Expenditures | 37.4 | 89.9 | 11.9 | 9.8 | 150.0 (net) | 129.1 | 75.5 | 21.2 | 139.5 | 7.4 | 38.1 |
| Long-term Debt, year end | 38.1 | 391.5 | 36.3 | nil | 314.6 | 201.6 | 166.0 | 10.7 | 392.0 | 48.6 | 34.9 |
| Equity, year end | 673.3 | 821.0 | 101.7 | 69.7 | 1,192.9 | 444.1 | 710.2 | 171.3 | 625.2 | 28.4 | 207.5 |
| Debt ÷ (debt and equity) Percent based on book values | 5.4 | 32.3 | 27.3[e] | nil | 20.9 | 31.2 | 19.0 | 5.9 | 38.5 | 63.1 | 14.3 |
| Scheduled Debt Repayment (1972 payment excluded from long-term debt at year end 1971) | | | | | | | | | | | |
| 1972 | 3.6 | 24.6 | 1.3 | | 43.4[e] | 8.7 | 0.1 | 1.0 | 35.7 | 2.9 | |
| 1973 | 3.6 | 19.2 | 7.0[e] | | 43.2[e] | 26.7 | 0.1 | | 23.4 | 6.5 | |
| 1974 | 3.6 | 35.5 | 7.0[e] | | 62.3[e] | 31.8 | 12.9 | | 27.5 | 6.0 | |
| 1975 | 5.2 | 58.1 | N.A. | | 5.1[e] | 44.3 | 0.1 | | 20.6 | 5.9 | |
| 1976 | 1.6 | 64.0 | N.A. | | 21.7[e] | 33.5 | 0.1[c] | | 29.7 | 5.9 | |
| Long-term Financing (in millions of dollars, 1971) | | | 20.0 | [b] | 200.0 | 101.9 | 150.0 | | 156.9 | 22.0 | |
| Employment, year end | 13,600 | 27,481 | 3,644 | 2,009 | 30,400 | N.A. | 15,500 | 4,503 (USA) | 16,000 | 2,700 1,940 @ Bunker Hill | |

Notes: p = preliminary; e = estimate
a/ Before extra-ordinary charge due to write-off of Chilean properties and other expense.
b/ Agreement for $13MM advances from toll customer.
c/ Above before $22 MM to be received from Conalco debentures.
d/ $19.7MM write-downs and reserves, net, excluded.
o/ Includes other revenues and/or income, as reported.

The information presented above has been obtained from company annual reports and SEC filings, statistical services, financial manuals, and other sources believed to be reliable, but its accuracy and completeness are not guaranteed.



Arthur D Little, Inc

# TABLE VIII-2

## FINANCIAL PERFORMANCE DATA

## COPPER, LEAD AND ZINC COMPANIES*

| Company | Net Sales For the Year | Operating Income Before Depreciation | Net After Tax Earnings (Before Extraordinary Items) | Capital Expenditures | Operating Ratio: Operating Income As A Percent of Sales | | Net After Tax Return On Stockholders' Equity | Ratio of Capital Expenditures To Gross Plant At Year End |
|---|---|---|---|---|---|---|---|---|
| | MILLIONS OF DOLLARS | | | | PERCENT | | | |
| **Amax** | | | | | | | | |
| 1971 | 756.9 | 97.9 | 55.4 | 139.5 | | | | |
| 1970 | 840.7 | 115.2 | 83.6 | 110.2 (ex. RST) | | | | |
| 1969 | 753.5 | 99.8 | 69.1 | 63.0 | | | | |
| 1968 | 570.6 | 81.9 | 59.8 | 101.2 | | | | |
| | | | Avg. 67.0 | Avg. 103.5 | Avg. 13.6% | | Avg. 13.5% | Avg. 14.6% |
| **Anaconda** | | | | | | | | |
| 1971 | 946.5 | 66.9 | (8.7) | 89.9 | | | | |
| 1970 | 977.4 | 108.9 | 68.1 | 90.5 | | | | |
| 1969 | 1410.6 | 393.1 | 99.3 | 127.0 | | | | |
| | | | Avg. 52.9 | Avg. 102.4 | Avg. 15.4% | Net Income/Sales | Avg. 4.7% | Avg. 8.1% |
| **Asarco** | | | | | | | | |
| 1971 | 656.8 | 26.3 | 46.0 | 37.4 | | | | |
| 1970 | 717.8 | 57.5 | 88.8 | 68.7 | | | | |
| 1969 | 771.0 | 60.1 | 99.4 | 25.0 | | | | |
| 1968 | 634.1 | 38.1 | 73.2 | 37.2 | | | | |
| | | | Avg. 76.9 | Avg. 42.1 | Avg. 6.5% | Avg. 11.0% | Avg. 13.1% | Avg. 9.9% |
| **Copper Range** | | | | | | | | |
| 1971 | 88.6 | 4.7 | (3.24) | 11.9 | | | | |
| 1970 | 97.5 | 21.9 | 9.6 | 14.0 | | | | |
| 1969 | 10.23 | 27.8 | 15.9 | 12.1 | | | | |
| 1968 | 82.1 | 19.9 | 9.7 | 14.4 | | | | |
| | | | Avg. 8.0 | Avg. 13.1 | Avg. 19.9% | | Avg. 9.6% | Avg. 7.9% |
| **Inspiration Consolidated** | | | | | | | | |
| 1971 | 65.8 | 16.9 | 8.7 | 9.8 | | | | |
| 1970 | 88.8 | 30.5 | 17.8 | 9.7 | | | | |
| 1969 | 69.5 | 22.5 | 13.4 | 9.4 | | | | |
| 1968 | 43.9 | 8.7 | 5.7 | 9.0 | | | | |
| | | | Avg. 11.4 | Avg. 9.5 | Avg. 28.1% | | Avg. 21.0% | Avg. 9.6% |
| **Kennecott Copper** | | | | | | | | |
| 1971 | 1053.4 | 191.4 | 87.2 | 162.5 | | | | |
| 1970 | 1133.1 | 322.3 | 185.0 | 163.2 | | | | |
| 1969 | 1050.0 | 286.9 | 165.4 | 152.0 | | | | |
| 1968 | 724.5 | 171.9 | 111.2 | 150.0 | | | | |
| | | | Avg. 137.2 | Avg. 156.9 | Avg. 24.4% | | Avg. 13.1% | Avg. 10.5% |
| **Cyprus Mines (incl. Pima Consol.)** | | | | | | | | |
| 1971 | 203.2 | 66.9 | 27.8 | 42.5 | | | | |
| 1970 | 202.5 [141.8 ex Pima] | 74.2 [32.6 ex Pima] | 27.4 | 28.1 | | | | |
| 1969 | 113.5 | 24.4 | 24.0 | 31.5 | | | | |
| 1968 | 113.0 | 21.2 | 21.3 | 8.5 | | | | |
| | | | Avg. 25.1 | Avg. 27.6 | Avg. 27.5% | (Including Pima 1970-1971) | Avg. 15.2% | Avg. 14.4% |
| **Phelps Dodge** | | | | | | | | |
| 1971 | 703.6 | 140.5 | 73.8 | 75.5 | | | | |
| 1970 | 716.2 Restated | 184.7 Restated | 108.0 | 89.2 | | | | |
| 1969 | 672.1 628.9 | 138.4 N.A. | 89.5 | 87.3 | | | | |
| 1968 | 550.4 531.7 | 98.1 N.A. | 64.6 | 77.7 | | | | |
| | | | Avg. 84.0 | Avg. 82.4 | Avg. 20.7% | | Avg. 14.7% | Avg. 10.1% |
| **St. Joe Minerals** | | | | | | | | |
| 1971 | 194.4 | 29.6 | 19.6 | 21.2 | | | | |
| 1970 | 161.3 | 35.2 | 26.2 | 15.2 | | | | |
| 1969 | 179.0 | 53.1 | 37.5 | 13.4 | | | | |
| 1968 | 150.8 | 36.8 | 25.0 | 10.3 | | | | |
| | | | Avg. 27.0 | Avg. 15.0 | Avg. 22.8% | | Avg. 18.7% | Avg. 6.8% |
| **Gulf Resources Chemical** | | | | | | | | |
| 1971 | 115.2 | 7.8 | (3.85) | 7.4 | | | | |
| 1970 | 114.4 | 13.1 | 4.56 | 4.0 | | | | |
| 1969 | 113.7 | 12.1 | 3.77 | 5.4 | | | | |
| 1968 | 104.9 | 11.7 | 3.45 | 9.5 | | | | |
| | | | Avg. 1.98 | Avg. 6.6 | Avg. 10.0% | | Avg. 3.9% | Avg. 6.2% |
| **Newmont Mining** | | ** | | | | | | |
| 1971 | 197.5 | 55.2 | 54.5 | 129.1 | | | | |
| 1970 | 214.8 | 97.6 | 75.2 | 135.3 | | | | |
| 1969 | 197.0 | 83.8 | 64.1 | 57.0 | | | | |
| 1968 | 154.1 | 61.3 | 50.3 | 58.1 | | | | |
| | | | Avg. 61.0 | Avg. 95.0 | Avg. 39.0% | | Avg. 17.4% | Avg. N.A. |

NOTE: While reasonable care was taken in compiling this data and presenting it in as consistent a fashion as is possible, we cannot guarantee absolute comparability from one company to the next, due to differences in the nature of earnings, and differences in their accounting for certain balance sheet and income statement items. To the best of our knowledge the above data present an accurate and meaningful basis for selective comparisons.

The information presented above has been obtained from company annual reports and SEC filings, statistical services, financial manuals, and other sources believed to be reliable, but its accuracy and completeness are not guaranteed.

*For a discussion of New Jersey Zinc Company, a subsidiary of Gulf and Western Industries, see text.
*This table should be read in conjunction with Table VIII-1.

**Excludes dividends, interest, net gain on sales of securities and other income in the following amounts:

1968 - $39.3
1969 - 40.4
1970 - 43.6
1971 - 43.0

many of the companies back in 1970 after passage of the Clean Air Act, may result in a further increase in their debt, and hence, according to financial convention and theory, further "deterioration" in their financial structures as a result of more highly-leveraged earnings (higher debt-to-equity ratios) and higher fixed charges.

## D. SELECTED COMPANY PROFILES

### 1. The Anaconda Company

Anaconda is the third largest producer of primary copper and the sixth largest aluminum producer in the United States. In addition to primary copper and aluminum, Anaconda produces brass and wire mill products and fabricated aluminum products. In 1971, total sales were $947 million. The estimated breakdown of sales and earnings by product line were presented in Tables VIII-1 and VIII-2, which also include a four-year financial review. Anaconda suffered substantially from the nationalization of its Chilean properties in July 1971. The Chilean copper mines provided, it is believed, over 40% of 1970 earnings and an even greater proportion in prior years. Anaconda's North American copper mines, which provide the majority of present earnings, are relatively high in cost, creating wide cyclical swings, depending on price movements. Production of lead bullion ceased as of December 31, 1971, and zinc production is expected to cease in 1972. Other products produced and sold by Anaconda include uranium oxide concentrates, silver, gold and also lumber. Cadmium production, which totalled 418,000 pounds last year, will no longer be produced after the closing of zinc operations. Over 40% of North American copper production comes from Montana, about 30% from Arizona and the balance from Nevada and Mexico. Major investments in Montana over the past two years have resulted in the ability to handle substantially larger tonnages at the Berkeley pit, the concentrator at Butte and at the Anaconda smelter. Except for strike periods last year, Anaconda's copper refineries were operated at capacity at both Great Falls, Montana and Perth Amboy, New Jersey.

During 1971, approximately 10% of consolidated sales were derived from operations in foreign countries, principally Canada and Mexico; these operations are expected to continue to be a significant source of income to Anaconda.

As of December 1, 1971, Anaconda held 27.7% of the stock of Inspiration Consolidated Copper Company, which accounts for about 5% of U.S. mine output and a net income before taxes of over $12 million in 1971. (Inspiration Consolidated will be discussed subsequently.)

Anaconda had aluminum and aluminum product sales of $177 million last year. It is committed to invest approximately $120 million in various aluminum production facilities, the major portion which relates to the aluminum plant in Sebree, Kentucky. According to Anaconda's annual report, "financing is now being negotiated to provide funds for

the Sebree production plant and for pollution control facilities at the Anaconda smelter, the only major scheduled projects not fully financed."

Anaconda has a 37% interest in an alumina production facility in Jamaica, West Indies. Anaconda is entitled to receive its share of the alumina produced and is committed to pay its share of the venture's costs. The new aluminum production plant at Sebree, Kentucky, will have a capacity of 120 million tons a year, supplied primarily from the Jamaica venture. With Sebree, Anaconda will be able to produce all the primary aluminum needed for its manufacturing operations (not yet substantial contributors to profits).

2. American Metal Climax, Inc. (AMAX)

On December 31, 1957, American Metal Co., Ltd., and Climax Molybdenum Co. merged under the name American Metal Climax, Inc. American Metal Co., Ltd. (incorporated 1887) grew rapidly from a purely trading concern into a factor in the mining and smelting industry in the United States and Mexico. In 1929, the company acquired its first interest in the Zambia copper mines, an interest that has grown tremendously up to 1970 when the Republic of Zambia acquired a substantial interest in these copper mines. Amax engages in metallurgical and petroleum enterprises through subsidiaries and stock interests in many companies. Industrial operations of the subsidiaries are in the United States, Mexico, Canada, Zambia, Botswana, South West Africa, South Africa, and most recently, Australia, but metal-trading activities are virtually world wide.

The principal products and by-products are aluminum, coal, coke, copper, copper-powder, gold, silver, palladium, platinum, selenium, tellurium, and arsenic; lead, lead powder, solder, terne metal, zinc, cadmium, bismuth, and germanium; molybdenum sulfide (concentrates), molybdenum trioxide, calcium molybdate, molybdenum, and ferromolybdenum; and potash, uranium, vanadium, and iron powder.

The wholly-owned subsidiary, United States Metals Refining Co., operates a copper smelter and refinery at Carteret, New Jersey, which produces refined copper from domestic and foreign ores, concentrates, blister copper, and copper scrap. The total annual refining capacity of 275,000 short tons consists of 150,000 tons of electrolytic capacity and 125,000 tons of fire-refining capacity.

In July 1972, Amax said it would enter the copper mining business in the U.S. in a two-step transaction in which it would acquire Banner Mining Co., which owns the Twin Buttes (Pima County, Arizona) property currently mined by Anaconda; and then enter into a joint venture with Anaconda to expand operations at Twin Buttes.

Other enterprises in which American Metal Climax, Inc., has substantial interests are:

Ponce Mining Company, Inc.
*Blackwell Zinc Company, Inc.
Missouri Lead Company
Heath Steele Company (Canada)
Climax Molybdenum Company & Subsidiaries
Climax Uranium Company
RST International Inc.

| | PERCENT |
|---|---|
| and minority interests in: | |
| (Roan Consolidated Mines Ltd. Chisangwa Mines Ltd.) | 20% |
| Botswana RST, Ltd. | 30% |
| Tsumeb Corporation, Ltd. | 29% |
| O'okiep Copper Company, Ltd. | 17% |
| Copper Range Company | 20% |
| Canada Tungsten Mining Corp., Ltd. | 41% |

3. American Smelting and Refining Company (ASARCO)

Asarco is an important non-ferrous metals miner and the leading smelter and refiner of metal ores, concentrates and scrap. The fifth-largest U.S. copper producer, it holds sizable equity interests in foreign mining subsidiaries. In 1971, equity in earnings of companies above 50%-owned was about 81% of total profits.

Mine output in 1971 was 75,800 tons of copper, 6,658,000 ounces of silver, 43,100 tons of zinc, and 18,700 tons of lead. Including purchased materials, refined output was 406,500 tons of copper, 56,311 ounces of silver, 189,000 tons of lead, and 133,700 tons of zinc and by-products.

Copper is mined primarily at the Mission and Silver Bell pits in Arizona. Zinc, lead and silver are also mined in the U.S. Extensive smelting and refining operations are at 13 U.S. plants. The Federated Metal Division carries on secondary metal and fabricating activities.

Asarco's holdings in other companies are:

| | | |
|---|---|---|
| Southern Peru Copper Corporation | - | 51.5% |
| Northern Peru Mining Corporation | - | 100% |
| Revere Copper & Brass Inc. | - | 33.6% |
| Asarco Mexicana S.A. | - | 49% |
| Neptune Gold Mining Co. | - | 51.8% |
| Lake Asbestos of Quebec Ltd. | - | 100% |
| Granduc Mines Ltd. (NPL) | - | 50% |

* will close their zinc smelter in Blackwell, Oklahoma

| | | |
|---|---|---|
| Asarco Exploration of Canada Ltd. | - | 100% |
| Asarco (Australia) Pty. Ltd. | - | 100% |

SOURCE: Jane's World Mining Who Owns Whom, 1970.

The company announced recently that it has begun a $13 million development of copper deposits on the San Xavier Indian Reservation near Tucson. On completion in 1973, the mine and processing plant will produce about 1000 tons per month of 82% cement copper.

The new project will mine about 4000 tons of ore daily for about eight years from two large low-grade deposits of ore, averaging only 0.5% copper. Leaching of the copper from the ore will consume about 11% of the sulfuric acid Asarco makes from sulfur dioxide stack gases at its Hayden, Arizona smelter, in a new acid plant.

American Smelting and Refining Company also recently announced it was going to spend $36 million to dig a combination open pit-underground mine with reserves of more than 47 million tons of 0.76% copper ore. This mine will be located about five miles from Casa Grande, 45 miles southeast of Phoenix. The company said it will begin as an open-pit mine in a little more than two years and be phased into an underground mine in 1979.

Asarco has announced publicly a $50 million program to improve air quality at its three copper smelters. The sulfuric acid plant at the Hayden, Arizona smelter was completed and dedicated on January 25 of this year. An acid plant is under construction at El Paso and construction of a liquid sulfur dioxide plant is expected to get under way soon at Tacoma. Each of these facilities will result in recovery of more than 50% of the sulfur contained in ores and concentrates smelted at the plant. In addition, Asarco is engaged in programs to control air quality at other smelters and secondary plants and to minimize liquid effluents and improve the appearance of waste dumps and tailings dams associated with mines.

Asarco has also acknowledged that the stricter Occupational, Health and Safety Standards (OHSA) under Federal legislation will call for significant outlays at most operations.

In 1971 with earnings considerably reduced, Asarco's cash flow fell short of its dividend and capital expenditures. The Board cut the dividend in October 1971 and the company entered into arrangements for $28 million of short term bank loans as well as arranged to deliver $18 million in five-year notes and part payment for the purchase of American Zinc assets. The company commented that the adjustment in the dividend rate brought the dividend "more in line with earnings and the requirements for substantial capital expenditures to maintain the strength of the company and to provide for its future growth." Furthermore, the considerable increase in inventory as a result of strikes in 1971 indicate the potential for liquidation of inventories this year of "at

least as much as $28 million in bank loans outstanding at the year end." Thus, Asarco continues to have a strong balance sheet and very low debt to equity ratio and by its own admission "is in a position to take advantage of attractive opportunities for profitable investment that may become available."

4. Inspiration Consolidated Copper Company

Inspiration is almost entirely a domestic copper producer, operating several open-pit mines located close together in Arizona. A copper rod-making facility rolls about 65% of Inspiration's mine output into a simple fabricated form.

Inspiration accounts for about 5% of the U.S. mine output, with the bulk of output coming from relatively low cost open-pit operations in Arizona. Sales were $66 million in 1971.

Total mine production in 1971 was 117,679,775 pounds of copper, of which some 75% was obtained from open-pit mining. The Inspiration area mines contributed 62%, Christmas Mine 13%, and leaching (including Ox Hide Mine's heap-leaching operations) 25%.

The average price received for the 108,679,160 pounds delivered was 51.98 cents a pound versus 58.12 cents in 1970. Costs before taxes, depreciation and depletion were about 37.6 cents a pound compared with 38.0 cents a pound in 1970.

Reserves are relatively small compared with other domestic producers but have been expanded periodically by inclusion of lower-grade ores as the company becomes able technically to treat such ores economically. While the amount of ore treated is expanded, the lower grades of ore are a partially offsetting factor.

Ore reserves at the Christmas mine are estimated at 283,803 tons mineable underground and 137,261 tons mineable in open-pits. Underground mining has been plagued by water inflow and unstable rock conditions which resulted in a fatal rock burst in 1966. Underground operations were subsequently suspended and the low-grade open-pit operations expanded. The underground operations are being maintained on a standby basis. An additional 14,852 tons of reserves are estimated at the Sanchez (Arizona) mine, presently being developed.

The oxide-sulfide ores are concentrated at the company's dual-process plant and shipped to a nearby smelter (acquired in 1969 from an Anaconda subsidiary) for smelting. Under the dual process, the oxide ores are first treated by acid leaching, and the leached ore is put through the flotation concentrator along with the pure sulfide ores. The company is undertaking to process pure oxide ores by leaching only, which would allow more sulfide ores to be processed in the concentrator. Anode copper produced in the smelter is then refined by electrolytic process in Inspiration's plant.

Inspiration faces one of the heaviest burdens for pollution abatement expenditures and costs, relative to the size of the company and its financial resources. Inspiration's plan for meeting Arizona smelter emission control standards by 1974 calls for a new installation costing about $45 million. Some $13.2 million will be advanced by a toll customer, to be repaid over the term of a ten-year contract for treating the customer's concentrates. The balance is being borrowed on bank revolving credit, to be replaced by long-term debt financing.

5. Duval Corporation (Subsidiary of Pennzoil United, Inc.)

Pennzoil United, Inc., formed in 1968 by the consolidation of Pennzoil Company and United Gas Corporation is a natural resource company engaged in oil and gas exploration; production, refining and marketing of motor oil, lubricants and related products; natural gas transmission; and the mining and processing of copper, silver, gold, molybdenum, potash and sulphur.

Duval Corporation, a wholly-owned subsidiary, mines and processes copper, molybdenum and silver ore in Arizona and copper, gold and silver ore in Nevada, mines and processes potash ore in New Mexico and Canada and mines sulphur in Texas.

The following table sets forth for the years 1967 through 1970 total assets, gross revenues and gross operating income (net income before total interest charges, Federal income tax, minority stockholders' interest, general corporate overhead and an extraordinary item in 1967) attributable to the major components of the business of Pennzoil United and its consolidated subsidiaries without adjustment for certain intercompany transactions. (In the opinion of the company, it is impracticable to allocate the foregoing items in such a manner as to fairly reflect the contribution of such components to net income.)

| | (Expressed in thousands) | | | |
|---|---|---|---|---|
| | 1967 | 1968 | 1969 | 1970 |
| **Total Assets** | | | | |
| Integrated Oil and Gas Operations | $331,381 | $354,024 | $391,047 | $409,455 |
| Natural Gas Transmission | $428,939 | $424,344 | $432,365 | $471,998 |
| Mining Operations of Duval | $183,850 | $220,015 | $295,161 | $347,993 |
| Retail Gas Distribution | $150,700 | $135,643 | $134,825 | $ --- |
| **Gross Revenues** | | | | |
| Integrated Oil and Gas Operations | $166,542 | $172,372 | $193,043 | $218,333 |
| Natural Gas Transmission | $332,690 | $359,420 | $394,131 | $440,444 |
| Mining Operations of Duval | $ 61,445 | $ 74,947 | $ 82,697 | $ 95,347 |
| Retail Gas Distribution | $ 68,795 | $ 78,020 | $ 77,247 | $ 51,018 |
| **Gross Operating Income (as defined)** | | | | |
| Integrated Oil and Gas Operations | $ 37,433 | $ 39,905 | $ 47,737 | $ 52,353 |
| Natural Gas Transmission | $ 33,943 | $ 33,014 | $ 27,461 | $ 42,756 |
| Mining Operations of Duval | $ 17,775 | $ 18,564 | $ 17,494 | $ 24,237 |
| Retail Gas Distribution | $ 8,909 | $ 12,913 | $ 13,915 | $ 13,705 |

Source: Pennzoil United Inc. Prospectus dated March 23, 1971.

The following table reflects the approximate contributions to gross income (net income before total interest charges, Federal income tax and unallocated general corporate overhead) attributable to the mining operations of Duval for the periods indicated:

| | 1966 | 1967 | 1968 | 1969 | 1970 |
|---|---|---|---|---|---|
| Metals | 77% | 86% | 86% | 98% | 90% |
| Potash | 14% | 3% | (1%) | (2%) | 7% |
| Sulphur | 9% | 11% | 15% | 4% | 3% |

( ) Indicates negative figure.

The potash data set forth above for the years 1966-1969 relates only to potash produced by Duval in New Mexico while the data for the year 1970 includes Duval's potash production in Canada.

Duval has three principal subsidiaries, Duval Sierrita Corporation, Duval Sales Corporation and Duval Corporation of Canada. Duval Sales Corporation is the marketing agency for Duval's potash, molybdenum, sulphur and a portion of its copper and conducts a brokerage business in fertilizer components. Duval carries on an active exploration program and maintains exploration offices in Texas, Arizona, Utah, Nevada, Canada and Australia.

The prospectus dated March 23, 1971, in connection with a Pennzoil United debenture offering presented the following financial and accounting information, which is useful to an understanding not only in the case of Duval, but perhaps more generally with respect to many other major, publicly-held, mining-based companies (e.g., a discussion of Kennecott's treatment of Peabody Coal).

> Mine development costs of Duval are capitalized for financial reporting purposes and are depreciated or depleted over the operating lives of the related properties. For Federal income tax purposes such costs are deducted as incurred. To the extent such capitalized costs are utilized in reducing current income tax, such reduction in current tax is charged to income and credited to deferred income tax. In 1969, Duval sold mineral production payments in the amount of $100 million and the taxes payable resulting from this sale have been charged to deferred income tax. Proceeds applied to the liquidation of the production payments are included in income as produced and the related income tax charged against income.

Duval operates two open-pit copper-molybdenum mines in Arizona known as the Esperanza and Mineral Park Properties. Duval estimates its proven ore reserves as of December 31, 1970, at Esperanza to be 25,936,000 tons, with an average copper content of 0.37% and an average molybdenum content of 0.034%, and at Mineral Park to be 33,797,000 tons with an average copper content of 0.47% and an average molybdenum content of 0.048%. The Esperanza Property has been in production since 1959 and the Mineral Park Property since the latter part of 1964.

Duval operates two copper-gold-silver open-pit mines located some 11 miles apart near Battle Mountain, Nevada, known as the Copper Canyon and Copper Basin mines, which were placed on a full production basis in July 1967. Duval estimates its proven ore reserves as of December 31, 1970, at Copper Canyon to be 13,942,000 tons with an average copper content of 0.78% and an average silver and gold content of 0.51 and 0.024 ounces per ton of ore, respectively; and at Copper Basin to be 1,331,000 tons with an average copper content of 1.55% and an average silver and gold content of 0.27 and 0.022 ounces per ton of ore, respectively. Duval constructed a concentrator and related facilities near the Copper Canyon mine. The concentrator has a design capacity of 4,000 tons of ore per day.

Duval Sierrita*

In November 1967 the United States Government through the General Services Administration (GSA) and Duval Sierrita Corporation, an operating subsidiary of Duval, entered into a domestic copper production

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* The above information is taken from Pennzoil-United's March 23, 1971 prospectus.

expansion contract pursuant to the provisions of the Defense Production Act of 1950 for the development of a low-grade copper-molybdenum ore body (Sierrita Property) adjacent to Duval's Esperanza Property. Construction of a mill and related facilities designed to process an annual average rate of ore throughput equal to not less than 66,000 tons per day and the pre-mining stripping of 126 million tons of waste overburden were substantially completed in March 1970. Approximately $181 million was required to develop the original project (not including the cost of the expansion project referred to below) of which $83 million was obtained from the GSA in the form of advances against future deliveries of copper produced from the property; $48.75 million from commercial bank loans guaranteed in part by the GSA; $10 million from the Company; and the remainder from Duval in equity or loans. Duval provides management and technical guidance to Duval Sierrita at cost.

The contract with the GSA provides that repayment of advances will be made by delivery of about 218.4 million pounds of copper to the GSA prior to June 30, 1975. The advances will be credited at the rate of 38¢ for each pound of refined copper delivered. While the contract provides that certain minimum deliveries must be made at stated intervals during the period from commencement of production to the final repayment date, Duval Sierrita is entitled to sell in the open market its molybdenum and by-product silver production and such amount of its copper production as may be necessary to cover all cash operating expenses and maintain working capital. The commercial bank loans are payable in installments from December 1975 through June 1978.

In May 1970 these contracts were amended to provide for an increase in the mine and mill capacity at the Sierrita Property. Duval Sierrita agreed to spend not less than $8 million on additional facilities and guaranteed the GSA an average rate of ore throughput on an annual basis of not less than 72,000 tons per day. In turn, the GSA and the commercial banks have agreed to permit Duval Sierrita to sell on the open market for its own account 90% of production attributable to any ore throughput exceeding 72,000 tons per day. The remaining 10% of such production (net of sales required to meet cash operating expenses attributable thereto) will be delivered to the GSA at a fixed price of 38¢ per pound. Cash flow generated by such sales for the account of Duval Sierrita will be available for general corporate purposes, including the payment of dividends and the repayment of advances from Duval or loans from others required to finance the expansion. It is anticipated that the expansion of the mill and mine capacity will cost about $13 million of which $6 million had been expended through December 31, 1970.

Start up and test operations commenced in the first quarter of 1970. Through December 31, 1970, 14,318,000 tons of ore having a copper and molybdenum content of 0.28% and 0.026%, respectively, had been milled. However, the facilities for integrated copper-molybdenum milling operations were not completed until the latter part of 1970 and normal production did not commence until after the end of 1970.

Duval estimates the proven ore reserves of the Sierrita Property to be 524 million tons with an average copper content of 0.33% and an average molybdenum content of 0.033%. The stripping ratio during the operational life of the mine, excluding pre-mining stripping of waste overburden, is estimated to be 1.28 to 1. The stripping ratio during the first five years of operations is estimated to be 2.25 to 1.

Marketing Conditions

In the years 1968, 1969 and 1970 Duval's production (including Duval Sierrita in 1970) of copper represented approximately 5%, 5% and 6%, respectively, of domestic mine production, the bulk of which was accounted for by three principal producers, and Duval's molybdenum production represented 6%, 5% and 9%, respectively. During the period July 1967 through March 1968 Duval made sales of copper in the foreign market pursuant to special export licenses granted by the Department of Commerce. Such sales were necessitated by work stoppages at smelters that previously processed Duval's concentrates and were made at prices generally more favorable than those theretofore prevailing in the domestic market.

American Smelting and Refining Company has agreed to purchase at least 50% of Duval and Duval Sierrita's aggregate production of copper concentrates and precipitates other than that to be delivered to the GSA (as previously described). The remaining concentrates and precipitates are smelted and refined on a toll basis by American Smelting and Refining Company with the resultant refined copper being marketed by Duval and Duval Sierrita to various copper consumers. The marketing of molybdenum production is the responsibility of the respective companies. Although the companies have a number of short-term sales contracts and to date have not encountered any difficulty in marketing copper production, there are no existing long-term contractual commitments for the sale of a substantial portion of the companies' copper production.

6. Copper Range Company

Copper Range Company owns and operates the White Pine Mine (in Michigan's Upper Peninsula), through White Pine Copper Co., a wholly-owned subsidiary. White Pine is an underground mine which produces approximately 5% of U.S. copper output. Reserves are estimated to exceed 300 million tons assaying 1% copper. The company is a relatively high cost producer deriving most of its revenues and virtually all of its net income from White Pine. The mill has sufficient concentrating capacity to handle 25,000 tons of ore per day and adequate smelter capacity to handle the output of the concentrating plant. The smelter reportedly can produce over 87,000 tons per year of lake grade copper (a fire refined metal).

Copper Range sells most of its output to U.S. and foreign fabricators. It has a captive demand through the Hussey Fabricating Division for a portion of output. Hussey accounts for about 1/3 of Copper Range's

consolidated sales. The Hussey Metals Division sales consist mainly of sheet and strip and the remainder from the distribution of various copper base products made by other mills.

Compared to Western ores, the White Pine ore has a low sulfur content and Copper Range states that it presently meets both the primary and secondary Federal Air Quality Standards under the Clean Air Act of 1970. The company has stated that "but given presently available technology, we do not believe that it would be economically feasible for us to meet a 90% emission standard. A research and development effort is in progress to identify and develop a process which will reduce sulfur dioxide emissions from our White Pine smelter on a reasonable economic basis."

7. Cyprus Mines Corporation

Cyprus Mines was incorporated March 10, 1916, in New York. It operated the Old Dick mine near Bagdad, Arizona. Together with Union Oil Company of California and Utah International Inc., each of whom owns about 25%, has a 50-percent interest in and manages Pima Mining Company, which operates the Pima open-pit mine near Tucson, Arizona. Pima's operations are now consolidated in Cyprus' financial statements. The company has leasehold concessions on copper and pyrite mines on the Island of Cyprus. Other non-ferrous interests are the wholly owned copper-zinc Bruce mine, Arizona and 60% ownership of the Anvil lead-zinc mine, Yukon Territory, Canada. The corporation also has interests in 43 producing oil wells and gas wells in Kansas, Texas, and Louisiana; owns United Sierra--a talc producer--, sawmills and plywood plants at Medford, Oregon, and timberlands in Oregon, California, Alabama, and British Columbia. It has minority interests in Marcona Mining Company, 46 percent; Mount Goldsworthy in Australia, 33 percent; Cia. San Juan, S.A., 44.65 percent; Albatross Sulfuric Acid and Chemical Works, Rotterdam, 45 percent; Hawaiian Cement Corp., 42 percent; and Titanium Dioxide Works, Ltd., Rotterdam, 22.50 percent. In addition, the company operates several divisions fabricating non-ferrous metal products.

8. Phelps Dodge Corporation

Phelps Dodge is the second largest domestic copper producer. The principal business of Phelps Dodge Corporation (PD) is the production of copper from mines located in the United States, the sale of part of such copper as refinery shapes or as rods, and the fabrication of the remainder of such copper (as well as copper purchased from others) for sale as wire, cable and tubular products. PD also smelts and refines copper, and rolls rod on toll for others. On March 31, 1971, the corporation's aluminum fabricating subsidiary, Phelps Dodge Aluminum Products Corporation, merged into Consolidated Aluminum Corporation ("Conalco"). As a result of such merger, PD holds 40% of the outstanding shares of the capital stock of Conalco.

PD Corporation obtains most of its copper requirements from its own domestic mines, but supplements its own copper with purchases from others. The corporation continues to import a relatively small tonnage of alumina, all or most of which it sells to Conalco.

During 1970 and 1971, mine output of copper averaged about 300,000 short tons. Some 40% was produced at the Morenci mine, 20% from Ajo, 20% at Bisbee, and 20% at Tyrone. Reserves are large, with the exception of the Bisbee mine. Additional capacity is expected to be brought in during the early 1970's to replace the Bisbee operations, raising overall capacity to 330,000 tons a year.

Rated refinery capacity of 537,000 tons is located at El Paso (445,000 tons electrolytic and fire-refined) and Laurel Hill, New York (72,000 tons electrolytic and 20,000 tons fire-refined). The latter plant is a custom operation, processing copper for other producers and treating scrap. Refined production including custom output totaled 604,900 tons in 1970. Wire mills are located in New York (4), New Jersey (2), Indiana (2), Kentucky, and Arkansas. Tube mills are in California and New Jersey. A brass foundry is operated in Alabama and interests are held in 13 foreign fabricating operations.

Copper Mining

The corporation expects to shut down the open-pit mine at Bisbee due to exhaustion of ore reserves early in 1973. It appears likely that the Bisbee underground mines will also shut down at that time, unless the price of copper is high enough to make their operation economic for a while longer.

In December 1970, the Company decided to stretch out by two years the development program of a new mine near Morenci, Arizona, to be known as the Metcalf mine. This mine is expected to be ready for production in late 1974 with an estimated annual rate of production in excess of 50,000 tons of copper. The cost of developing the Metcalf mine will be in excess of $150,000,000 of which $38,000,000 was expended through December 31, 1970.

All the ore at Phelps Dodge's mines is classified as sulphide ore, except for some oxide ores at the Bisbee underground mines. As of January 1, 1971, Phelps Dodge estimated the copper ore reserves at its mines at not less than 1,524,300,000 tons of ore. The table below sets forth such ore reserves (expressed in millions of tons), together with average ore grades, at each of such mines:

| | Ore Reserves | Grade of Ore |
|---|---|---|
| Morenci | 737 | 0.80% |
| Ajo | 138 | 0.70 |
| Bisbee | | |
| Open-Pit | 8 | 0.94 |
| Underground | 2 | 5.41 |
| Tyrone | 292 | 0.81 |
| Metcalf | | |
| Open-Pit | 221 | 0.74 |
| Underground | 127 | 0.92 |

In general, Phelps Dodge is thought to be one of the lowest cost copper producers. The company has reported that production costs at Phelps Dodge's operating mines, per pound of copper mined, are lowest at Morenci, which is its largest mine, and are by far the highest at the Bisbee mines. Costs at Ajo and Tyrone are somewhat higher than at Morenci and are about the same as the average costs of all Phelps Dodge operating mines. Phelps Dodge anticipates that costs of production at the Metcalf mine, when it begins operation, will be similar to those at Ajo and Tyrone and thus appreciably lower than those at Bisbee.

Copper Smelting

Phelps Dodge's copper smelters are located at Morenci, Ajo and Douglas, Arizona. Production of the Morenci mine and most of that from Tyrone is treated at the Morenci smelter, which has the capacity to treat approximately 900,000 tons annually of new metal-bearing material (that is, copper-bearing materials such as concentrates, ore and scrap). Production of the Ajo mine, and a portion of the Tyrone production, is treated at the Ajo smelter, which has the capacity to treat approximately 300,000 tons of new metal-bearing material annually. Production from the Bisbee mines and a portion of that from Tyrone, as well as custom material and scrap, is treated at the Douglas smelter, which has the current capacity to treat approximately 860,000 tons of new metal-bearing material annually. The smelters produce anode copper--copper which is nearly pure and which is then shipped to Phelps Dodge refineries for refining. The combined current capacity of Phelps Dodge's three smelters would be sufficient to treat the increased production anticipated when the Metcalf development has been completed.

Under the air quality law of Arizona, standards were established in 1970 fixing the amounts of particulate matter and sulfur dioxide to be permitted in the general atmosphere, and emission regulations to implement those standards were issued. Phelps Dodge's smelters did not comply with these emission regulations as this report went to press. The Arizona law requires that smelters must meet the emission regulations by the end of 1973. Until then, each smelter may only operate under an annual permit issued by the state and conditioned on satisfactory

performance under a plan for compliance acceptable to the state. Phelps Dodge has instituted programs, based in part upon technology not heretofore applied in a copper smelter, designed to enable it to satisfy the regulations at each of its smelters, and it has received permits to operate each smelter. The Douglas smelter faces the most severe pollution abatement costs to meet proposed standards, and there has been much publicity concerning its likely shut down.

PD has announced that it plans to construct, at a cost of approximately $100 million, a new copper smelter in New Mexico to treat the production of its Tyrone, New Mexico mine.

Substantial capital expenditures, as well as increased operating expenses, will be required to enable Phelps Dodge to comply with existing Arizona air quality regulations at its existing smelters. Construction of air pollution control facilities at the Ajo smelter, the Company's smallest smelter, is under way at an estimated cost of $27,000,000. The proposed programs at Morenci and Douglas are more complicated because the material being treated contains more sulfur per ton of copper than at Ajo and because the design of those smelters will necessitate the replacement of basic furnace units.

The program at Ajo includes new converter flues with waste heat boilers, improved electrostatic precipitators, an absorption plant--of a size beyond any ever tried before--to concentrate the $SO_2$, and a large sulfuric acid plant.

At the Morenci and Douglas smelters installation of new electrostatic precipitators, either replacing or supplementing less efficient existing units, was completed during 1971 and at Morenci construction of a new reverberatory furnace with improved emission control equipment was begun. Detailed engineering and cost studies were completed for additional emission control facilities that may be required at these two smelters.

Investments and Holdings

Phelps Dodge has the following investments and stock holdings in other corporations:

| | Percent of Voting Power |
|---|---|
| American Metal Climax | 3% |
| Southern Peru Copper Corporation | 16 |
| Allied Nuclear Corporation (Wyoming) | 34 |
| Apache Powder Company (New Jersey) | 38 |
| Consolidated Aluminum Corporation (New York) | 40 |
| Metminco Incorporated (Delaware) | 43 |
| PhelDrak International Corporation (Delaware) | 50 |
| Phelps Dodge Enfield Corporation (Delaware) | 71 |
| Phelps Dodge Svenska Metallverken International Corporation (Delaware) | 67 |

## 9. Newmont Mining

Newmont is a diversified holding company, whose subsidiaries explore, develop, finance, manage and operate mineral properties. Newmont also has interests in petroleum and cement companies and maintains a securities portfolio.

Magma Copper Company, wholly owned, is the fourth largest U.S. copper producer. Its principal copper properties are located at Superior and San Manuel, Arizona, which together treat some 44,700 tons of ore daily. In Canada, the Granduc copper mine in Northern British Columbia, jointly leased with American Smelting & Refining Company, is expected to reach full operation at a rate of 7,500 tons daily in late 1971. The wholly-owned Similkameen project being developed near Princeton, B.C. should begin producing copper concentrates by mid-1972. Design capacity is 15,000 tons of ore daily. Newmont has sold its share of concentrates production at both Canadian properties for several years to Japanese interests.

Newmont has announced that it will spend $30 million by the end of 1973 to reduce sulfur dioxide emissions from Magma's copper smelter in San Manuel, Arizona. The expenditures cover a converter gas collection system and an acid plant of 2,000 tons per day capacity which will handle the entire sulfur dioxide output from the converters. The San Manuel smelter can treat about one million tons of copper concentrates in a year.

O'okiep Copper Company, 57.5% owned, operates several South African copper mines with current production of about 9,000 tons of ore daily. Other mining subsidiaries include Carlin Gold Mining Company, wholly-owned; Draw Mining Company, 51% owned; and Idarado Mining Company, 80.1% owned. A joint venture with Asarco is developing a lead-zinc property in Colorado; production began early in 1971.

Newmont is engaged in petroleum and natural gas exploration and production in the U.S. and Canada. It also owns, jointly with Cerro Corporation, Atlantic Cement Company Newmont's equity in Atlantic's net assets at the end of 1970 was $36,590,000.

Investments are substantial and, at December 31, 1971, had a market value of $291 million. Investments include 18.8% ownership of Canadian Export Oil & Gas Ltd.; 4.4% of Continental Oil Co.; 32.8% of Foote Mineral Co.; 11.9% of Highveld Steel & Vanadium Corp., Ltd.; 42.3% of Palabora Holdings Ltd.; 2.7% of Palabora Mining Co., Ltd.; 8.1% of St. Joe Minerals Corp.; 39.6% of Sherritt Gordon Mines Ltd.; 10.3% of Southern Peru Copper Corp.; 38.7% of Tsumeb Corp., Ltd.; and 1.6% of Transcontinental Gas Pipe Line Corporation.

Dividends, paid each year since 1934, averaged 47% of reported net in 1967-71.

Beginning in 1972, Newmont will account on an equity basis for investments in companies 20% owned or more.

10. Kennecott Copper Corporation

Kennecott Copper Corporation is the largest domestic producer of copper, the second largest domestic producer of molybdenum and an important source of gold, silver, lead, zinc, high quality iron and titanium slag. Kennecott is an integrated producer of minerals, metals and metal products. Kennecott is also engaged in the coal mining business through its wholly-owned subsidiary, Peabody Coal Company. Total annual revenues exceed $1 billion. Peabody is one of the two largest producers of coal in the domestic market and the largest supplier of coal to the electric utility industry in the United States.*

Kennecott's 49% interest in Sociedad Minera El Teniente S.A., a Chilean corporation which owns and operates the El Teniente copper mine in Chile, was expropriated by the Chilean Constitutional Reform Bill, which became effective in July 1971. In prior years, Kennecott received over $20 million per year in dividends from El Teniente. (Kennecott's investment in Chile was carried at $143.3 million at December 31, 1971. $84.6 million is the subject of a Contract of Guaranty with the U.S. Overseas Private Investment Corporation.)

Wholly-owned subsidiaries include Chase Brass and Copper Co., and Ozark Lead Company. Chase is a leading fabricator of copper and brass mill products. Chase buys a large portion of its copper from Kennecott, accounting for 15-20% of Kennecott's domestic copper mine output. Profit margins are typically low in this part of the industry; in fact, Chase showed a loss in 1971.

Kennecott also holds two-thirds of Quebec Iron & Titanium Corporation. (Gulf & Western and New Jersey Zinc have minority interests.)

Kennecott operates four copper properties in the United States. In 1971, these divisions produced 456,000 tons of copper, and 13,000,000 pounds of molybdenum. Kennecott's Utah Copper Division mine in Bingham, Utah is the second largest copper producer in the world, ranking next to Chile's Chuquicamata mine. (The El Teniente mine in Chile is the world's largest underground copper mine.) Blister copper from the Utah smelter is refined at the company's electrolytic refinery at Garfield, with an annual capacity of 204,000 tons.

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* In 1968, the Federal Trade Commission issued a complaint against Kennecott alleging that the acquisition of Peabody Coal violated Section 7 of the Clayton Act and seeking divestiture if such a violation is established. A resolution of these issues is not expected until early 1973.

The Chino Mines Division comprises the Chino mine at Santa Rita, New Mexico and a concentrator and smelter at Hurley, New Mexico, nine miles away. The Chino mine is an open-pit operation and produced 80,000 tons in 1970 and 71,500 tons in 1971. The Ray Mines Division operates an open-pit mine at Ray, Arizona. The ore is concentrated and smelted in company facilities at Hayden, Arizona.

At the Nevada Mines Division, mining is by the open pit method in Ruth, Nevada. The ore is concentrated, then smelted in company plants at McGill, Nevada. Blister copper produced from the Ray Mines and Nevada Mines is refined at the refineries of Kennecott Refining Corporation and American Smelting and Refining Company in Baltimore, Maryland.

The following tables show, for the period indicated, the approximate amounts of Kennecott's consolidated sales and income (before income taxes, minority interest and extraordinary items) attributable to each of its principal lines of business or other source:

| | (In Thousands of Dollars) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1967 | | 1968 | | 1969 | | 1970 | |
| | Sales | Income | Sales | Income | Sales | Income | Sales | Income |
| Minerals, metals & metal products (1) . . . . . | 489,322 | 115,059 | 548,768 | 130,762 | 789,263 | 198,686 | 849,567 | 239,712 |
| Coal(2) . . . . | - | - | 175,720 | 21,527 | 260,726 | 23,843 | 283,494 | 21,694 |
| Dividends & other non-operating income(3) . . . . | - | 52,999 | - | 44,291 | - | 42,509 | - | 41,998 |
| Non-operating income deductions(4) | - | (46,158) | - | (46,839) | - | (32,237) | - | (35,580) |
| Total . . . . | 489,322 | 121,900 | 724,488 | 149,741 | 1,049,989 | 232,801 | 1,133,061 | 267,824 |

(1) In both 1967 and 1968 operations were adversely affected by an eight month industry-wide strike which ended in March 1968.

(2) Peabody Coal Company was acquired on March 29, 1968. Sales and income exclude revenues applied against the Peabody production payment.

(3) Includes dividends and interest received from Sociedad Minera El Teniente S.A. after April 13, 1967.

(4) Consists of unallocated interest expense, research, shutdown and other general corporate expenses.

Source: Kennecott Prospectus dated April 22, 1971.

Breakdown of Sales of Minerals & Metal Products (In Thousands of Dollars)

| | 1967 | 1968 | 1969 | 1970 |
|---|---|---|---|---|
| Copper & copper products(1) | $408,784 | $457,746 | $645,629 | $695,007 |
| Gold . . . . . | 7,529 | 11,325 | 18,181 | 14,552 |
| Silver . . . . . | 4,317 | 6,132 | 6,465 | 5,569 |
| Molybdenum . . . . . | 19,301 | 16,845 | 40,267 | 35,877 |
| Titanium slag . . . . . | 22,040 | 26,051 | 28,186 | 33,478 |
| Sorelmetal(2) . . . . . | 16,707 | 19,569 | 23,607 | 29,060 |
| Lead and zinc . . . . . | 3,591 | 4,734 | 14,520 | 18,860 |
| Other . . . . . | 7,053 | 6,366 | 12,408 | 17,164 |
| Total . . . . . | $489,322 | $548,768 | $789,263 | $849,567 |

(1) Does not include sales of Sociedad Minera El Teniente S.A. after April 13, 1967. Includes minor amounts of non-copper fabricated metal products.

(2) Trade name for a high quality iron produced by the Company's subsidiary, Quebec Iron and Titanium Corporation.

Source: Kennecott Prospectus dated April 22, 1971.

For financial statement purposes mining costs attributable to Peabody's production of coal dedicated under a reserved production payment agreement are being capitalized. Such costs are being amortized using per ton rates designed to write off the total estimated mining costs to be capitalized over the Company's share of the estimated tonnage to be produced in a thirty-year period. (These costs are deducted for income tax purposes, as incurred.) Revenues of $45,125,523 in 1971 and $52,184,848 in 1970 have been excluded from income and applied against the reserved production payment, including principal and interest. The unpaid principal amount (off the balance sheet) at December 31, 1971, was $217,839,960. Capitalized mining costs and amortization thereof amounted to $41,478,700 and $7,397,800, respectively, in 1971, compared to $45,602,400 and $8,112,200, respectively, in 1970.

Kennecott's expenditures for property, plant and equipment exclusive of such coal mining costs capitalized were $121.1 million in 1971 and $115.6 million in 1970.

## E. HOW SECURITY ANALYSTS AND INSTITUTIONAL INVESTORS VIEW SELECTED NON-FERROUS METALS COMPANIES TODAY[1]

The primary non-ferrous metal companies are viewed by institutional analysts in the context of cyclical commodity-based businesses which are, for the most part, quite sensitive to changes in metal prices and relatively vulnerable to adverse foreign political developments such as nationalization of properties, or changes in the basis for taxation. In

[1] Based in part on a Non-Ferrous Metals Forum presented by The Wall Street Transcript and published in the April 10, 1972, edition.

respect to copper, there seems to be a consensus that the demand for copper will remain fairly steady with a secular growth trend of 4-5% per year in consumption. Kennecott is acknowledged to be the largest producer with copper mining costs estimated at about 40¢ a pound. However, Kennecott is noted to be spending the bulk of its financial resources on diversification into coal, and shows little commitment to expand domestic copper production. Phelps Dodge, the second largest producer, is believed to have the lowest costs, perhaps around 32¢ per pound, and the company is in the midst of an important expansion program of domestic mining capacity, rather than deploying its resources in a diversification move. Anaconda, the third largest producer, is considered somewhat of a special situation because of new management, the huge tax loss carryforwards, and the sensitivity of Anaconda's earnings to copper price changes as a result of the fact that it is a very high cost producer (with estimates that its mining costs are on the order of 45¢ a pound). Analysts note that while the profitability of the major copper companies has eroded from what it has been historically, they are still enormously profitable relative to many other companies and industries. In terms of return "anyway you want to measure--on invested capital, return on sales, absolute dollar of profit generated . . . they generate a great deal but they don't generate it with any degree of growth or consistency." Because mine production is typically such a large part of earnings, there is concern that restrictions on smelting capacity in the United States will prevent mines from realizing maximum production and hence profitability under current market conditions. Currently the market appears to be fairly healthy in terms of demand for the metal.

With respect to the non-ferrous metals companies in general, there seems to be a consensus that growth rates are probably going to decline, except for copper. The massive capital expenditure programs which have already been undertaken by most of the companies in the normal course of their business expansion have eroded their capital structures, bringing them towards a very highly-leveraged financial situation. Given the new uncertainties of large, but undetermined pollution abatement expenditures, there is concern about their ability to consistently pay the high dividends which institutional investors require as a safety factor or, equivalently, as a "risk premium" in cases of companies with highly-leveraged financial structures. It is already expected by institutional analysts that dividend payout policies of these companies will have to become more conservative for the most part.