

INTRODUCTION

Copper has been used in jewelry, utensils, weapons, and tools for thousands of years. Such objects were hammered from native copper—the naturally occurring pure metal—in areas around the Mediterranean Sea and Lake Superior as long ago as 6000-5000 BC. The metal was first smelted from ores around 4000-3500 BC. Ancient mines have been found in Israel, Cyprus, Spain, and Britain. The Industrial Revolution and the age of electricity created the need for a highly developed copper industry.

u s e s

Copper's excellent electrical conductivity makes it important for power, lighting, and communications. In addition, its strength, durability, malleability, and resistance to corrosion and fatigue make it useful in a variety of structural applications.

In the United States, the largest market for copper is the construction industry. An estimated 41 percent of domestic copper mill shipments went to this industry in 1988.¹ Uses there include electrical wiring, plumbing and heating, air-conditioning and refrigeration, and architectural applications (e.g., gutters and roof and wall cladding). The second largest market (22 percent of shipments) was the electrical and electronics industry for uses such as telecommunications, power utilities, industrial controls, business electronics, and lighting and wiring. Other major markets include the industrial machinery and equipment industry (14 percent), the transportation sector (12 percent), miscellaneous consumer goods (e.g., appliances, cooking utensils, jewelry, and objets d'art), military applications, coinage, pharmaceuticals, and chemicals.

Across all markets, copper is used primarily for electrical and electronic applications. Copper use in

these applications accounted for 70 percent of apparent domestic consumption in 1988.²

Production Methods and Technologies

Modern copper production techniques were established around 1900. Until then, only very rich ores (those containing 5 to 30 percent copper) could be processed economically. The commercial exploitation of lower grade ores became possible with the development of precipitation and flotation technologies and large-scale mining and processing methods. Today, most copper comes from ores containing 0.5 to 2 percent copper.

Copper is produced primarily from sulfide minerals such as chalcopyrite (CuFeS_2), chalcocite (Cu_2S), bornite (Cu_2FeS_4), and covellite (CuS). Some production, though, is based on oxide minerals such as malachite ($\text{Cu}_2(\text{OH})_2\text{CO}_3$), azurite (CuSiO_3), chrysocolla ($\text{Cu}_3(\text{OH})_2(\text{CO}_3)_2$), and cuprite (Cu_2O). Copper ore may be mined by either open pit, underground, or solution mining methods. Open pit mines account for about 60 percent of nonsocialist world (NSW) production and 85 percent of U.S. production. Copper is extracted from the ore by two principal methods: pyrometallurgical (concentration-smelting-refining) and hydrometallurgical (leaching-solvent extraction-electrowinning).

The pyrometallurgical route is the more common production method. The first step, ore concentration, occurs at the minesite. It involves crushing, grinding, and flotation of the ore into concentrates which contain 20 to 30 percent copper. Concentrates are the crudest intermediate product that is marketed.

The next processing steps (roasting, smelting, and converting) are performed at the smelter.⁴ Roasting is an optional step which is sometimes used to upgrade the concentrates. Smelting breaks down the

¹Annual Data 1989, Copper Development Association Inc. (Greenwich, CT).

²Janice L.W. Jolly and Daniel Edelstein, "Copper," *Minerals Yearbook*, vol. I, 1988 ed. (Washington, DC: U.S. Department of the Interior, Bureau of Mines, 1990).

³U.S. Congress, Office of Technology Assessment, *Copper: Technology and Competitiveness*, OTA-E-367 (Washington, DC: U.S. Government Printing Office, September 1988). John G. Peacey, "Copper Metallurgy," *McGraw-Hill Encyclopedia on Science and Technology* (New York: McGraw-Hill, 1987). Janice L.W. Jolly, "Copper," *Mineral Facts and Problems*, 1985 ed. (Washington, DC: U.S. Department of the Interior, Bureau of Mines, 1985).

⁴The term "smelting" commonly refers to all processes carried out at the smelter.

complex minerals to produce a liquid copper-sulfide matte (35 to 75 percent copper). There are four basic smelting technologies: flash, reverberatory, electric, and continuous.⁵ Converting, usually carried out in a Pierce-Smith converter, oxidizes the matte into blister copper (98.5 to 99.5 percent copper). Environmental regulations and process economics make the control of sulfur dioxide (SO₂) gas a very important aspect of the various smelting processes. In recent years, concerns about the air quality impacts of reverberatory furnaces have led to the widespread adoption of electric and flash furnaces in the United States.

Most of the impurities remaining in the blister copper are removed at the refinery. First, the molten blister copper is fire-refined (to further reduce its sulfur and oxygen content) and then cast into anodes. The anodes are then electrolytically refined (electrorefined). They are hung vertically between cathode starter sheets in long tanks (cells) filled with an acidic copper sulfate solution. An electric current is run through the solution (between the electrodes) and the copper gradually corrodes from the anode and plates onto the cathode. The end product, cathode copper, is 99.99+ percent copper. Cathodes are melted and cast into wirebar or continuous bar stock (for wire manufacture), slabs (for mechanical use), or ingots (for alloying).

In the hydrometallurgical production route, copper is recovered from the ores using aqueous (water-based) solutions. This method is applied mainly to oxide ores, and to low-grade oxide and sulfide mine wastes.⁶ It is a very low-cost method of producing copper. When mining costs are excluded (or nonexistent as in the case of waste dump

leaching), copper can be produced for around \$0.30/lb. In 1988, about 16 percent of domestic primary copper output was produced by hydrometallurgical techniques.

The first step, leaching, involves percolating sulfuric acid (H₂SO₄) through the ore or waste. The acid (leachate) dissolves the copper minerals and carries them away. The copper is recovered by solvent extraction and electrowinning (SX-EW).⁷ In solvent extraction, an organic chemical that dissolves copper but not impurity metals is mixed with the leachate.⁸ The organic solution collects the copper and is then treated with sulfuric acid (H₂SO₄) to strip the copper into an electrolytic solution. Copper is recovered from the electrolyte by electrowinning, a process similar in principal to electrorefining (described above). The main difference is with the anodes. Electrowinning uses inert (non-dissolving) anodes since the copper is already in the electrolyte. Application of the electric current deposits the copper on to the cathode. The cathode copper is then stripped from the starter sheets (which are reused), and shipped to the rod mill or fabricator.

THE 1980s

The U.S. copper market started the 1980s in a shortage situation (see figures 2-1 and 2-2). In 1980, domestic primary copper production (1.2 million tonnes) was low and prices (averaging \$1.01/lb) were high compared with previous years. Production increased in 1981, but then fell to the 1.0 to 1.2 million tonnes per year (tpy) range during 1982-87. Prices were also low in this period. They averaged \$0.75/lb in 1982-83 and \$0.67/lb in 1984-86. These prices were similar in nominal terms to those of the

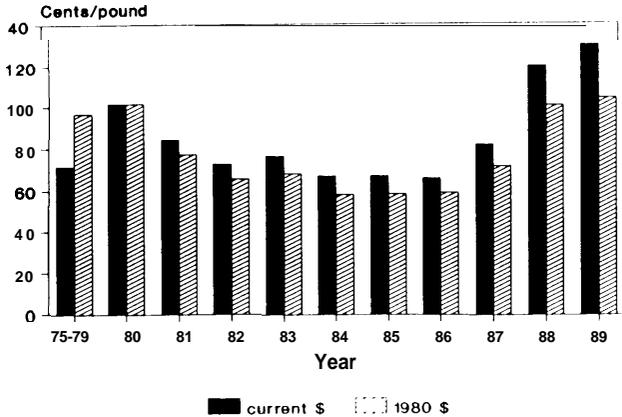
⁵Flash processes (Inco and Outokumpu) combine roasting and hearth smelting. The sulfide particles in the concentrates react with an air/oxygen mixture to produce a large proportion of the thermal energy needed for smelting. As a result, flash furnaces have relatively low fuel costs. Further, their waste gases are rich in SO₂, permitting economic pollution control. The reverberatory process was widely favored over the last 50 to 60 years because of its versatility; all types of material, lumpy or free, wet or dry, could be smelted. However, the reverberatory furnace has relatively high fuel requirements, and its sulfur dioxide gas is too dilute for economic conversion into sulfuric acid or treatment with other pollution control methods. The electric process uses an electrically heated hearth furnace that is similar in operation to the reverberatory furnace, but with more advantageous control of the effluent gases. The process makes limited use of heat generation from sulfide oxidation, and the heavy reliance on external energy can result in relatively high energy costs. Two continuous processes (Noranda and Mitsubishi) are in limited use. They combine roasting, smelting, and converting in one operation that produces blister copper directly from concentrates, while taking advantage of the heat generated by the oxidation of sulfides. The benefits of continuous processes include lower capital cost, reduced materials handling, low heat losses, very low energy requirements, economical sulfur dioxide gas recovery, and the ability to apply online computer controls to the entire copper-making process. Neither of these processes, however, has yet proven to be truly continuous. Their slags, which have high copper contents and must be recycled, can only be processed with auxiliary equipment.

⁶Roasting, a pyrometallurgical process, is sometimes used to convert sulfide minerals to more easily leachable oxides and sulfates.

⁷An older method of recovering copper from the leachate is the iron precipitation, or cementation, process. The pregnant leach solution flows through a pile of scrap iron/steel. Copper flakes and powder precipitate onto the steel surfaces, but are carried away under the force of the flowing solution. The copper is relatively impure, however, and subsequent treatment is required, usually through normal smelting and refining.

⁸Solvent extraction is largely confined to copper oxides. This includes naturally occurring oxide ores and sulfide ores that have been oxidized by the atmosphere (e.g., in waste dumps) or by roasting. Similar processes for sulfides and complex ores are still being developed.

Figure 2-1-Copper Prices, 1975-89



NOTE: U.S. producers price—Cathode copper delivered. Prices in constant 1980 dollars were calculated using producer price index. Bars labeled 75-79 represent averages for the period 1975-79.

SOURCE: U.S. Bureau of Mines.

1975-79 period, but about one-third lower in real (inflation adjusted) terms. The market began recovering in 1987. In 1989, production had reached 1.5 million tonnes and prices had risen to \$1.32/lb in 1989.

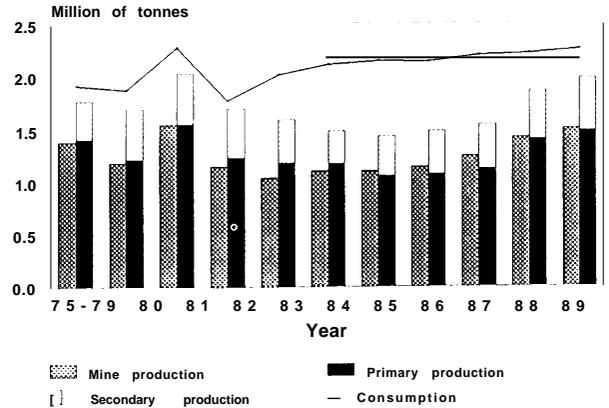
U.S. production of secondary (scrap-based) copper followed a similar pattern to that of primary copper. It started the decade around 470,000 tpy, fell to 310,000 tonnes in 1984, and then recovered to 500,000 tonnes in 1989. Over the entire decade, secondary material accounted for 26 percent of total U.S. refined copper production (compared with 20 percent in 1975 -79).⁹

The United States consumed 1.9 million tonnes of copper in 1980.¹⁰ Consumption rose in 1981, but then fell to 1.7 million tonnes in 1982 (a recession year). In 1983, consumption increased even though production continued to fall. By 1985, consumption had risen to 2.1 million tpy. It has grown an average of 1.3 percent per year since. The difference between consumption and total refined production changed greatly over the decade. This gap, which is met with imports or inventory reductions, grew from 165,000

⁹These figures represent the refined copper recovered from both new and old scrap. As such they overstate the amount of refined copper that is actually entering the manufacturing stream. Old scrap comes from discarded products, new scrap is waste from fabricating and other manufacturing processes. In 1988, 1.3 million tonnes of secondary copper were recovered from old scrap (519,000 tonnes) and new scrap (793,000 tonnes), and recovered as refined metal (453,000 tonnes) and brass, foundry products, and other "non-refined" products (861,000 tonnes). Janice L. W. Jolly and Daniel Edelstein, "Copper," *Minerals Yearbook*, vol. I, 1988 ed. (Washington DC: U.S. Department of the Interior, Bureau of Mines, 1990).

¹⁰In this report, consumption is defined in terms of unmanufactured metal products. Consumption does not include the metal contained in imported manufactured products such as automobiles or electronics.

Figure 2-2—U.S. Copper Production and Consumption, 1975-89



NOTE: Secondary production is refined metal recovered from old and new scrap. Bars labeled 75-79 represent averages for the period 1975-79.

SOURCE: *Metal Statistics*, Metallgesellschaft Aktiengesellschaft.

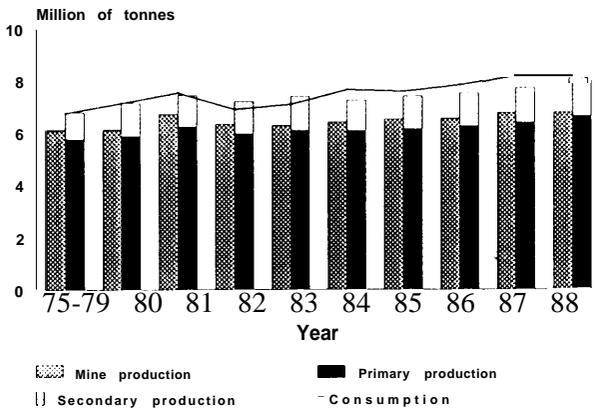
tpy in 1980-82 to 615,000 tpy in 1983-87. The gap narrowed somewhat in 1988-89.

For the nonsocialist world (NSW) as a whole, copper production and consumption were relatively stable during the 1980s (see figure 2-3). Over the period 1980-88, primary refined production grew at an annual rate of 1.5 percent and consumption rose at a rate of 1.9 percent. Secondary production averaged 17 percent of total NSW refined copper production.

The openings, closings, and ownership changes that occurred in the U.S. primary copper industry during the 1980s are profiled in table 2-1. Three new copper mines (Troy, Pines Altos, Miami) opened during the decade. A lead mine (Casteel) which produces copper also opened. Five mines (Sacaton, Copperhill, Magma, New Cornelia, and Continental) closed permanently during the 1980s. Many more mines closed temporarily at some time during the 1980s because of low prices, strikes, and modernization shutdowns.

In the processing sector, five smelters and three refineries (electrolytic and fire refineries) closed. Environmental regulations and aging facilities were

Figure 2-3—NSW Copper Production and Consumption, 1975-88



NOTE: Secondary production is refined metal recovered from old and new scrap. Bars labeled 75-79 represent averages for the period 1975-79.

SOURCE: *Metal Statistics*, Metallgesellschaft Aktiengesellschaft.

major causes of the decline in this sector. No greenfield plants were constructed, but several new facilities were built at existing sites (the Hayden smelter, the Sam Manuel smelter, and the White Pine refinery). There is talk, however, of building a new smelter in Texas in the early 1990s. The picture was more positive in the electrowinning sector, seven facilities opened and five closed. In addition, existing facilities were expanded. Electrowinning production grew from 118,000 tonnes in 1980 to 228,000 tonnes in 1988 and the expansion is continuing. During 1980-88, U.S. smelter capacity declined 36 percent to 1.2 million tonnes, electrolytic refining capacity fell 22 percent to 1.6 million tonnes, and electrowinning capacity rose 57 percent to 300,000 tonnes.

The number of companies involved in the U.S. copper industry declined during the 1980s. Large producers such as Amax, Anaconda Copper, Cities Service, Duval, Inspiration, and Noranda left the industry. All of their facilities, except for one mine and one refinery, were purchased by existing copper producers. Montana Resources and Cox Creek Refining were the only new companies to enter the

industry. Major changes occurred in the ownership of many producers. Cyprus was spun off from Amoco in 1985. Magma was spun off from Newmont in 1987. Copper Range changed hands several times before it was bought by Metall Mining in 1989. Kennecott was acquired by SOHIO (a subsidiary of British Petroleum) in 1981 and then sold to RTZ in 1989.

PRODUCER PROFILES, 1990

Chile and the United States dominate all sectors of the primary copper industry: mining, smelting, and refining (see figure 2-4). They have been the industry leaders for much of this century. Japan, the third ranked smelting and refining country, has little mine capacity and relies on imports of concentrates to feed its industry. The medium-sized producers are Canada, Zambia, and Zaire. Together, these six countries control about two-thirds of the NSW primary copper output. The United States, Japan, and Western European countries are the largest secondary copper producers.

Less developed countries (LDCs) play a larger role in the copper industry than in the aluminum, lead, and zinc industries. Chile, Zambia, Zaire, Peru, Mexico, and the Philippines are involved in all aspects of the primary copper industry, not just the mining sector. In 1988, developing countries world accounted for 57, 48, and 39 percent of NSW mine, smelter, and refinery production respectively.

Copper production is a major part of some LDCs' economies.¹¹ Consequently, the governments of these countries keep tight control over, and often own, the production companies. In 1981, 62 percent of LDC mine capacity was held by companies which were majority government owned.¹² The tendency for developing countries to run their industries for political as well as financial goals exacerbated the problems for the U.S. industry in the 1980s.

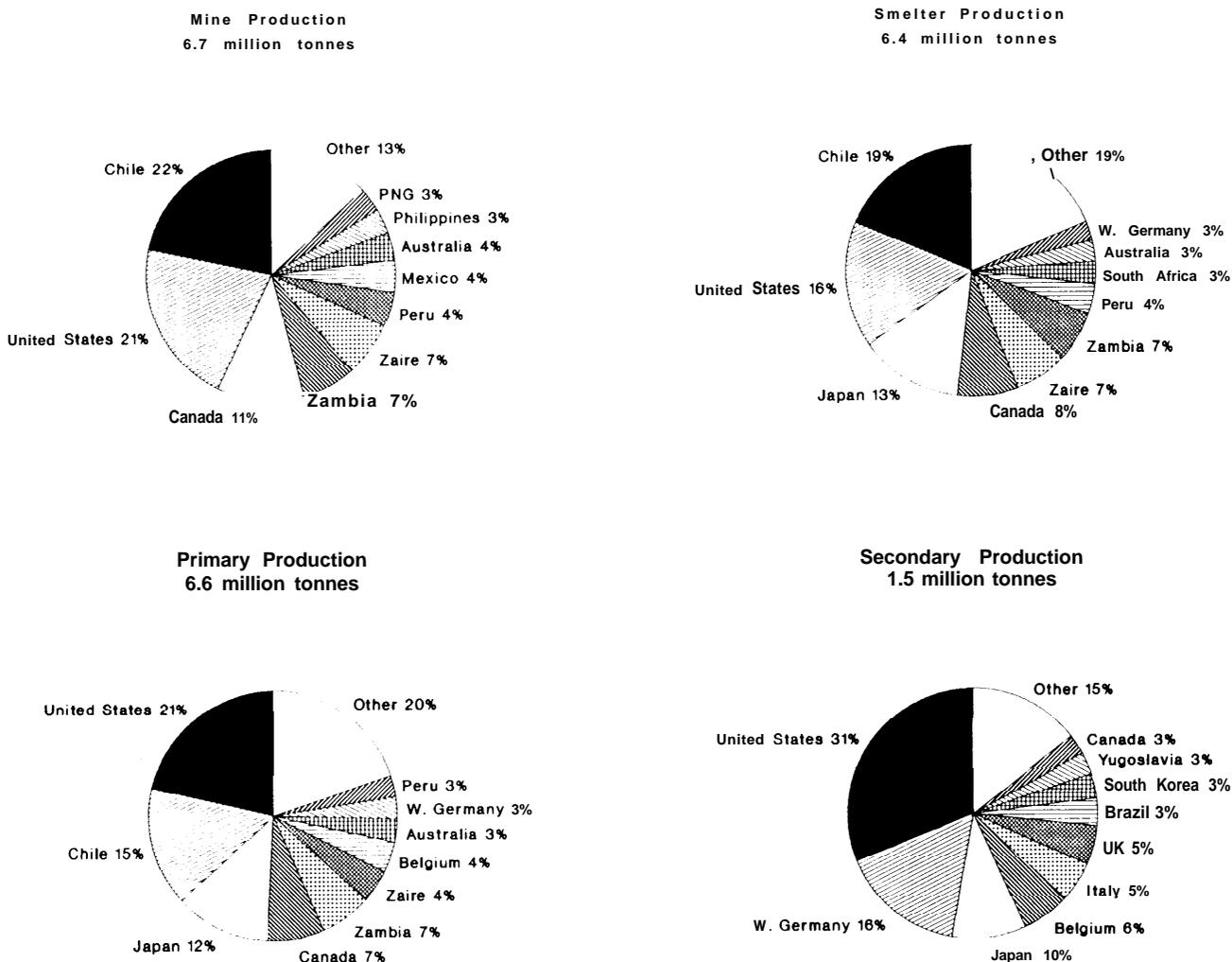
Chile, Peru, Zambia, Zaire, Indonesia, Australia, Papua New Guinea (PNG), and Yugoslavia belong to the Intergovernmental Council of Copper Exporting Countries (CIPEC).¹³ Established in 1967, this trade association conducts marketing studies, dis-

¹¹Copper accounted for 80 to 97 percent of the total export earnings of Zambia (1983-88), 20 to 58 percent for Zaire (1981-83), 41 to 50 percent for Chile (1983-89), 34 to 65 percent for Papua New Guinea (1983-89), and 13 to 22 percent for Peru (1983-87). International Monetary Fund (IMF), *International Financial Statistics*.

¹²Marian Radetzki, *State Mineral Enterprises* (Washington DC: Resources for the Future, 1985).

¹³Conseil Intergouvernemental des Pays Exporteurs de Cuivre.

Figure 2-4—NSW Copper Production, Country Profile, 1988



NOTE: Secondary production is refined metal recovered from old and new scrap.

SOURCE: *Metal Statistics*, Metallgesellschaft Aktiengesellschaft.

seminates information on copper developments, and seeks to promote expansion in the industry. During 1974-76, in the wake of the Organization of Petroleum Exporting Countries (OPEC) success in raising oil prices, CIPEC attempted to establish itself as a cartel. It tried, but failed, to stabilize then falling copper prices through production cutbacks. The group has discussed price stabilization numerous other times but has been unable to agree on a program. CIPEC's power to manage supply and stabilize markets has never been established.¹⁴

United States

The United States ranks as the first or second largest producer in all sectors of the NSW copper industry. Most U.S. producers are integrated from mining through to the refining stage. Several companies also have facilities to produce copper rod and other semi-manufactured products.

There are currently approximately 35 domestic copper mines in production. The 13 largest ac-

¹⁴U.S. Congress, Office of Technology Assessment, *Copper: Technology and Competitiveness*, OTA-E-367 (Washington, DC: U.S. Government Printing Office, September 1988).

Table 2-I—Profile of U.S. Primary Copper Production Industry, 1980 and 1990

	1980	1990	
Major mines:			
Ray, AZ	Kennecott	Asarco	Sold to Asarco 1986
Mission Complex, AZ	Asarco	Asarco	Comprises Mission, Eisenhower San Xavier, and Pima mines.
Eisenhower, AZ	Asarco-Anamax ^{ab}	Asarco	Anamax share sold to Asarco 1987; made part of Mission Complex
Pima, AZ	Cyprus-Utah Int'l ^{cd}	Asarco	Sold to Asarco 1985; made part of Mission Complex
Troy, MT	—	Asarco ^e	Opened 1981
Silver Bell, AZ	Asarco	Asarco	
Sacaton, AZ	Asarco	—	Closed 1983
Copperhill, TN	Cities Service	—	Closed 1987; sold to Tennessee Chemical 1982
White Pine, MI	Copper Range ^f	Copper Range ^g	Sold to Echo Bay 1984, Northern Copper (ESOP) 1985, Metall Mining 1989
Bagdad, AZ.....	Cyprus ^c	Cyprus	Note 1
Sierrita, AZ.....	Duval ^h	Cyprus	Sold to Cyprus 1986; includes Sierrita and Esperanza mines-combined 1986
Miami, AZ.....	Inspiration	Cyprus	Note 2; includes inspiration and Ox Hide mines
Bluebird, AZ	Rachers Exp. & Dev.	Cyprus	Sold to Inspiration and integrated with Inspiration (Miami) mine 1984; Note 2
Twin Buttes, AZ.....	Anamax ^{ab}	Cyprus	Sold to Cyprus 1988
Pines Altos, NM.....	—	Cyprus	Opened 1987; owned by Exxon until 1982; sold to Boliden 1982, Cyprus 1987
Mineral Park, AZ	Duval ^h	Cyprus	Sold to Cyprus 1986
Casa Grande (Lakeshore), AZ..	Noranda	Cyprus	Sold to Cyprus 1987; renamed Casa Grande 1987
Casteel (Viburnum #35), MO.,	—	DoeRun ⁱ	Opened 1984; owned by Fluor (St. Joe); later became Doe Run; see Table 4-1
Bingham Canyon, UT	Kennecott	Kennecott ^j	Modernization 1985-1987; Note 3
Carr Fork, UT	Anaconda Copper ^b	Kennecott ^j	Sold to Kennecott and integrated with Bingham Canyon mine 1985; Note 3
San Manuel, AZ.....	Magma ^k	Magma	Note 4
Pinto Valley, AZ	Cities Service	Magma	Notes 5&4
Miami, AZ.....	—	Magma	Opened 1983; developed by Cities Service; Notes 5&4
Magma, AZ	Magma ^k	—	Closed 1982
Butte Mines, MT.....	Anaconda Copper ^b	Montana Resources ^l	Sold to Montana Resources 1985; minority share sold to Asarco 1989
Morenci/Metcalf, AZ	Phelps Dodge	Phelps Dodge ⁿ	Minority share sold to Sumitomo 1985
Tyrone, NM	Phelps Dodge	Phelps Dodge	
Chino, AZ	Kennecott	Chino Mines ⁿ	Modernization 1981-84; Note 6
New Cornelia(Ajo), AZ	Phelps Dodge	—	Closed 1984
Continental, NM	Sharon Steel	—	Closed 1982
Smelters:			
Great Falls, MT.....	Anaconda Copper ^b	—	Closed 1980
Hayden, AZ	Asarco	Asarco	Reverberatory furnace replaced with flash 1982-83
El Paso, TX.....	Asarco	Asarco	
Tacoma, WA	Asarco	—	Closed 1985
Hayden (Ray), AZ	Kennecott	—	Closed 1982; sold to Asarco 1986
Copperhill, TN.....	Cities Service	—	Closed 1987; sold to Tennessee Chemical 1982
White Pine, MI.....	Copper Range ^f	Copper Range ^g	
Miami (Globe), AZ	inspiration	Cyprus	Note 2
Garfield, UT.....	Kennecott	Kennecott,	Modernization 1985-87; Note 3
McGill NV.....	Kennecott	—	Closed 1983
San Manuel, AZ	Magma ^k	Magma	Reverberatory furnace replaced with flash 1986-88; Note 4
Hildago, NM	Phelps Dodge	Phelps Dodge	
Hurley, NM.....	Kennecott	Chino Mines ⁿ	Note 6
Douglas, AZ	Phelps Dodge	—	Closed 1987
Morenci, AZ.....	Phelps Dodge	—	Closed 1985; minority share sold to Sumitomo 1985
Ajo, AZ	Phelps Dodge	—	Closed 1984
Texas City, TX.....	—	—	Construction under consideration by Texas Copper, a joint venture led by Mitsubishi

Table 2-1—Profile of U.S. Primary Copper Production Industry, 1980 and 1990-Continued

	1980	1990	
Refineries:			
Electrolytic and fire refining:			
Great Falls, MT.....	Anaconda Copper ^b		Closed 1980
Amarillo, TX.....	Asarco	Asarco	
White Pine, MI.....	Copper Range ^f	Copper Range ^g	Fire-refining process replaced with electrolytic 1982-86
Baltimore, MD.....	Kennecott	Cox Creek Refining ^h	Sold to Cox Creek 1986
Miami (Globe), AZ.....	Inspiration	Cyprus	Note 2
Garfield, UT.....	Kennecott	Kennecott ⁱ	Modernization 1985-87; Note 3
Hurley, NM.....	Kennecott		Closed 1984; Note 6
San Manuel, AZ.....	Magma ^k	Magma	Note 4
El Paso, TX.....	Phelps Dodge	Phelps Dodge	
Laurel Hill, NY.....	Phelps Dodge		Closed 1983
Carrolton, GA.....	Southwire	Southwire	
Electrowinning:			
Arbiter, MT, , , ,.....	—	Anaconda Environ-Refining	Closed since 1977; to reopen 1990
Braithwaite, LA.....	Amax	—	Closed 1985
Hayden (Ray), AZ.....	Kennecott	Asarco	Sold to Asarco 1986
Miami (Globe), AZ.....	Inspiration	Cyprus	Note 2
Casa Grande, AZ.....	Noranda	Cyprus	Sold to Cyprus 1987
Twin Buttes, AZ, , ,.....	Anamax ^a	Cyprus	Closed 1985; reopened 1989; leased to Cyprus 1988
Bagdad, AZ.....	Cyprus ^c	Cyprus	Note 1
Sierrita, AZ.....	—	Cyprus	Opened 1987
Johnson, AZ.....	Cyprus ^c	—	Closed 1986; Note 1
Battle Mountain, NV, , ,.....	Duval ^l	—	Closed 1984
Sierrita, AZ.....	Duval ^l	—	Closed 1982
San Manuel, AZ.....	—	Magma	Opened 1986; Note 4
Pinto Valley, AZ.....	—	Magma	Opened 1981; Note 4
Miami, AZ, , ,.....	Magma ^k	Magma	Note 4
Tyrone, NM.....	—	Phelps Dodge	Opened 1984; operated by the Burro Chief subsidiary
Morenci, AZ.....	—	Phelps Dodge	Opened 1987
Chino, NM.....	—	Chino Mines ⁿ	Opened 1988; Note 6
Globe, AZ.....	Ranchers Exp. & Dev.	—	Closed 1982

NOTES:

^aAnamax was a subsidiary of Anaconda Copper and Amax.^bAnaconda Copper was a subsidiary of Atlantic Richfield (Arco).^cCyprus was a subsidiary of Standard Oil of Indiana (Amoco). d_{pi} was owned 75% by Cyprus and 25% by Utah International.^eAsarco owns 75 percent of the Troy, MT mine.^fCopper Range was a subsidiary of Louisiana Land.^gCopper Range is a subsidiary of Metall Mining Corp, a subsidiary of Metallgesellschaft.^hDuval was a subsidiary of Pennzoil.ⁱD_{Run} is a subsidiary of Fluor.^jKennecott is a subsidiary of RTZ.^kMagma was a subsidiary of Newmont.^lMontana Resources is a subsidiary of Washington Corp. The Butte Mines are owned by Montana Resources and Asarco.^mThe Morenci/Metcalf mine and smelter are 85% owned by Phelps Dodge and 15% by Sumitomo.ⁿChino Mines is a subsidiary of Phelps Dodge and Mitsubishi.^oCox Creek Refining is partially owned by Mitsubishi 20%, Southwire 200/& and Hajstead Industries 20%.¹Cyprus spun off from Amoco 1985.²Cyprus acquired Inspiration's copper mines, smelter, refinery, and rod mill 1988.³Kennecott was acquired by Standard Oil (SOH IO), a majority-owned subsidiary of British Petroleum (BP), 1981. Kennecott was held under the BP America subsidiary. BP became full owner of SOHO and merged Kennecott with Amselco to form BP Minerals America 1987. Most of BP's metals assets were sold to RTZ 1989.⁴Magma spun off from Newmont 1987.⁵Cities service sold Pinto Valley and Miami mines to Newmont 1983. Newmont combined them with its Magma subsidiary 1988.⁶Mitsubishi acquired a one-third share of Kennecott's Chino Mines Division (including the Chino mine and the Hurley smelter and refinery) 1981. Kennecott sold its share of Chino Mines to Phelps Dodge 1986.SOURCE: Office of Technology Assessment, 1990. Compiled from *Minerals Yearbook* (various issues), U.S. Bureau of Mines (Washington, DC).

counted for more than 95 percent of production in 1989.¹⁵ A small amount of copper is produced as a byproduct of gold, lead, silver, or zinc at an additional 30 mines. The largest copper-producing States are Arizona, New Mexico, Utah, Michigan, and Montana. Mining in the United States is

characterized by a high proportion of surface mines (85 percent of capacity), low feed grade (average 0.65 percent copper), and high wage rates. Although most operations produce at least some byproduct, revenues from byproducts are on the average fairly low. The number of surface mines, the use of modem

¹⁵U.S. Department of the Interior, Bureau of Mines, *Mineral Commodity Summaries*, 1990 ed. (Washington, DC:1990).

technology, and the establishment of good management practice make U.S. mines and mills among the most productive in the world in terms of workhours per tonne of ore. In this regard, U.S. facilities improved dramatically in the 1980s.

There are currently eight domestic primary smelters in operation. Reverberatory smelting furnaces are used at El Paso (Asarco) and White Pine (Copper Range). The one electric furnace smelter, Miami (Cyprus), has been among the most costly of the domestic plants to operate because of high electricity rates. Newer, more efficient, flash furnaces are used at Hayden (Asarco), San Manuel (Magma), and Chino and Hidalgo (Phelps Dodge). The Noranda continuous process is used at the Garfield (Kennecott) smelter. Smelting in the United States is characterized by stringent air pollution controls and, until recently, an unattractive sulfuric acid market.¹⁶

There are currently eight electrolytic and twelve electrowinning refineries in operation operating in the United States. In 1988, approximately 16 percent of U.S. refined production came from the electrowinning process. Leaching and SX-EW technologies, because of their low costs, were an important aspect in the U.S. industry's financial turnaround in the late 1980s.

The United States is the world's largest secondary copper producer. The secondary sector accounted for about a quarter of total domestic production in 1988. There are five secondary smelters, two electrolytic refineries, and six fire refineries in operation.

Seven domestic companies (Phelps Dodge, Cyprus, Magma, Asarco, Montana Resources, Cox Creek, and Southwire) and two European firms (RTZ and Metallgesellschaft) have major holdings in the primary copper industry in the United States (see figure 2-5). In addition, two Japanese firms (Mitsubishi and Sumitomo) have partial holdings in U.S. mines.

Phelps Dodge

Phelps Dodge is North America's largest, and the world's second largest, copper miner.¹⁷ In 1988, it

produced one-third of the copper mined and about a one-quarter of the copper smelted and refined in the United States. It is primarily a copper company, but it makes other products as well. The corporation is organized into two major divisions. The Mining division includes the company's domestic copper operations (from mining through rod production, marketing, and sales), the foreign mining operations and investments, and the exploration programs. In 1986-88, this division accounted for 62 percent of the company's revenues and 81 percent of its earnings. The other division, Industries, runs most of the corporation's manufacturing operations. It includes Columbian Chemicals (a carbon black and synthetic iron oxide company), ACCURIDE (a steel wheel manufacturing company), and the Phelps Dodge Magnet Wire Co. It also includes interests in companies that produce wire, cable, and rod in 14 foreign countries.

Phelps Dodge's major domestic mines are Morenci/Metcalf in Arizona and Chino and Tyrone in New Mexico. Each mine has an associated electrowinning plant. The company owns smelters at Hurley (Chino) and Playas (Hidalgo) in New Mexico, and a refinery and rod mill at El Paso, Texas. Phelps Dodge has holdings in several foreign operations that produce primary copper. It owns 16 percent of the Southern Peru Copper Corp. (SPCC) which runs two copper mines and a smelter in Peru. Smaller amounts of copper are produced by the wholly owned Ojos del Salado copper-gold mines in northern Chile and the 45-percent-owned Black Mountain lead-silver-zinc-copper mine in South Africa. Phelps Dodge also has a feasibility study underway for the La Candelaria deposit in Chile. This mine could possibly be producing 100,000 tpy by the mid-1990s.

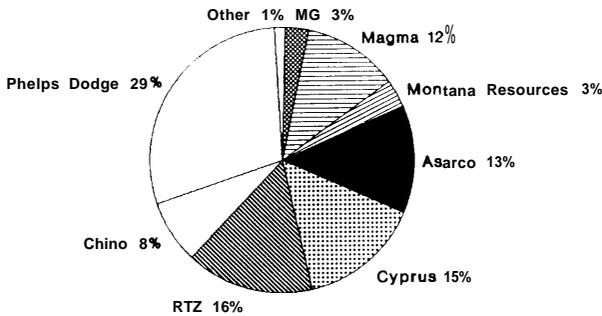
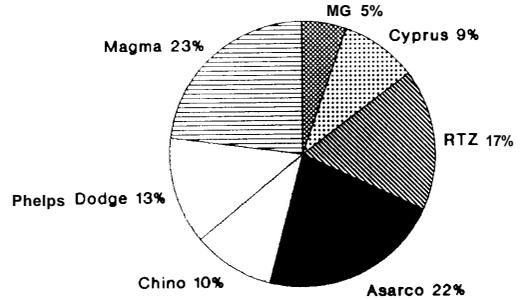
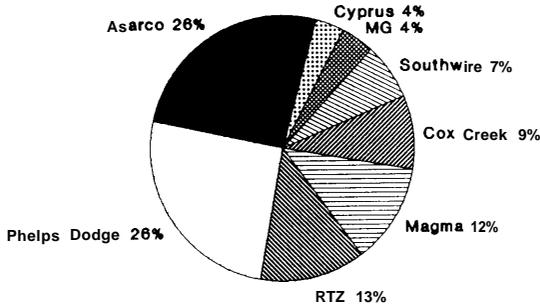
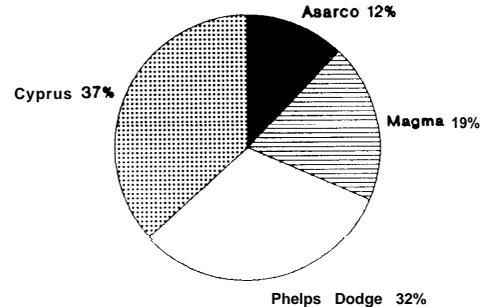
The company's domestic mines produce much more concentrate than its smelters can handle. In 1986, Phelps Dodge sold 15 percent of the Morenci mine to Sumitomo to divert some of the concentrate to Sumitomo's smelters, and more importantly, to raise cash for restructuring programs. Mitsubishi owns one-third of the company's Chino mine and smelter.¹⁸

¹⁶Sulfuric acid is recovered by the air-pollution control processes in copper smelting and is often sold as a byproduct or used in SX-EW operations.

¹⁷Among all NSW mining companies, Phelps Dodge ranks well behind Codelco (Chile), but just ahead of Gecamines (Zaire) and ZCCM (Zambia). It is the largest private producer, these other leading producers are all state-owned. In several years though, the company will rank behind RTZ in mining, but not in the smelting/refining sector.

¹⁸A prior owner, Kennecott, sold a one-third interest in all of the output of Chino Mines to MC Minerals, a joint venture between Mitsubishi Corp. and Mitsubishi Metal Corp. Phelps Dodge purchased the remaining two-thirds from Kennecott in 1986.

Figure 2-5--U.S. Copper Industry, Company Profile, 1988

Mine Production
 1.4 million tonnes

Smelter Capacity
 1.2 million tonnes

Electrolytic Refinery Capacity
 1.6 million tonnes

Electrowinning Refinery Capacity
 0.3 million tonnes


NOTE: Phelps Dodge's mine production includes 40,400 mt produced for other's accounts. Asarco's mine production includes 5,200 mt produced for other's accounts.

SOURCES: *Minerals Yearbook* (various issues), U.S. Bureau of Mines; *Non-Ferrous Metal Data 1988*, American Bureau of Metal Statistics Inc.; company annual reports.

The Sumitomo and Mitsubishi shares together account for about 5 percent of total U.S. mine production.¹⁹ Even after Mitsubishi takes its portion of the mine output, Phelps Dodge still has surplus concentrates. In 1988, the smelters handled only about 70 percent of the company's concentrate share, the rest was toll smelted. Production should be more in balance when the Tyrone mine closes in the early 1990s.

Phelps Dodge has invested heavily (and continues to do so) in SX-EW facilities. In 1988, the company processed 80,800 tonnes (18 percent of its mine output) by the SX-EW method. That figure may rise to 40 percent in the 1990s.

Phelps Dodge has established itself in the copper fabrication sector. It is the world's largest producer of copper rod (the basic feed for the electrical wire

¹⁹Mitsubishi does not have processing facilities in the United States. The U.S. concentrate is shipped to smelters in Japan. The company has talked, however, of building a new smelter in Texas which would presumably process its U.S. concentrates as well as those from the La Escondida project in Chile.

and cable industry). The domestic continuous cast copper rod mills are in El Paso, Texas and Norwich, Connecticut. The rod production exceeds the company's internal sources of refined copper, so the supplies are supplemented with purchases.

Phelps Dodge is credited with leading the U.S. copper industry out of the 1980s recession. It was the first company to deal aggressively with its unions, cut its costs, and return to profitability.²⁰ Its business plan, in effect since 1984, has three elements. The first is to reduce production costs in the copper operations and to enhance their profit margins rather than to maximize production. The second is to build and strengthen the non-copper businesses to help the company better withstand copper price swings. In this regard, the company stresses significant market share, internationally competitive costs and quality, specialized engineering capabilities, and stable earnings and cash flow. The third element is to strengthen the financial structure of the corporation.²¹

Kennecott/RTZ

Kennecott (owned by London-based RTZ) is the second largest copper mining company, and the fourth largest smelting and refining company, in the United States. The company's Bingham Canyon mine and its Garfield smelter and refinery are located in Utah. The Bingham Canyon mine, which underwent a \$400 million modernization from 1985-87 under the ownership of BP America, is the largest copper mine in the country. RTZ obtained these facilities in 1989 when it purchased most of British Petroleum's (BP) metals mining division. The operation was renamed Kennecott (after the company that ran the mine for much of this century).

RTZ is one of the world's largest metal mining corporations. It produces copper, aluminum, iron ore, lead, molybdenum, tin, zinc, gold, and silver at various subsidiaries and related companies throughout the world. It also produces energy (coal, oil, and uranium) and industrial products including borax, silica, specialty chemicals, fabricated and engi-

neered products, and construction materials and services. In 1987, prior to the BP acquisition, RTZ's earnings profile was: industrial sector (63 percent), metals sector (24 percent), and energy sector (13 percent).²² RTZ's companies operate under a decentralized management style. The chief operating units are left to manage themselves under strategic guidelines that are agreed to every two years.²³

RTZ's foreign copper holdings include Bougainville (PNG), Highland Valley (Canada), Palabora (South Africa), Somincor (Portugal) and ER&S (Australia).²⁴ It also has a 30 percent stake in the 300,000 tonne per year (tpy) Escondida project in Chile. With its acquisition of BP and its interests in these major new mines, RTZ will be the largest private copper mining company in the world (surpassing Phelps Dodge) in several years. It will be a somewhat smaller presence in the smelting/refining sector.

Cyprus

Cyprus is the third largest domestic copper mining company, but is smaller in the smelting and refining sectors. It has mines at Bagdad, Sierrita, Miami, Twin Buttes, Casa Grande, and Mineral Park in Arizona and Pines Altos in New Mexico. About a third of the mine production is oxide ore. The company has leaching and SX-EW facilities at five of its mines. It also has a roaster at Casa Grande which is used to prepare sulfide ore for leaching and SX-EW processing. In addition, there is a smelter, refinery, and a rod plant at Miami (Claypool), Arizona; and a rod plant in Chicago, Illinois. Until 1988, when Cyprus acquired the Miami facilities from Inspiration Copper, most of the company's copper concentrates were toll smelted under short-term contracts. Now, about half of the concentrates are processed at the Miami smelter or the Casa Grande roaster. The remainder are smelted at Magma's San Manuel plant under a long-term contract.

Cyprus, once the mining subsidiary of Amoco, was spun off as an independent company in July

²⁰Phelps Dodge led the U.S. industry's drive to lower wages and relax work rules. In 1983, Phelps Dodge continued production despite a prolonged strike at its facilities. Workers at the company's Arizona mines (at that time Morenci and New Cornelia) and El Paso refinery voted against continued union representation in the fall of 1984.

²¹Phelps Dodge Annual Report, 1988.

²²RTZ Annual Report, 1987.

²³American Mining Congress, *AMC Journal* (Washington DC: October 1989).

²⁴Olympic Dam in Australia is part of BP, not RTZ. The two companies terminated their agreement regarding the sale of Olympic Dam in late 1989.

1985. Since then it has grown through a very aggressive acquisitions program. All of its copper properties, except Bagdad, have been purchased since the spinoff. It has acquired properties from Duval, Noranda, and Inspiration Copper. The company keeps its labor costs low by insisting prior to its acquisitions that the facilities be closed and the workers be terminated. When Cyprus takes possession of (and restarts) the mine or plant, it rehires the workers it needs without union contracts.

Cyprus is strongest in the mining sector of the minerals business. Besides copper, Cyprus produces molybdenum, lithium, zinc, silver, gold, coal, and industrial minerals. It is the largest domestic producer of molybdenum, which it mines as a primary product in Nevada and Idaho and recovers from the copper ores at Sierrita (coproduct) and Bagdad (byproduct). The molybdenum processing facilities are in New Jersey. Cyprus acquired Foote Mineral, the largest NSW producer of lithium, from Newmont in 1988. The lithium mines are in Nevada and Chile, and the processing facilities are in Virginia, Pennsylvania, Tennessee, North Carolina, and Chile. Cyprus began recovering zinc and silver, as well as copper, from the Pines Altos mine in New Mexico in 1989. The company is evaluating a zinc-silver deposit in northern Mexico and a beryllium deposit in Texas.

Copper and coal have been at the center of Cyprus' business. During 1986-88, these two products accounted for about 80 percent of sales. However the proportions have changed significantly. In 1986, 50 percent of sales was from coal and 30 percent was from copper. In 1988, the proportions were reversed.

Asarco

Asarco is the second largest U.S. smelter and refiner and fourth largest miner.²⁵ It has copper mines at Ray and the Mission Complex in Arizona and at Troy in Montana. In addition, it *owns* half of the Butte, Montana mine. It has smelters at Hayden, Arizona and El Paso, Texas, and a refinery at Amarillo, Texas. Of the U.S. copper producers, Asarco is perhaps the most active in foreign projects. It is the majority shareholder (52 percent) in SPCC, the Peruvian copper mining and smelting concern. It also owns (through Medimsa) about 30 percent of Mexicana de Cobre which runs the La Caridad

copper mine and Nacozari smelter in Mexico. Asarco also has ties to the Australian concern MINI, which owns copper facilities at Mt. Isa and has interests in base metal operations all over the world. Asarco owns 19 percent of MIM, and MIM owns 25 percent of Asarco. This link is a passive relationship that does not involve operational control.

Asarco was originally a smelting and refining company. However, in recent years it has become more involved in the mining sector to ensure its supply of concentrates. It got caught short on its concentrate supplies in the 1980s and has been buying mines to prevent this from happening again. The company thinks "the custom smelting and refining business has limited growth potential because there are fewer mines and mining companies today than in the past" and plans to "continue to make investments to increase its own mine production and expand ore reserves."²⁶ When the expansions are complete (in 1992), Asarco expects to have the capacity to provide all of the feed required by its copper smelters, compared to less than 25 percent in 1985. In 1989, Asarco joined with Montana Resources in the operation of the Butte, Montana copper mine. Asarco also has a large project underway to modernize its El Paso, Texas smelter.

Magma

Magma is the third largest domestic copper smelter and refiner and fifth largest miner. It had been a subsidiary of Newmont until 1987, when it was spun off. The company's operations are characterized by their physical proximity and technological interaction with one another. All the facilities are located in Arizona. Magma has two mining/milling/leaching complexes (San Manuel and Pinto Valley), three SX-EW facilities, a smelter and refinery (San Manuel), and one rod plant (San Manuel).

In 1989, Magma produced 22 percent of its copper by leaching and SX-EW methods. The company has excess smelting, refining, and rod making capacity. In contrast to Asarco, it is striving to develop its position as a custom smelter. The new flash furnace at San Manuel has a capacity of more than 1 million tpy of concentrates (about 270,000 tpy of blister copper) and is the largest copper smelting furnace in the world. It was scheduled to finish its commissioning period at the end of 1989. In 1989, tolling

²⁵Asarco is also a major lead and zinc producer (see chs. 4 and 5).

²⁶Asarco Annual Report, 1988.

accounted for 27 percent of Magma's refined copper production.

In 1989, Magma sold 65 percent of its copper as continuous cast rod, down from 93 percent in 1988. The company is decreasing its rod capacity to focus on producing cathode (primarily for Asian markets). It sold its Chicago rod plant to Cyprus in December 1989.

Magma is primarily a copper company, but it produces some molybdenum disulfide, gold, and silver. The company's strategy stresses modernization (e.g., the capital investment in San Manuel) and marketing (e.g., product quality, technical service, and customer relationships).

Montana Resources

Montana Resources, a smaller copper mining company, operates the historic Continental pit in Butte, Montana. In 1985, Washington Construction purchased the Butte operations from Anaconda Copper (a subsidiary of Arco) intending to salvage them for scrap. After conferring with Anaconda's former general manager, however, Washington Construction determined that the mine and mill could reopen profitably. The State and local governments, eager to see the operation contributing to the economy once again, procured credit lines, granted tax cuts, and quickly approved the necessary permits. The company obtained a \$0.12/lb reduction in the transportation and refining costs Anaconda had paid to ship the concentrate by rail to California and have it processed in Japan. The local power company granted lower rates for electricity. Finally, the number of workers was cut almost 50 percent, and the top wage was reduced from \$22 to \$13/hr. As a result, when the East Berkeley Pit reopened early in 1986 as Montana Resources, it was reportedly mining copper for \$0.58/lb, compared to Anaconda's \$0.97/lb.²⁷ In 1989, Asarco purchased 49.9 percent of a new partnership that owns and operates the Montana copper properties.

Copper Range/Metallgesellschaft

Metall Mining, a Canadian subsidiary of Metallgesellschaft (MG) bought the Copper Range mine, smelter, and refinery in Michigan in 1989. The high-cost underground operation had at various times in the 1980s been owned by Louisiana Land,

Echo Bay, and Northern Copper (an Employee Stock Option Plan). MG (based in Frankfurt, West Germany) is a large metals trading company whose other copper interests are minority holdings in Cominco (Canada) and Norddeutsche Affinerie (West Germany). The Michigan refinery was converted from the fire-refining process to the electrolytic process in the 1982-86 modernization program.

Cox Creek

Cox Creek began full production at its Baltimore, Maryland refinery and rod mill (formerly owned by Kennecott) in 1988. The company has no mine or smelting capacity. It purchases blister and scrap (for anode production), anode (for cathode production), and cathode (for rod production). Most of the primary feed is imported. Mitsubishi, a partner in the venture, supplies some of the raw material for cathode and rod production. Other partners include Southwire and Halstead Industries.

Southwire

Southwire operates a refinery in Carrolton, Georgia. It produces copper from both primary and secondary source material.

U.S. Interests in Other Countries

Several U.S. firms that do not have domestic primary copper facilities are involved in copper projects overseas. Exxon operates the Disputada mine and smelter in Chile. Freeport McMoRan owns 85 percent of the Ertzberg mine in Indonesia. Cerro Copper (part of the Marmon Group) and Newmont have interests in SPCC in Peru.²⁸ Amoco owns 30 percent of the Ok Tedi mine in Papua New Guinea, USX until recently held equity in Prieska in South Africa. In 1989, the mine closed and USX sold its interest,

Chile

Chile is the United States' strongest competitor in the copper business. It ranks first in mine and smelter production and second in the refining sector. Copper mining began in Chile in the 1850s. After several periods of growth and decline, the country became a consistent producer early in the 20th century. Chile exports 97 percent of its copper production, two-thirds in the form of refined copper. Its primary

²⁷"There's a Gleam in the Eye of Copper Producers," *Business Week*, 1986.

²⁸Cerro Copper has a secondary copper smelter in Sauget, Illinois.

markets for refined copper are Europe (about 50 percent), Asia (20 percent), and the United States (15 percent).

Codelco, owned by the Chilean government, controls about three-quarters of the country's capacity. It is the world's largest copper company, operating four major mines (Chuquicamata, El Teniente, El Salvador, and Andina) with a combined capacity of about 1.1 million tpy.²⁹ Current expansion programs are expected to increase the capacity by 27 percent (300,000 tpy) by the early 1990s.³⁰ Codelco also has three smelter/refinery complexes (Chuquicamata, Caletones, and Potrerillos).

ENAMI, another government-owned company, operates four concentrators, two smelters, and a refinery. The company accounts for about 18 percent of Chile's smelter capacity and 25 percent of its refinery capacity. The ENAMI facilities process concentrates from small and medium-sized independent mines and surplus materials from the Codelco mines.

Most private copper production in Chile is run by foreign interests. These companies have been attracted by Chile's moderately rich ores, favorable investment climate, well-developed mining infrastructure, and low paid and highly skilled work force. Exxon operates the Disputada mines and smelter. Anglo American of South Africa has a majority interest in the Mantos Blancos mine, smelter, and refinery. Phelps Dodge runs the small Ojos del Salado copper-gold mine in northern Chile and is exploring the La Candelaria deposit. BHP (Australia), RTZ (U.K.), Mitsubishi and Nippon Mining (Japan), and the World Bank have invested in the La Escondida project. La Escondida "the hidden one" is slated to come on stream in the early 1990s with a capacity of 320,000 tpy. It is the world's largest new copper project.

Chile's long-term competitiveness is being challenged by declining ore grades. Chilean ore grades,

though still higher than average, are falling faster than those elsewhere in the world. The decline is especially pronounced at Chuquicamata where the ore grade was 2.12 percent in 1980, but is projected to fall to 1.0 percent by 2000. Codelco has addressed this decline through capacity expansion and exploitation of oxide resources.³¹ The strategy has been to expand ore processing capacity enough to keep total refined copper output (and market share) constant or expanding. Central to this plan are the exploitation of oxide reserves from Mina Sur and the Chuquicamata pit, plus the leaching of waste dumps and low-grade sulfide ores.³² The divestment has been substantial; Codelco has spent \$300 to \$400 million per year since 1984 for capital improvements and expansions.³³

Japan

Japan's copper mining industry is very small, but its smelting/refining sector has ranked in the NSW top three since 1970. The industry was built in the 1960s to lessen dependence on foreign supplies and to capture the added value of raw materials processing. Despite having such a large industry, Japan is still a net importer of refined copper. It imports about a quarter of its needs, primarily from Zambia, Chile, and the Philippines. Exports of refined copper are small.

To feed its industry, Japan has had to import enormous quantities of concentrates.³⁴ In fact, to ensure supplies of concentrates, the Japanese supported the development of mines in the Philippines, PNG, Indonesia, and elsewhere. During 1985-88, Japanese smelters imported an average of 3.1 million tonnes of ores and concentrates. The major suppliers were Canada (29 percent), the United States (14 percent), the Philippines, Chile, Papua New Guinea, Indonesia, and Australia. Approxi-

²⁹Chuquicamata and El Teniente are the two largest copper mines in the world.

³⁰*Financial Times Mining International Yearbook 1989* (Chicago, IL: St. James Press, 1989).

³¹Chile has a vast reserve of oxide resources and a climate that tends to oxidize the wastes and tailings from sulfide operations. Thus leaching and SX-EW have great potential in Chile. Leaching operations produced approximately 90,000 tonnes in 1986; their capacity is expected to triple by 2000.

³²Drexel, Burnham, Lambert, *Special Copper Report*, December 1983.

³³Janice L.W. Jolly and Daniel Edelstein, "Copper," *Minerals Yearbook*, vol. I, various editions (Washington, DC: U.S. Department of the Interior, Bureau of Mines).

³⁴The tariff structure in Japan (high for refined copper, but low for concentrates) has allowed Japanese smelters to outbid others for feed concentrates, and has been the source of trade friction.

mately 60 percent of the copper concentrate traded in 1986 was shipped to Japan.³⁵

Six firms (Nippon Mining, Onahama, Sumitomo, Mitsubishi, Hibi Kyoda, and Dowa) are engaged in both smelting and refining in Japan. A seventh (Mitsui) is involved in refining only. Given the interests of Mitsubishi and Dowa in Onahama and of Mitsui in Hibi Kyodo, the effective control of Japan's smelting capacity is Nippon Mining (26 percent), Mitsubishi (26 percent), Sumitomo (16 percent), Dowa (12 percent), and Mitsui (10 percent). The percentages are similar for the refining sector.

Most, but not all, Japanese smelter capacity is located on the coast. This greatly facilitates the delivery of concentrates and the shipping of copper and sulfuric acid to their markets. About 60 percent of the capacity is based on flash furnace technology. Reverberatory furnaces account for most of the rest.

In the 1980s, Japan sought new joint projects to counter the tight concentrate markets and production cutbacks by traditional suppliers. These new ventures included projects in Colombia and Chile and equity positions in the United States. Mitsubishi acquired a one-third interest in Chino Mines (including the Chino mine and Hurley smelter and refinery) in 1981. Sumitomo acquired a 15 percent share of the Phelps Dodge Morenci/Metcalf mine in 1985. In addition, Japanese firms are expected to receive much of the copper (in the form of concentrate) from the La Escondida project in Chile when it goes into production.³⁶

Canada

Canada, a medium-sized copper producer, ranks third in NSW mine production and fourth in smelter and refinery production. The country's mine output is greater than its smelter capacity, so it is a net exporter of concentrates. Canada exports over a third of its concentrate production (primarily to Japan) and over half of its refined production (mostly to the United States and Europe).

About three-quarters of Canada's mine production comes from five producers; Highland Valley and BHP-Utah in British Columbia, Falconbridge and Inco in Ontario, and Hudson Bay in Manitoba.

Highland Valley (jointly owned by Cominco, Rio Algom, Teck, and Highmont) is the largest. It has no associated smelting and refining capacity, and sells most of its concentrate to Japan.

In general, Canadian mines are noted for their large quantities of co-products and byproducts (e.g., nickel, gold, silver, zinc, and molybdenum). About 20 percent of copper mine production comes as a byproduct of the Inco and Falconbridge nickel operations in Ontario's Sudbury district.

There are four companies (Noranda, Inco, Falconbridge, and Hudson Bay) involved in Canada's smelting and refining sector. Noranda with its Quebec operations (the Gaspé and Home smelters and the Canadian Copper Refiners division) is the largest. The company has little copper mine capacity, but is a major custom smelter and refiner. In 1989, Noranda and Trelleborg acquired full control of Falconbridge which has mining, as well as smelting and refining, facilities in Canada. With the acquisition, Noranda effectively controls an estimated 55 percent of Canada's smelting capacity and 65 percent of its refinery capacity.

Zambia and Zaire

The central African copper industry was developed in the 1910s and 1920s by colonial interests. The British operated in Zambia (then Northern Rhodesia) and the Belgians were based in Zaire (then the Belgian Congo). Shortly after Zambia and Zaire gained independence in the 1960s, their industries were nationalized.

Both countries export nearly all of their copper. Zambia's exports are mostly refined copper and are destined for Europe, Japan, and India. Zaire exported 6 percent of its copper as concentrates, 51 percent as blister (primarily to Belgium), and 43 percent as refined copper (mostly to Europe) in 1985-88.

All Zambian copper facilities are run by the state-owned Zambia Consolidated Copper Mines (ZCCM). The major mines are Nchanga, Mufilira, and Nkana. The ores are very rich (averaging 2.0 percent copper). Zambia's developed ore reserves are declining quickly and are expected to be depleted by early next century. Large undeveloped reserves exist, however. Recently, Zambia has supplemented

³⁵World Bureau of Metal Statistics data.

³⁶J. C. Wu, "The Mineral Industry of Japan," *Minerals Yearbook*, vol. III, 1985 ed. (Washington, DC: U.S. Department of the Interior, Bureau of Mines, 1987).

its mine production by toll smelting Zairean concentrates. ZCCM runs three smelters, four refineries, and three electrowinning facilities. Almost a quarter of Zambia's refined production comes from leach and electrowinning operations.

The state-owned Gecamines operates Zaire's principal mines, Dikuluwe/Mashamba, Kov, and Kamoto. The ores average 4.1 percent copper and are the richest copper ores mined in the world. Zaire is less involved in the processing sector than is Zambia. Gecamines does, however, run a smelter and two refineries.

The copper industries in Zaire and Zambia share many operating characteristics and problems. They both, for example, produce large amounts of by-product cobalt. Also, most of their copper output is exported, because the regional market for the metal is small. Transportation is a particularly important factor to these industries. The mines are remote and the transportation network to the distant seaports is cumbersome and unstable. Rail transportation in the region may become more reliable in coming years, because of improving prospects for political stability in southern Africa. However, the investment required to renovate the railroads will be great. Zambia and Zaire also have been plagued with internal political strife, hard currency shortages, power outages, and the acute threat of Acquired Immune Deficiency Syndrome (AIDS). These factors make it difficult to get and keep skilled expatriate personnel and to obtain spare parts for maintenance of the mining equipment.

Peru

Peru is a medium-sized copper producer which exports 90 percent of its production. During 1985-88, Peru exported 18 percent of its copper as concentrates (to Japan and West Germany), 28 percent as blister (mostly to Japan and the United Kingdom), and 54 percent as refined copper (to Europe, the United States, and Japan).

Peruvian production is dominated by the Southern Peru Copper Corp. (SPCC) open pit mines at Cuajone and Toquepala and smelter at Ilo. SPCC is owned by four U.S. companies-Asarco, Cerro Copper, Phelps Dodge, and Newmont. The venture accounts for about 60 percent of Peru's production.

There are also numerous smaller operations in Peru, some state-owned and some private, that mine complex silver-copper-lead-zinc ores primarily for the silver. State-owned Centromin runs a smelter and refinery at La Oroya to process its own concentrates as well as those from private mines. Minero Peru, also state-owned, runs a refinery at Ilo. Peru's perennial economic, political, and weather problems make foreign investment there generally risky.

Mexico

Mexico produces refined copper for domestic uses and exports surplus concentrates. The United States (primarily Magma) is Mexico's largest customer for concentrates.

There are two major Mexican copper operations: Mexicana de Cobre and Cananea. Mexicana de Cobre, which is partially owned by U.S.-based Asarco, runs the La Caridad mine and the Nacozari smelter. The company accounts for about 55 percent of Mexico's mine production and 65 percent of its smelter capacity. Cananea, owned by the government, runs a mine and smelter. The company has been slated to be sold under a privatization effort, but efforts in this regard have failed thus far. The privatization is made even more contentious, because the mine is a sensitive national symbol. The mine's 1906 strike helped trigger the Mexican Revolution.³⁷ Cobre de Mexico runs the country's only refinery-the Atzacotalco plant in Mexico City. The company has no mines or smelters.

Australia

Australia exports about a quarter of its concentrate production and almost 40 percent of its refined production. MIM's Mt. Isa complex in Queensland dominates the domestic industry. The complex includes a mine (with very rich ore, 3.3 percent copper) and a smelter. The company also has a refinery at Townsville. The Electrolytic Refining and Smelting Co. of Australia (ER&S) runs a smelter/refinery at Port Kembla. The company is partially owned by RTZ. Australia's capacity recently rose with the opening of the 55,000 tpy Olympic Darn (Roxby Downs) project. The operation, which includes amine, smelter, and refinery, is owned by Western Mining and BP.

³⁷Larry Rohter, "Feelings Running High as Copper Mine Is Shut," *New York Times*, Aug. 30, 1989.

The Philippines

The Philippines is a major exporter of copper concentrates. In the early 1980s, nearly all of its copper was exported as ores and concentrates. Now, about half of the production is exported as concentrates (mostly to Japan) and the other half is exported as refined copper.

Philippine copper production is dominated by the Atlas mines (Lutopan, Carmen, and Biga). Atlas accounts for about 40 percent of the country's mine production. Other companies include Maricalum, Marcopper, North Davao, Benguet, and Lepanto. PASAR runs the country's only smelter and refinery.

Papua New Guinea (PNG)

PNG began mining copper in the early 1970s. Japan helped finance the PNG mines in order to feed its smelters. All of PNG's production is exported as concentrates. About 40 percent of the concentrates are sent to Japan and 30 percent are sent to West Germany.

Two companies produce copper in PNG: Bougainville and Ok Tedi. Bougainvillea, accounted for three-quarters of production in 1988. It was shut-down in May 1989, because of sabotage actions protesting the mine's location on ancestral lands.³⁸ It is not expected to reopen soon, if ever. Ok Tedi began production in 1987. Its capacity is about 600,000 tpy of concentrates, or roughly 200,000 tpy copper. However, the operation been plagued with problems and has yet to operate near its design capacity. Ok Tedi is owned by Amoco (United States), BHP (Australia), several West German firms, and the government of PNG.

South Africa

South Africa is a smaller copper producer which exports about two-thirds of its production. During 1985-88, the country exported 9 percent of its copper as concentrates, 46 percent as blister, and 44 percent as refined copper to Europe and Japan.

The major South African producer is the Palabora operation with its mine, smelter, and refinery in the

Transvaal near the Mozambique border. Palabora (partially owned by RTZ) accounts for about 80 percent of South Africa's copper production. It also produces uranium and zirconium. O'okiep runs a copper mine and smelter in Cape Province near Namibia.

West Germany

West Germany is a major copper smelting and refining country, but its mine production is small. It imports nearly all of the concentrates needed to feed the smelting industry. The major sources during 1985-88 were PNG (34 percent), Mexico (19 percent), and Chile (10 percent). West Germany also imports about 55 percent of the refined copper it consumes. The principle sources in 1985-88 were Chile (24 percent), Poland (18 percent), and Zaire (15 percent).

The major West German primary copper smelter is run by Norddeutsche Affinerie in Hamburg. The firm is owned by MG, MIM, and Degussa.

Belgium

Belgium is a major copper refining country but has no mining or primary smelter capacity. It that imports nearly all its blister and anode copper. Over one-half of the blister comes from Zaire (a former colony). South Africa and Sweden accounted for about 11 and 9 percent of imports respectively in 1985-88. Belgium's sole primary copper producer is Metallurgic Hoboken-Overpelt (MHO), a subsidiary of Acec-Union Miniere. It runs the refinery at Olen.

Other Countries

Other large copper mining companies around the world include: Boliden (Sweden), Freeport Indonesia (Indonesia), Rio Tinto Minera (Spain), and Somincor (Portugal). Other major smelting and refining operations include: Boliden (Sweden), Caraiba Metais (Brazil), BICC (United Kingdom), IMI Refiners (United Kingdom), Korea Mining & Smelting (South Korea), Outokumpu (Finland), and RTB Bor (Yugoslavia).

³⁸ "An Audacious Rebel in Papua New Guinea Shakes Copper Market," *Wall Street Journal*, Jan. 2, 1990.