5

Copper

For nearly 5,000 years, copper was the only metal known to man. It remains one of the most used and reused of all metals. The demand for copper is due to its good strength and fatigue resistance, excellent electrical and thermal conductivity, outstanding resistance to corrosion, and ease of fabrication. Copper offers moderate levels of density, elastic modulus, and low melting temperature. It is used in electrical cables and wires, switches, plumbing, heating, roofing and building construction, chemical and pharmaceutical machinery. It is also used in alloys such as brass and bronze, alloy castings, and electroplated protective coating in undercoats of nickel, chromium, and zinc.

Forms of Copper

Copper deposits are found in a variety of geological environments, depending on the rock-forming processes that occur at a particular location. These deposits can be grouped in the following broad classes:

- Porphyry and related deposits
- Sediment-hosted copper deposits
- Volcanic-hosted massive sulfide deposits
- Veins and replacement bodies associated with metamorphic rocks
- Deposits associated with ultramafic, mafic, ultrabasic, and carbonatite rocks

The most commonly mined type of copper deposit, porphyry copper, is found predominantly in areas along the western continental edges of North and South America, as well as the southwestern United States, and is associated with large granite intrusions.

5.1 Process Overview

5.1.1 Copper Ore Mining

Copper is commonly extracted from surface, underground and increasingly, from in situ operations. In 2000, the principal mining States, in descending order, Arizona, Utah, New Mexico, and Montana, accounted for 99 percent of domestic production. Copper was also recovered at mines in three other States. Although copper was recovered at about 30 mines operating in the United States, 15 mines accounted for about 99 percent of production. At yearend, four primary smelters, four electrolytic and four fire refineries, and 15 solvent extraction-electrowinning facilities were operating.[1]

Surface Mining

Surface mining requires extensive blasting as well as rock, soil, vegetation, and overburden removal to reach lode deposits. Benches are cut into the walls of the mine to provide access to progressively deeper ore as upper-level ore is depleted. Ore is removed from the mine and transported to beneficiation plants for milling and concentrating. The concentrate is then smelted and refined. Open-pit mining is the primary domestic source of copper.

Underground Mining

Underground mining entails sinking a shaft to reach the main body of ore. Drifts or passages are then cut from the shaft at various depths to access the ore, which is brought to the surface for beneficiation. While underground mines do not create the volume of overburden associated with surface mining, some waste rock must still be brought to the surface for disposal. Waste rock may either be returned to the mine as fill or put in a disposal area.

Solution (In Situ) Mining

Solution or in-situ mining requires drilling into the rock and using chemical solutions to dissolve lode deposits. During solution mining, the leaching solution (usually a dilute acid) penetrates the ore, dissolving soluble metals. This pregnant leach solution is then retrieved for recovery at a solvent extraction and electrowinning (SX/EW) plant.

5.1.2 Copper Beneficiation and Processing

The two major processes employed in the United States to recover copper from ores are classified as either (1) pyrometallurgical methods (copper processing), or (2) hydrometallurgical methods (copper beneficiation). Pyrometallurgical methods consist of smelting technology, and are widely used. Hydrometallurgical methods involve leaching and recovery by precipitation or electrowinning. These methods are gaining in extraction/electrowinning (SX/EW).

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[1] U.S. Department of Interior, U.S. Geological Survey, *Mineral Commodity Summary*, Copper, 2001

5.1.3 Copper Processing

Prior to pyrometallurgical, the ore (which often contains less than one percent copper) is crushed and ground with water and placed in a concentrator. The rock/water slurry is subjected to physical and chemical actions (i.e., air sparging and hydrophobic chemical reagents) inside a flotation tank. The chemical reagents assist the flotation process by acting as frothing and collector agents. Methylisobutyl carbonal (MIBC) is a typical frothing agent, and sodium xanthate, fuel oil, and VS M8 (a proprietary formulation) are typical collector agents. As a result of the physical and chemical actions, the copper value rises to the surface of the flotation unit as froth. The material remaining on the bottom of the flotation tank ("gangue") is partially dewatered and then discharged to tailing ponds for disposal.

The concentrate resulting from the flotation circuit contains approximately 30 percent copper and, in some instances, may also contain significant recoverable concentrations of molybdenum. If molybdenum is readily recoverable, the concentrate is sent to the molybdenum plant for recovery; otherwise, the concentrate is ready for subsequent pyrometallurgical operations. Alternatively, the concentrate can be dewatered and the dry product may either be stored for further processing or shipped to another facility for processing. The collected water is usually recycled in the milling circuit.

Copper processing or pyrometallurgical processes employ high-temperature chemical reactions to extract copper from its ores and concentrates. Generally, these processes are used with copper sulfides and, in some cases, high-grade oxides. Depending on the copper mineral and the type of equipment, pyrometallurgical recovery may take as many as five steps:

- Roasting
- Smelting
- Converting
- Fire refining

> **Roasting** – Roasting dries, heats, and partially removes the sulfur and volatile contaminants from the concentrated ore to produce a calcine suitable for smelting. Modern copper smelters generally have abandoned roasting as a separate step and have combined this function with the smelting furnace. In older systems using multiple brick hearths, however, the copper concentrate moves from the top of the hearth towards the base while air is injected counter-current to the concentrate. The roasted ore leaves through the bottom brick hearth and sulfur dioxide (2-6 percent) exits through the top.

> **Smelting** – Smelting involves the application of heat to a charge of copper ore concentrate, scrap, and flux to fuse the ore and allow the separation of copper from iron and other impurities. The smelter furnace produces two separate molten streams: copper-iron-sulfide matte and slag in addition to sulfur dioxide gas. The smelter slag, essentially a mixture of flux material, iron and other impurities, is a

RCRA special waste. Special wastes are excluded from the RCRA statute. The slags from some smelting furnaces are higher in copper content than the original ores taken from the mines. Therefore, they may be sent to a concentrator for copper recovery. Tailings from flotation of copper slag are a second RCRA special waste.

Traditionally, reverberatory furnaces have been the most common furnaces used for smelting, however, they are being replaced by electric or flash furnaces, which are more energy efficient. Reverberatroy furnaces also produce large volumes of low concentration SO_2 gas, which is difficult to use in sulfur recovery. The gases produced by electric smelting are smaller in volume, lower in dust (less than one percent) and have a higher SO_2 concentration, which allows better sulfur recovery in an acid plant. Gases from smelting operations contain dust and sulfur dioxide. The gases are cleaned using electrostatic precipitators, and are then sent to the acid plant, which converts the sulfur dioxide-rich gases to sulfuric acid (a useable and/or saleable product). In the interest of conserving energy and improving efficiency, many companies are now using flash smelting to produce matte feed.

Converting - In the converter (the most common being the Pierce-Smith converter, followed by the Hoboken converter and the Mitsubishi continuous converter), a high silica flux and compressed air or oxygen are introduced into the molten copper matte through pipes called tuyeres. The furnace is rotated so that the tuyeres are submerged and air is blown into the molten matte, causing the remainder of the iron sulfide to react with oxygen to form iron oxide and sulfur dioxide. The furnace is rotated again to pour off the iron silicate slag. Most of the remaining iron combines with the silica to form converter slag, a RCRA special waste. After removing the slag, additional air or oxygen is blown in to oxidize the sulfur and convert the copper sulfide to blister copper, which contains about 99 percent copper. Thesulfur is removed in the form of SO_2 gas, which reports to an acid plant where it is converted to high grade sulfuric acid. Depending on the efficiency of the acid plant, differing amounts of SO_2 are emitted into the atmosphere.

Fire Refining - Oxygen and other impurities in blister copper must be removed before the copper can be cast into anodes for electrolytic refining. Blister copper is fire refined in reverberatory or rotary furnaces known as anode furnaces. When co-located with a smelter or converter, the furnace may receive the blister copper in molten form so remelting is unnecessary. Air is blown in to oxidize some impurities, while flux may be added to remove others. The residual sulfur is removed as sulfur dioxide. A slag is generated during anode furnace operation. This slag is also a component of the RCRA special waste. The final step in fire refining is the reduction of the copper and oxygen removal by feeding a reducing gas such as ammonia, reformed gas, or natural gas into the copper while it is still in the anode furnace. The molten copper is then cast into anodes for further electrolytic refining. Smelted copper typically retains metallic impurities at concentrations that can interfere with electrical uses.

Electrorefining – Electrorefining purifies the copper anodes, by virtually eliminating the oxygen, sulfur, and base metals that limit copper's useful properties. In electrorefining, the copper anodes produced from fire-refining are taken to a "tank house," where they are dissolved electrolytically in acidic copper sulfate solution (the electrolyte). When a DC current is passed through the cell, the copper is dissolved from the anode, transported through the electrolyte and redeposited on the cathode starting sheet, which is relatively pure copper with only trace contaminants -- less than a few parts per million for sale and/or direct use. The concentration of copper as well as impurities in the electrolyte are monitored and controlled resulting in a product that is 99.99 percent copper.

5.1.4 Copper Beneficiation

Copper beneficiation may consists of: crushing and grinding, washing, filtration, sorting and sizing, gravity concentration, flotation, roasting, autoclaving, chlorination, dump and in situ leaching, ion exchange, solvent extraction, electrowinning, and precipitation. Crushing and grinding is the most energy intensive.

The methods selected vary according to ore characteristics and economic factors. Approximately half of copper beneficiation occurs through dump leaching, while a combination of solvent extraction, froth flotation, and electrowinning is generally used for the other half. Often, more than one metal is the target of beneficiation activities.

According to EPA's Office of Solid Waste Technical Resource Document, copper is increasingly recovered by solution methods including dump and in situ leaching. Because most copper ores are insoluble in water, chemical reactions are required to convert copper into a water-soluble form. Copper is recovered from a leaching solution through precipitation by SX/EW. Solution beneficiation methods account for approximately 30 percent of domestic copper production. Two-thirds of all domestic copper mines use some form of solution operations. Typical leaching agents used in solution beneficiation are hydrochloric and sulfuric acids. Microbial (or bacterial) leaching is used for low-grade sulfide ores; however, this type of leaching is much slower than standard acid leaching. Its use is still being piloted.

Hydrometallurgical copper recovery is the extraction and recovery of copper from ores using aqueous solutions. Hydrometallurgical operations include the following: (1) acid extraction of copper from oxide ores; (2) oxidation and dissolution of sulfides in waste rock from mining or *in situ* ore bodies (e.g., low grade oxide and sulfide mine wastes); and (3) dissolution of copper from concentrates to avoid conventional smelting. In summary, the copper-bearing ore (and in some cases, the overburden) is leached, then the copper is recovered from the pregnant leachate through precipitation, SX/EW.

Dump leaching is the simplest form of hydrometallurgical beneficiation of low-grade ores, waste rock, and overburden practiced at large, open-pit copper mines. Dump leaching is a method of treating copper ore that has been extracted from a deposit. This

method refers to the leaching of oxide and low-grade sulfide ore on typically unlined surfaces. These operations involve the application of leaching solution, which is usually a dilute sulfuric acid solution, collection of pregnant leach solution (PLS), and extraction of copper by SX/EW or cementation. Natural precipitation or mine water is generally used to leach low-grade sulfide ore, while dilute sulfuric acid is commonly used to leach oxide ores. Copper dump leaches are massive, ranging in height from 20 to hundreds of feet, covering hundreds of acres and containing millions of tons of ore. Dump leaching operations may take place over several years.

There are several other types of leaching operations: in situ, heap or pile, vat, and heat or agitated leaching. In some cases, roasting is employed prior to leaching in order to enhance the leachability of the material. In roasting, heat is applied to the ore which enhances its amenability to leaching without destroying the physical structure of the ore particles. The roasted material is then subjected to leaching as described above. The copper-rich leachate, referred to as "pregnant solution," is subjected to further beneficiation while the waste material is either left in place (in the case of dump, in situ, heap, or pile leaching) or managed in tailing ponds (as in vat, heat, or agitated leaching). The major potential environmental impact of hydrometallurgical beneficiation involves acid seepage into the ground. In addition, hydrometallurgical sludges may contain undissolved metals, acids, and large quantities of water.

Copper is removed from the pregnant leachate through either iron precipitation (or cementation) or solvent extraction and electrowinning. In cementation, once the most popular method for recovering copper from the pregnant leachate, the leachate is combined with detinned iron in a scrap iron cone or vibrating cementation mill where the iron replaces the copper in the solution. The copper precipitates are removed for subsequent pyrometallurgical processing.

In solvent extraction, now the most popular process, an organic chemical (chelator) that binds copper but not impurity metals is dissolved in an organic solvent (often kerosene). The chemical is then mixed with the pregnant leach solution. The copper-laden organic solution is separated from the leachate in a settling tank. Sulfuric acid is then added to the pregnant organic mixture, which strips the copper into an electrolytic solution ready for electrowinning. The barren leachate (or raffinate) is sent back to the leaching system. Electrowinning is the recovery of copper from the loaded electrolyte solution produced by solvent extraction, yielding refined copper metal. The copper-poor (or lean) electrolyte from electrowinning is returned to the SX plant. Excess lean electrolyte from the SX unit is returned to the raffinate pond to be recycled into the leaching circuit. Filter clay is used to filter the electrolyte. Impurities left on the bottom of the electrowinning cells are referred to as "muds" or "slimes." Both this anode sludge and lead anodes that are no longer usable are periodically removed from the cells and sent to lead smelting facilities for resource recovery. Electrowinning is functionally equivalent to electrolytic refining, but differs in that electrowinning uses a permanent, insoluble anode.

5.2 Summary of Inputs/Outputs

The following lists the key inputs and outputs for copper extraction, beneficiation, and processing. Key inputs and outputs are:

Inputs	**Outputs**
Electricity	Copper Ore
Fuels	Copper Concentrates
Explosives	Copper Anodes
Sulfuric Acid Solution	Blister Copper
Water	Sheet/wire/rod Copper
Reagents	Mineral Co-products
Chelator	Spent Ore
Organic Solvent	Overburden
	Tailings
	Slimes
	Discarded Furnace Bricks
	Discarded Converter Bricks
	APC Dust
	Waste Water
	Spent Electrolytes
	Anode Slimes
	Acid
	Gases
	Acid Plant Blowdown
	Effluents
	Crud
	Copper Slags

Figure 5-1. Copper Mining Flow Diagram

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        ┌──────────────┐
        │  Overburden  │ ───────▶  *Overburden*
        │   Removal    │
        └──────┬───────┘
               │
        ┌──────▼───────┐
        │   Drilling   │
        └──────┬───────┘
               │
        ┌──────▼───────┐
        │   Blasting   │
        └──────┬───────┘
               │
        ┌──────▼───────┐
        │     Ore      │
        │   Removal    │
        └──────┬───────┘
               │
        ┌──────▼───────┐
        │   Loading    │
        └──────┬───────┘
               │
        ┌──────▼───────┐
        │  Hauling &   │ ───────▶  *Spent Ore*
        │  Conveying   │
        └──────┬───────┘
               │
        ┌──────▼───────┐
        │  Processing  │
        │(see Figure 5-2│
        │  and 5-3)    │
        └──────────────┘
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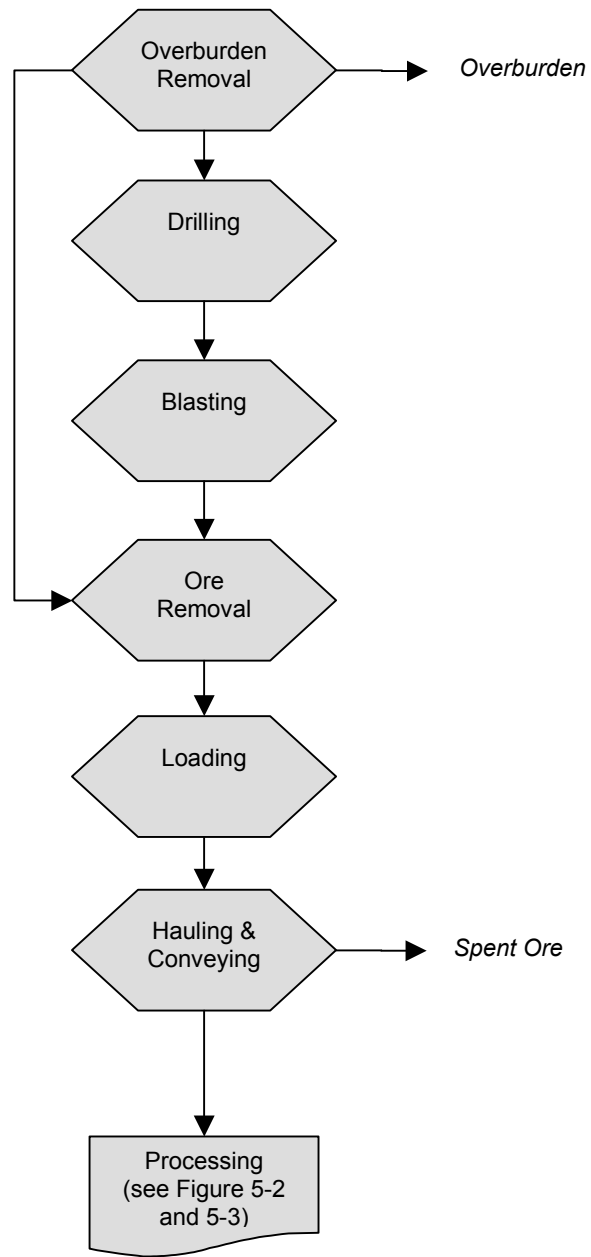
Figure 5-2. Pyrometallurgical Process Flow Diagram for Copper Ore
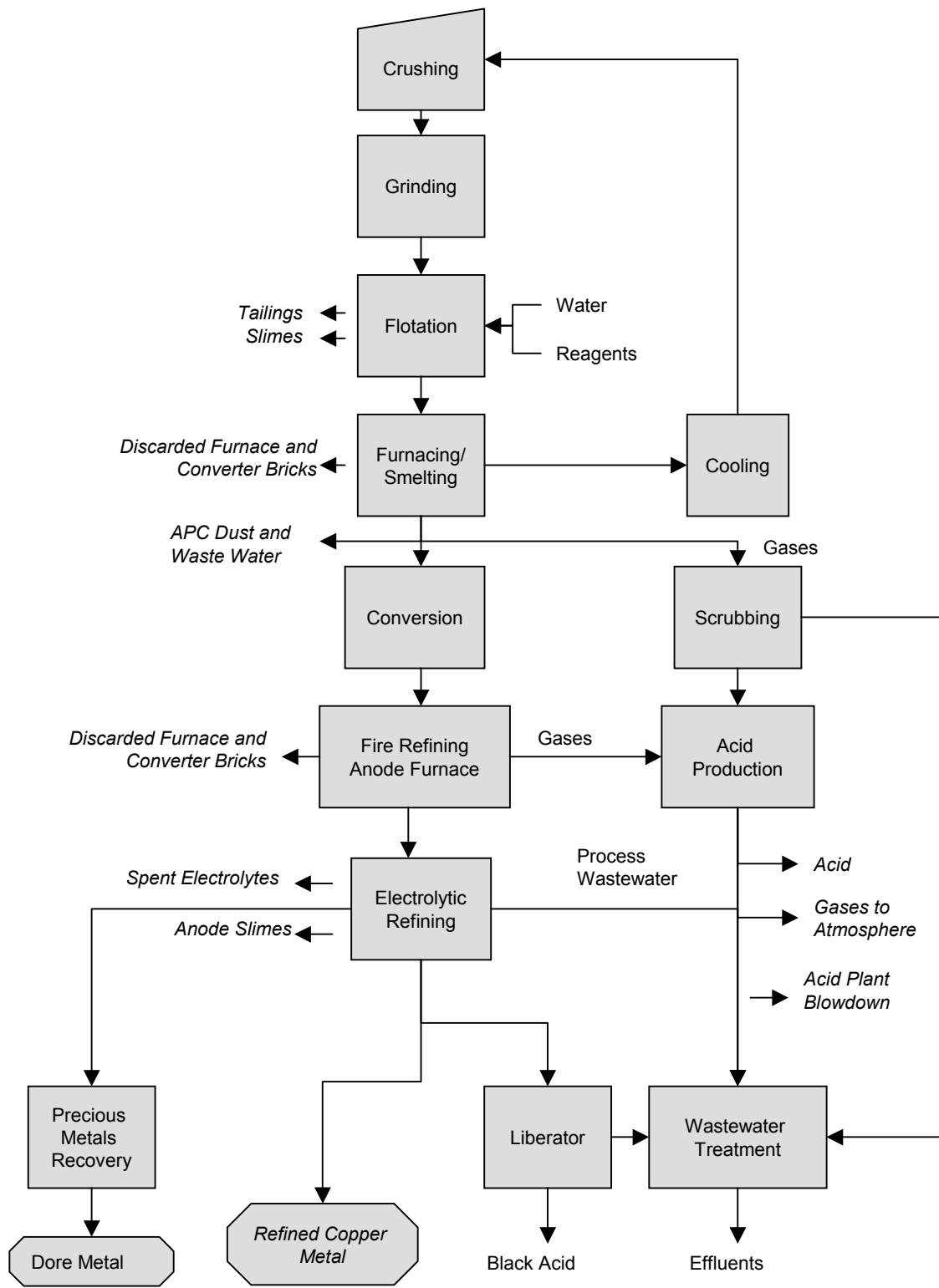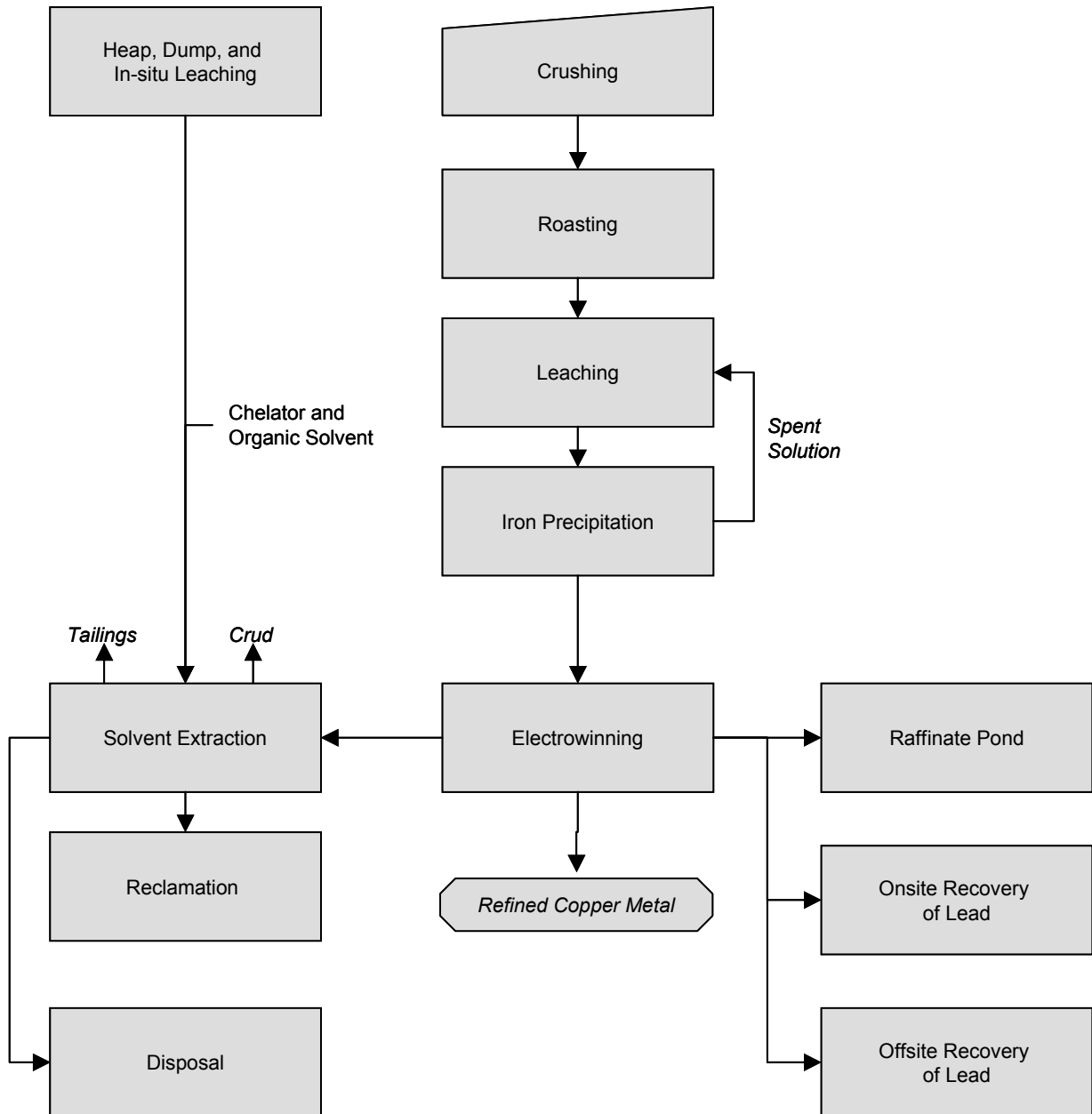
Figure 5-3. Hydrometallugical Process Flow Diagram for Copper Ore

5.3 Energy Requirements

Surface mining may extend to depths as much as 1,500 feet below the rim. The energy used and the cost of hauling rock from such depths become important limiting factors. The five principal energy-using units in mining are drilling, blasting, loading, hauling, and ancillary processes. Of these, hauling by truck consumes 54 percent of the total energy required in mining.[2]

In processing, grinding and concentration consume about 45 percent of the energy used, with grinding accounting for the majority of the energy consumed. The lower the mill-head grade of ore being processed, the more ore must be processed and the finer the grinding required to achieve the same metal recovery; and thus, the more energy consumed. Assuming a mill-head grade of 0.55 percent copper and an average copper recovery of 87.5 percent in concentrates and 98.7 percent in conventional smelting, the theoretical energy requirement for mining is 20.13 million British thermal units (Btu) per ton; for milling, 42.57 million Btu per ton; and for conventional smelting, 30.92 to nearly 40 million Btu per ton of cathode copper recovered.[3]

Major improvements in energy use in mining and milling have been made in recent years through improved strategies in grinding, concentration, and ore transportation. Mobile in-pit crushers, autogenous and semiautogenous mills, as well as continuous belt ore conveyors to replace haulage trucks in the open pits have resulted in significant savings. The use of large flotation cells has improved concentration process efficiency and also lessened energy usage. A major source of inefficiency is often uncontrolled fluctuation in the quality of ore coming into the plant. Significant advances also have been made in on-line control and measurement instrumentation of mineral processing systems.[4]

Flash furnace technology has also resulted in significant energy savings, as have the newer proven continuous smelting technologies.[5] Energy consumption in some of these technologies are as follows, in millions of Btu per ton of cathode copper produced: Outokempu flash smelting (18.92 million Btu), Inco flash smelting (21.25 million Btu), Noranda continuous smelting (24 million Btu), Mitsubishi continuous smelting (19.16 million Btu), and Oxy Fuel Reverberatory smelting (26.62 million Btu).[6]

5.3.1 Materials handled

Materials handled refers to the total amount of ore and waste material that must be handled in mining. Figure 5-4 shows the amount of copper mined in relation to the amount of waste materials produced in copper mining. In 1998 the amount of copper crude ore produced was 691 million tons and the amount of waste produced was 573

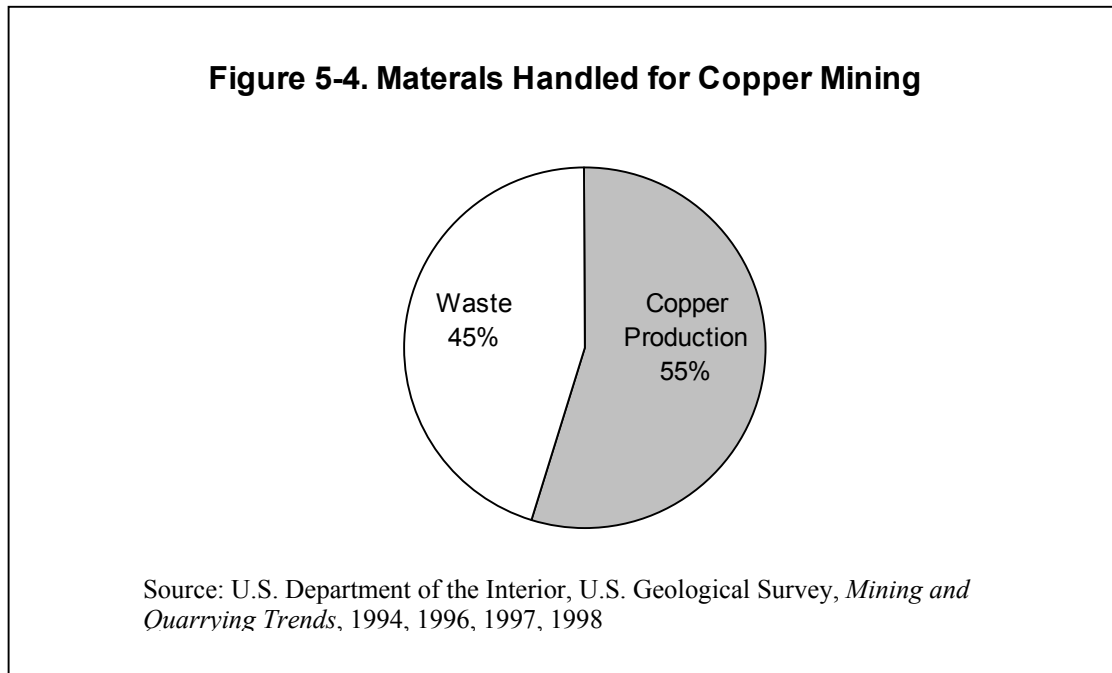[2] U.S. Department of Interior, Bureau of Mines, Mineral Facts and Problems, p. 197-221, 1985
[3] Ibid.
[4] Ibid.
[5] Ibid.
[6] Ibid.

million tons. This calculates to 1174 million tons of materials handled. From 1994 to 1998, the average crude ore ratio was 52 percent.

Figure 5-4. Materals Handled for Copper Mining

Waste
45%

Copper
Production
55%

Source: U.S. Department of the Interior, U.S. Geological Survey, *Mining and Quarrying Trends*, 1994, 1996, 1997, 1998

5.3.2 Energy Requirements for Copper Mining

Major energy sources for copper mining include purchased electricity and fuel oil. In 1992, copper mining consumed a total of 42.6 trillion Btu.[7] Table 5-1 shows the type and quantity of fuels consumed during iron ore preparation.

In 1982, the Department of the Interior evaluated energy requirements for a large hypothetical copper deposit. Other than the Department of the Interior report, few analyses have been done on energy use in copper mining.

Due to the lack of current information on energy use in mining and processing, the *SHERPA Mine Cost Estimating Model* along with the *Mine and Mill Equipment Cost, An Estimators Guide* from Western Mine Engineering, Inc., was used to calculate the energy requirements of mining and processing copper. Data from the Department of the Interior was used to develop inputs for the quantity of equipment and amount of ore mined. A small hypothetical mine was selected in order to fit the model's requirements. This copper mine operates over a 24-year lifetime with a 600 million ton ore output at the end of its life. The mine runs 364 days per year, with one shift per day of 8.00 hours. This gives it a daily production rate of 68,493 tons. Both the ore and waste material must be hauled 2,296 feet out of the mine at a gradient of 8 percent. Listing the results of the mine model and Equipment Cost Guide, reasonable energy consumption estimates were

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[7] U.S. Department of Commerce, Bureau of Census, Census of Mineral Industries, Subject Series, *Fuels and Electricity Consumed*, 1992

Table 5-1. Copper Production and Energy Consumed by Type [a]				
	Units	**1987**	**1992**	**1997**
Copper Production	Thousand tons	-	1,940.1	2,138.5
Energy Consumption				
Coal	Thousand tons	Withheld	Withheld	N/A
Fuel oil [b]	Million bbl.	1.5	1.5	N/A
Gas	Billion Cubic Feet	9.4	2.4	N/A
Gasoline	Million bbl.	Withheld	Withheld	N/A
Electricity Purchased	Million kWh	4,800	6,600	N/A
Electricity Generated Less Sold	Million kWh	Withheld	Withheld	N/A

a   Copper is SIC Code 1021 (1997 NAICS Code 212234)
b   Summation of distillate and residual fuel oil
Sources: U.S. Department of Commerce, Economics and Statistics Administration, Bureau of the Census, Census of Mineral Industries, *Industry Series*, Copper Ores.
US Department of the Interior, US Geological Survey, *Minerals Year Book*, Statistical Summary, 1997 & 1994

developed for mining. These provide a frame-of-reference in identifying energy-intense operations.

Table 5-2 shows model outputs for energy requirements for a surface copper mine in the U.S. As with mining in general, transportation accounts for the majority of energy consumption. At 66 percent of total energy consumed, the operations of rear-dump trucks accounted for the majority of energy consumed. The rear-dump trucks run on diesel fuel and are also the most energy intensive piece of equipment at the mine. Rear-dump trucks, along with other transportation equipment such as bulldozers, service trucks, bulk trucks and pick-up trucks account for 83 percent of the total energy consumed.

Table 5-2. Energy Requirements for a 68,493 ton/day Surface Copper Mine					
		Equipment Energy Consumption			
Equipment (number of Units)	Daily hours/ unit	Single Unit (Btu/ton)	All Units (Btu/hour)	All Units (Btu/day)	All Units (Btu/ton)
Rear Dump Trucks [b] (30)	24.00	1,500	130,000,000	3,100,000,000	45,600
Bulldozers [b] (11)	24.00	831	26,200,000	628,000,000	9,100
Cable Shovels [a] (7)	24.00	1,200	24,300,000	582,000,000	8,500
Pick-up Trucks [b] (26)	24.00	72.4	5,40,000	129,000,000	1,900
Graders [b] (2)	24.00	425	2,400,000	58,300,000	849
Rotary Drills [a] (2)	24.00	395	2,300,000	54,200,000	790
Water Tankers [b] (1)	24.00	875	2,500,000	60,100,000	875
Pumps [b] (3)	24.00	166	1,400,000	34,100,000	497
Service Trucks [b] (2)	24.00	119	679,000	16,300,000	237
Bulk Trucks [b] (2)	24.00	119	679,000	16,300,000	237
Total			**196,000,000**	**4,701,000,000**	**68,600**

a   Calculated at $0.049 per kWH: average for Rocky Mountain Region, 1999
b   Calculated at $0.535 per gallon: average prices for sales to end-users in U.S. Petroleum Administration for Defense District No. IV, 1999
Note: Mine operates over a 24-year lifetime with a 600 million-ton output at the end of its life. Mine runs 364 days per year with one shift per day of 8.00 hours. Assume daily production rate of 68,493 tons per day. Assumes both ore and waste material must be hauled 2,296 feet at a gradient of 8 percent.
Sources: BCS, Incorporated estimates (May 2000) using the Western Mining Engineering, Inc. *SHERPA Mine Cost Software* and *Mine and Mill Cost, An Estimators Guide*
        U.S Department of Interior, Office of Surface Mining, *The Effects of Increasing Costs on the Future Relation Between Open Pit and Underground Mining*, Michigan Technology University, Department of Mining Engineering, 1982

Table 5-3 shows the energy requirements for the pyrometallurgical processing of copper. Most energy consumed is in the operation of the SAG and ball mills. SAG mills are by far the most energy intensive equipment in processing requiring 92,400 Btu each per ton of copper ore mined. Crushing and grinding overall account for 84 percent of the total energy consumed per ton for processing.

Table 5-3. Energy Requirements needed for Pyrometallurgical Processing of Copper					
Unit (number of units)	Daily hours/ unit	Energy Consumption			
		Single Unit (Btu/ton)	Btu/hour	Total Btu/day	Btu/ton
SAG Mills [a] (4)	24.00	92,400	1,100,000,000	25,400,000,000	370,000
Ball Mills [a] (8)	24.00	4,600	106,000,000	2,500,000,000	37,000
Flotation [a] (57)	24.00	1,300	205,000,000	4,900,000,000	71,400
Cyclone [a] (8)	24.00	618	14,200,000	340,000,000	4,900
Crusher [a] (1)	24.00	265	757,000	18,200,000	265
Furnace (1)	24.00	238	681,000	16,300,000	238
Thickeners [a] (3)	24.00	170	1,500,000	35,100,000	510
Total			1,390,000,000	33,200,000,000	484,000

a   Calculated at $0.049 per kWH: average for Rocky Mountain Region, 1999
b   Calculated at $0.535 per gallon: average prices for sales to end-users in U.S. Petroleum Administration for Defense District No. IV, 1999
Note: Mine operates over a 24-year lifetime with a 600 million-ton output at the end of its life. Mine runs 364 days per year with one shift per day of 8.00 hours. Assume daily production rate of 68,493 tons per day. Ore and waste material hauled 2,296 at a gradient of 8 percent.
Source: BCS, Incorporated estimates (May 2000) using the Western Mining Engineering, Inc., *SHERPA Mine Cost Software* and *Mine and Mill Equipment Cost, An Estimators Guide*
U.S Department of Interior, Office of Surface Mining, "The Effects of Increasing Costs on the Future Relation Between Open Pit and Underground Mining, Michigan Technology University, Department of Mining Engineering, 1982

Table 5-4 shows the energy requirements for the hydrometallurgical processing of copper. The largest energy user is, again, the crusher. This accounts for 52 percent of the total energy needed per ton in the hydrometallurgy process. Roasting is another energy-intensive step. It accounts for 48 percent of the energy consumed per ton in the hydrometallurgy process.

Comparing the pyrometallurgical and hydrometallurgical methods with mining, the hydrometallurgical method requires less energy than the pyrometallurgical method. The difference between the two methods is 482,510 Btu per ton of copper mined.

Table 5-4. Energy Requirements needed for Hydrometallurgical Processing of Copper					
Unit (number of Units)	Daily hours/ unit	Equipment Energy Consumption			
		Single Unit (Btu/ton)	Btu/hour	Total Btu/day	Btu/ton
Crusher [a] (1)	24.00	771	2,200,000	53,000,000	771
Roasting (1)	24.00	713	2,040,000	49,000,000	713
Elecrowinning [a] (1)	24.00	5.80	16,700	401,200	5.80
Total			4,260,000	102,000,000	1,490

a   Calculated at $0.049 per kWH: average for Rocky Mountain Region, 1999
Note: Mine operates over a 24-year lifetime with a 600 million-ton output at the end of its life. Mine runs 364 days per year with one shift per day of 8.00 hours. Assume daily production rate of 68,681.32 tons per day. Ore and waste material hauled 2,296 at a gradient of 8 percent.
Source: BCS, Incorporated estimates (May 2000) using the Western Mining Engineering, Inc., *SHERPA Mine Cost Software and Mine* and *Mill Equipment Cost, An Estimators Guide*
            Conversations with Industry Experts

5.4 Emissions

Table 5-5 shows the quantities of air emissions associated with copper processing. APC dusts/sludges are generated during smelting operations and may contain significant concentrations of copper. These dusts/sludges are typically fed back to the smelter. Estimates of low, medium, and high annual waste generation are rates of 100 metric

Table 5-5. Emissions from Copper Ore Processing	
Emission	Quantity (metric tons/year)
APC dusts/sludges	450,000

Source: U.S. Environmental Protection Agency, Office of Solid Waste, *Identification and Description of Mineral Processing Sectors and Waste Streams.*

tons/yr., 222,000 metric tons/yr., and 450,000 metric tons/yr.[8]

5.5 Effluents

Table 5-6 shows the quantities of effluents from copper processing. Used contact cooling water results from heat exchanging operations such as those taking place at the smelter. The water used for anode cooling is reported to contain dissolved arsenic, copper, and zinc and also to pick up aluminum and chlorides, probably from mold dressing compounds. Approximately 13,000 metric tons of contact cooling water is generated annually and is recycled and classified as spent material.

Effluents from the wastewater treatment plant (WWTP) are discharged through a NPDES permitted outflow; therefore, it is not considered a waste. Approximately 4,590,000 metric tons of WWTP liquid effluent are generated annually.

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[8] U.S. Environmental Protection Agency, Office of Solid Waste, *Identification and Description of Mineral Processing Sectors and Waste Streams*, p. 233-279, April 1998

Process wastewaters result from cooling and electrorefining operations. Process wastewaters may either be treated on site at wastewater treatment facilities or discharged to tailings ponds, surface impoundments, or receiving streams. The waste exhibits the hazardous characteristics of toxicity (for arsenic, cadmium, lead, and mercury) and corrosivity. Approximately 4,891,000 metric tons of process wastewaters are generated annually and are recycled and classified as spent material.

Table 5-6. Effluents from Copper Ore Beneficiation and Processing	
Effluent	**Quantity (metric tons/year)**
Waste Contact cooling water	13,000
WWTP liquid effluent	4,590,000
Process wastewaters	4,891,000
Surface impoundment waste liquids	615,000

Source: U.S. Environmental Protection Agency, Office of Solid Waste, *Identification and Description of Mineral Processing Sectors and Waste Streams*.

Surface impoundment waste liquids frequently contain mixtures of tailings and process wastewater (such as slag concentrate filtrate), which may have been treated in a wastewater treatment plant. Often, the solids are allowed to settle out and the liquids are discharged through permitted outfalls. Approximately 615,000 metric tons of surface impoundment liquids are generated annually and is partially recycled and classified as spent material.

5.6 By-products and Solid Waste

By-products

There are a large number of by-products associated with copper mining. These include molybdenum and bismuth. Table 5-7 shows the quantities of by-products from copper mining and processing. At a molybdenum recovery plant, the copper concentrate contains approximately one percent molybdenum disulfide (which in itself is a saleable co-product). To isolate the molybdenum from the copper concentrate, the concentrate undergoes additional flotation steps. The copper concentrate is added to a rougher flotation cell where sodium cyanide is added to suppress the copper, thus causing the molybdenum to float to the surface. The copper concentrate falls to the bottom and the underflow is sent for drying and thickening prior to smelting. The molybdenum-containing overflow is sent to additional cleaner and recleaner circuits. At the last recleaner circuit, 70 percent of the overflow is filtered and

Table 5-7. By-products from Copper Ore Beneficiation and Processing	
By-product	**Quantity (metric tons/year)**
Slime or "muds"	3,000
Crud (often referred to as "gunk," "grungies," or "grumos")	2,000
Tankhouse slimes or "anode slimes"	4,000
Acid plant blowdown	4,847,000

Source: U.S. Environmental Protection Agency, Office of Solid Waste, Identification and Description of Mineral Processing Sectors and Waste Streams.

dried. The remaining 30 percent is returned to the filter at the beginning of the recleaner circuit. The filtered, dry molybdenum disulfide product (95 percent) is packed into 55-gallon drums and sold as molybdenite.

Bismuth can be recovered from air pollution control solids. Specifically, in copper smelting, a portion of the bismuth is volatilized in the copper converter and caught along with such elements as lead, arsenic and antimony as a dust in a baghouse or cottrell system. The dust is then transferred to a lead smelting operation. A major portion of the bismuth, however, also remains with the metallic copper. Therefore, during electrolytic refining of the copper, the bismuth accumulates in the anode slime and can be reclaimed during recovery operations.

A clay/copper material called *slime* is often generated during the flotation of copper ore containing a large amount of clay minerals. Slime is separated from the gangue, reground, and refloated to remove additional copper value. The slime is ultimately disposed of along with the tailings. There is no information on the quantity of slime generated annually. Note that this slime is much different in composition than the slimes or muds generated by electrolytic refining. Slimes or muds result from the deposition of sediment in electrowinning cells. These materials often contain valuable quantities of precious metals and are either processed on-site or are drummed and sent off-site for recovery. Approximately 3,000 metric tons of slimes are generated annually.

Crud (often referred to as gunk, grungies, or grumos) is generated during solvent extraction. Crud is made of solid particles associated with oil/water dispersions of varied complexity and typically forms stable multi-phase emulsions. Crud is periodically removed from the system. The crud is centrifuged or otherwise treated to remove the organics, which are returned to the solvent extraction circuit for reuse. Approximately 2,000 metric tons of crud is generated annually.

Tankhouse slimes are often referred to as "anode slimes" and are the result of material deposition in electrolytic cells. Slimes contain the constituents in a copper anode that remain insoluble during the electrorefining process and ultimately settle to the bottom of the cells. Generally, slimes generated from copper refining of various ores have the same values and impurities including gold, silver, platinum group metals, copper, selenium, arsenic, tin, lead, and tellurium. However, their metals concentrations may vary widely depending on the ore from which the copper anodes have been obtained. The raw slimes always have high copper contents and the selenium content is also usually high. Therefore, normal slime treatment includes initial decopperization of the slimes followed usually by deselenization. Traditionally, these slimes are then sent to smelting in a doré furnace followed by refining. A new method of metals recovery gaining popularity is wet chlorination, which uses chlorination and solvent extraction to recover these values. These materials often contain valuable quantities of precious metals and are either processed on-site or are drummed and sent off-site for recovery. Approximately 4,000 metric tons of tankhouse slimes are generated annually and classified as a by-product.

Acid plant blowdown originates in the gas cleaning section of the acid plant. It is generated from the water spraying of smelter converter gases and consists largely of smelter feed carryover solids. Blowdown has been reported to contain 14 percent sulfate, 15 percent total dissolved solids, 1 percent copper, 1 percent iron, and 70 percent water. Acid plant blowdown also may contain significant concentrations (i.e., >1,000 mg/L) of arsenic, cadmium, lead, molybdenum, and selenium. Approximately 4,847,000 metric tons of acid plant blowdown are generated annually and classified as a by-product.

Solid Waste

Table 5-8 shows the quantities of by-products from copper mining and processing. Spent ore from mining operations, along with overburden, is generated from the actual removal of copper ore from the ground and contains little or no recoverable copper values. These materials are typically hauled form the mine site and are placed in overburden or waste rock piles. In 1980, more than 282 million tons of waste rock was removed.

Tailings (or gangue) result from the flotation of ground ore/water slurry. The composition of tailings varies according to the characteristics of the ore. This waste is comprised of very fine host rock and nonmetallic minerals. Tailings are sent to tailings impoundments for disposal, but may first be dewatered in thickeners. Tailings generated during the flotation processes are excluded from RCRA Subtitle C regulation under the Bevill Amendment. In 1985, the industry disposed of more than 189 million tons of gangue.

Raffinate or barren leachate is generated when the pregnant leachate is stripped and is recycled back to the leaching circuit. Approximately 70,036,000 metric tons of raffinate is generated annually and recycled back into the leaching circuit.

Spent kerosene is commonly used as the organic material in solvent extraction, spent kerosene is purified using filter clay. The resulting impurities, or grungies, are recycled back to the heap-leaching area.

Spent bleed electrolyte results from electrolytic cells. Normally, spent electrolyte is purified in liberator cells. Liberator cells are similar to normal electrolytic cells, but they have lead anodes instead of copper anodes. The electrolyte is cascaded through the liberator cells and an electric current is applied. Copper in the solution is deposited on copper starting sheets. As the copper in the solution is depleted, the quality of the copper deposit is degraded. Liberator cathodes containing impurities are returned to the smelter to be

Table 5-8. Solid Wastes from Copper Ore Beneficiation and Processing	
Solid Waste	**Quantity (metric tons/year)**
Waste rock	256
Tailings	171
Raffinate or barren leachate	70,036,000
Spent Bleed electrolyte	307,000
Discarded Furnace and Converter Brick	3,000
Chamber solids and scrubber sludges	31,000
WWTP sludge	6,000

Source: U.S. Environmental Protection Agency, Office of Solid Waste, *Identification and Description of Mineral Processing Sectors and Waste Streams*

melted and cast into anodes. Purified electrolyte is recycled to the electrolytic cells. Any bleed electrolyte can be neutralized with mill tailings and disposed of in tailing ponds or pumped to a raffinate pond, from which it is pumped to on-site copper leaching dumps. Sludge that falls on the floor of the liberator cell is returned to the smelter or sold. Approximately 307,000 metric tons of bleed electrolyte are generated annually. Bleed electrolyte exhibits the hazardous characteristics of toxicity and corrosivity. This partially recycled waste stream was formerly classified as a spent material. Spent bleed electrolyte is not believed to be land stored.

Acid plant blowdown is partially recycled and classified as a by-product.

Acid plant thickener sludge results from the treatment of weak acid plant blowdown (see above). In the past, this waste stream generally was discharged to either a tailings pond or evaporation pond. Recent site-specific information indicates that this waste stream is no longer generated.

Scrubber blowdown results when low volumes of high total dissolved solids (TDS) materials are removed from the gas scrubbing system and is partially recycled and classified as spent material.

Discarded furnace and converter brick is a maintenance waste and is periodically generated during rebuilding of the furnace and converters. At one facility, bricks are crushed and stockpiled for recycling to the sulfide mill, where the copper is recovered through beneficiation. Approximately 3,000 metric tons of furnace brick is generated annually. Revert (molten matte that is spilled during its transfer in the smelting process) also contains significant concentrations of copper and is returned to the crushing/grinding circuit.

Approximately 31,000 metric tons of chamber solids and scrubber sludges are generated per year.

Spent black sulfuric acid sludge is obtained from the vacuum evaporation of decopperized electrolyte. The black acid liquor may be also be used in leaching operations or sold to fertilizer manufactures. Existing data and engineering judgement suggest that this material does not exhibit any characteristics of hazardous waste.

WWTP sludge results from the neutralization of process waters using magnesium hydroxide or lime. Approximately 6,000 metric tons of solids and sludges are generated annually. This waste may exhibit the characteristics of toxicity for cadmium and lead. This waste stream is partially recycled and classified as sludge.

5.7 Hazardous Waste

The commodity copper ore was evaluated from extraction to the first saleable product. There are no RCRA-listed (Resource Conservation and Recovery Act) hazardous wastes

associated with copper ore mining, beneficiation, and processing. The material generated from copper ore mining, beneficiation, and processing is managed through recycling.