

Chapter 8

Environmental Aspects of Copper Production

CONTENTS

	<i>Page</i>
Air Quality	162
Pollutants of Concern and Their Regulation	162
Smelter Pollution Control	163
Costs and Benefits of Pollution Control	168
Water Quality and Waste Disposal	170
Pollutants of Concern	173
Waste Management Practices174

Boxes

Box	<i>Page</i>
8-A. Alternative Byproducts From the Control of Strong SO ₂ Emissions	165
8-B. Collecting Converter Gases	168
8-C. The Resource Conservation and Recovery Act...	173
8-D. Factors Affecting the Potential for Contamination	175

Figures

<i>Figure</i>	<i>Page</i>
8-1. Environmental impacts of Copper Production	161
8-2. Gas Cleaning in Copper Smelting	165
8-3. Copper Converter Operation	167
8-4. Air Curtain Control System	169
8-5. Cost of SO ₂ Removal With an Acid Plant	171
8-6. Sulfur Dioxide Control	172
8-7. Wasteland Management Practices	176

Tables

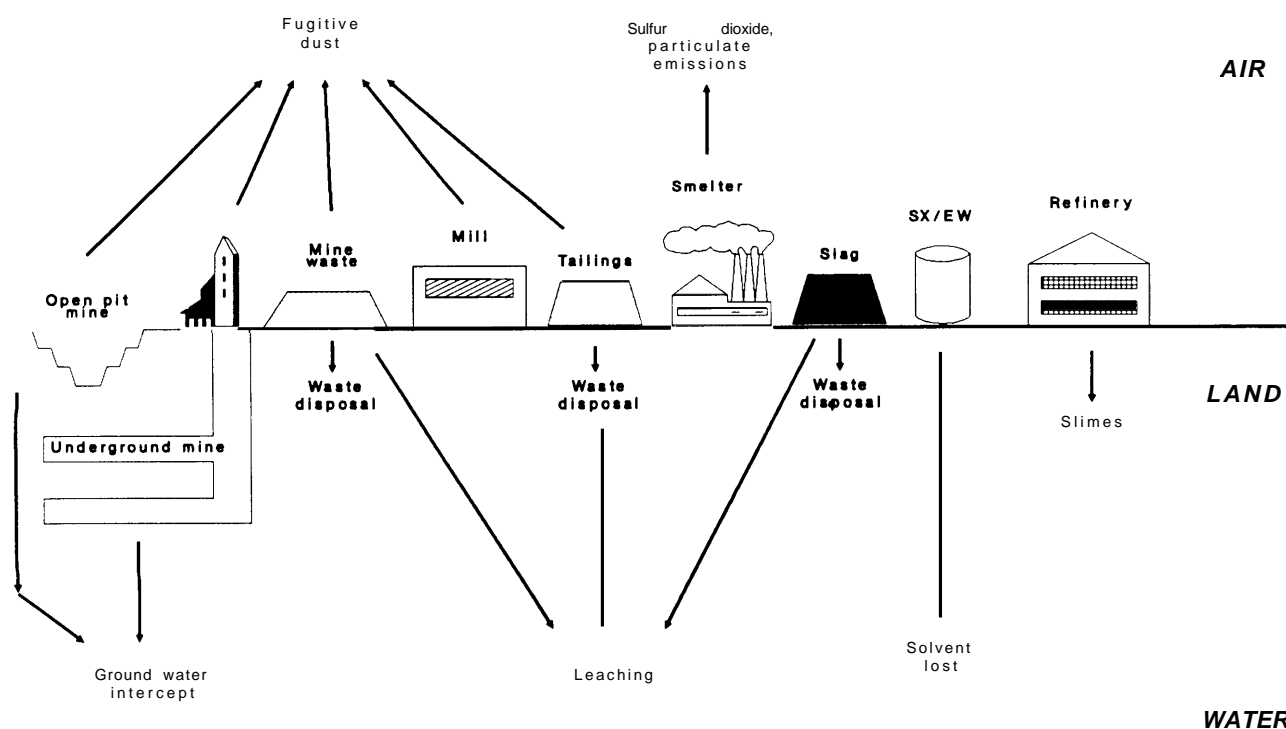
<i>Table</i>	<i>Page</i>
8-1. 1980 Sulfur Dioxide Emissions in the United States	162
8-2. State and Federal Primary Ambient SO ₂ Standards	163
8-3. Smelting Technology and Associated Emissions	164
8-4. Effluent Limitations on Discharges From Mines, Mills, and Leach Operations.	172

Environmental Aspects of Copper Production

Copper production is not an environmentally benign activity. From mining and milling through hydro- and pyrometallurgical processing to refining, copper production can have significant adverse impacts on air quality, surface and ground-water quality, and the land (see figure 8-1). While these impacts can be severe when the materials handled include toxic or hazardous substances (e.g., ores with a relatively high concentration of arsenic), they also can be modest due to technological and other pollution controls, and because of mitigating features of the climate, geology, and ecology of most copper-producing areas in the United States.

As with all other industrial activities in the United States, **copper production is subject to extensive environmental regulation related to air and water quality, and materials handling and disposal practices. This regulation has had significant impacts on the mode and cost of domestic copper production.** For example, sulfur dioxide emission limitations resulted in the replacement of domestic reverberatory smelting furnaces with flash, electric, or continuous furnaces connected to plants that convert the sulfur dioxide to sulfuric acid. Operation of the acid plant increases smelter costs. For some domestic producers, the sulfuric acid is a salable by-

Figure 8-1.-Environmental Impacts of Copper Production



SOURCE: Office of Technology Assessment

product or usable at a nearby mine for leaching. It also can be a "red ink" item if there are no markets within an economical transportation distance.

Operational changes resulting from environmental regulation have conferred significant (but less easily quantifiable) benefits for human health and the environment, but also have had a substantial adverse impact on the competitiveness of U.S. copper producers. Any tightening

of the present air quality or waste management requirements would result in further closures of domestic copper operations.

This chapter reviews the environmental aspects of copper production. It presents a brief overview of the rationale for regulation, the technological controls, and the impact of those controls on domestic competitiveness. Further analysis of environmental regulation and its impact on the U.S. copper industry may be found in chapter 10.

AIR QUALITY

Pollutants of Concern and Their Regulation

Uncontrolled copper smelting processes emit large quantities of particulate matter, trace elements, and sulfur oxides, which can have adverse effects on human health. Sulfur dioxide (SO₂), and the sulfates and sulfuric acid aerosols it forms in the atmosphere, can be lung irritants and aggravate asthma. Estimates of the magnitude of health risks and the influence of SO₂ and secondary pollutants from *all* emission sources range from 0 to **50,000** premature deaths per year in the United States and Canada.¹ Sulfur dioxide emissions from smelters also have been linked to visibility degradation and acid deposition.² Al-

though fossil-fueled electric powerplants are the major source of SO₂ emissions in the United States, smelters contribute significantly to total emissions in the sparsely populated copper-producing areas of the West (see table 8-1).

Fugitive emissions from furnaces and converters can cause health problems in the work place and/or result in elevated levels of toxic pollutants such as lead and arsenic in the immediate vicinity of the smelter. Generally, employees are exposed to the highest concentrations of toxic elements because they work in enclosed areas. However,

¹U.S. Congress, Office of Technology Assessment, *Acid Rain and Transported Air Pollutants: Implications for Public Policy*, OTA-O-204 (Washington, DC, U.S. Government Printing Office, June 1984), p. 13.

²Robert A. Eldred et al, "Sulfate levels in the Southwest during the 1980 Copper Strike," *Journal of Air Pollution Control*, vol. 33,

No. 2, 1983; John Trijonis, "Visibility in the Southwest—An Exploration of the Historical Data Base," *Atmospheric Environment*, vol. 13, 1979, pp. 833-843, and sources cited therein; see also Robert Yuhnke and Michael Oppenheimer, *Safeguarding Acid Sensitive Waters in the Intermountain West*, Environmental Defense Fund, November 1984; see also "Acid Deposition in the Western United States," *Science*, July 4, 1986, pp. 10-14.

³ Fugitive emissions are those that escape capture by normal air pollution control equipment.

Table 8-1.—1980 Sulfur Dioxide Emissions in the United States (million metric tonnes)

Source	National		East		West	
	Tons	Percent	Tons	Percent	Tons	Percent
Electric utilities	15.8	65.6	14.6	73.5	1.2	28.6
Nonferrous smelters ^a	1.4	5.8	0.2	0.8	1.2	29.0
Transportation	0.8	3.3	0.5	2.5	0.3	7.3
Other	6.1	25.3	4.6	23.2	1.5	35.1
Total ^c	24.1	100.0	19.8	100.0	4.3	100.0

^aIncludes 28 nonferrous smelters, of which 27 were operating in 1980. Sixteen of the 28 are copper smelters—13 are in the

West. Eight of the copper smelters are still in operation

^bIndustrial, commercial, and residential sources

^cTotals may not add due to rounding

SOURCE U S Congress, General Accounting Office, *Air Pollution Sulfur Dioxide Emissions from Nonferrous Smelters Have Been Reduced*, report to the Chairman, Subcommittee on Oversight and Investigations, Committee on Energy and Commerce, House of Representatives, GAO/RCED-86-91, April 1986.

contamination of the soil surrounding a smelter also is of concern. Fortunately, toxic metals are present only in very small concentrations in most domestic copper ores.⁴ Only Asarco's El Paso smelter currently treats concentrates that are considered to have high levels of volatile impurities. The Anaconda-Butte and Asarco-Tacoma smelters used to treat such concentrates, but they closed in 1980 and 1985, respectively,

The Clean Air Act established National Ambient Air Quality Standards for six pollutants (see table 8-2). The Act requires that these standards be met throughout the United States, including the improvement of air quality in "dirty" areas and the prevention of significant deterioration of air quality in "clean" areas. These goals are achieved through emission limitations on various types of sources (including non-ferrous smelters) that require the use of technology-based controls. The Act also regulates emissions of hazardous pollutants. Substantial financial penalties are imposed for non-compliance.

⁴State of Arizona, Bureau of Air Quality Control, *Third Annual Report on Arizona Copper Smelter Air Pollution Control Technology*, April 1979.

^aA "high level of volatile impurities" means a total smelter charge containing more than 0.2 percent arsenic by weight, 0.1 percent antimony, 4.5 percent lead, or 5.5 percent zinc, on a dry basis. Code of Federal Regulations, Title 40, Part 60.161. July 1, 1986.

Table 8-2.—State and Federal Primary Ambient SO₂ Standards

Federal	0.03 ppm 0.14 ppm ^a 0.50 ppm ^a	annual average 24-hour average 3-hour average
Arizona	0.03 ppm 0.14 ppm 0.50 ppm	annual average 24-hour average 3-hour average
Montana	0.02 ppm 0.10 ppm ^b 0.05 ppm ^c	annual average 24-hour average 3-hour average
New Mexico	0.02 ppm 0.10 ppm	annual average 24-hour average
Utah	0.03 ppm 0.14 ppm 0.50 ppm	annual average 24-hour average 3-hour average

KEY: 1 ppm SO₂ = 2620 µg/m³
ppm = parts per million
µg/m³ = micrograms per cubic meter.

NOTE The 3-hour average is an annual geometric mean, to be used in assessment of plans to achieve the 24-hour standard

^aNo more than 1 violation/year

^bNo more than 2 violations/year

^cNo more than 19 violations/year

SOURCE Federal Code of Regulations, Title 40, Part 57102, July 7 1986

Smelter Pollution Control

All stages of pyrometallurgical processing emit gases of varying content and volume (see table 8-3). Most technological methods of control involve collecting the gases and converting the SO₂ to some other product. The characteristics of the gases dictate the type of control technology, which in turn determines the kind of byproducts produced. For example, acid plants—the most widely used control technology—require a relatively high (at least 4 percent) SO₂ concentration in the off-gas for economical operation and compliance with pollution limitations. Roasters, flash furnaces, electric furnaces, continuous smelting furnaces, and converters all produce gases that can be treated in an acid plant. Weak gases, such as those from reverberatory furnaces and fugitive emissions, must be treated by alternate means. b

Strong Sulfur Dioxide Emissions

Acid plants (figure 8-2) convert the sulfur dioxide in emissions to sulfuric acid (H₂SO₄). Other conversions, including to gypsum, elemental sulfur, and liquid SO₂ are technologically feasible, but usually not economically viable (see box 8-A).

In making sulfuric acid, the hot gases are first collected from the roasters, furnaces, and converters (see box 8-B). The gases are cooled, cleaned (through three series of dust collection systems) to recover copper from the dust and prevent fouling of the acid plant, and then treated with sulfuric acid to remove any water vapor. Catalysts convert the SO₂ gas to sulfur trioxide (SO₃), which is absorbed in a circulating stream of 98.5 percent sulfuric acid and 1.5 percent water, and reacts with the water to form more concentrated acid.

There are two basic types of acid plants. In single contact/single absorption (SC/SA) plants, the gas goes through the system once; such plants average conversion (SO₂ to H₂SO₄) efficiencies of 96 to 98 percent. Double contact/double absorption (De/DA) plants maximize SO₂ capture

^bIn the conventional roasting-reverberatory smelting-converting sequence, only 50-70 percent of the SO₂ produced by the smelter can be captured with an acid plant.

Table 8-3.—Smelting Technology and Associated Emissions

Technology	Off gases (% SO ₂ by volume)	Fugitive emissions
Multihearth roaster	5-10	Leakage through the shell and open ports and during the filling of the transfer car (to transport matte to the furnace).
Fluid bed roaster	10-12	
Reverberatory furnace	0.5-2.5	Emissions escape through openings in the brickwork, during charging of calcine or green concentrate, during addition of converter slag, at slag and matte launders during tapping, at uptake and waste heat boilers.
Pierce-Smith converter:		
during blowing	15-21	Emissions escape through the primary hooding system and are emitted directly from the mouth of the converter during charging and pouring.
during charging (change due to dilution with air)	1-7	
Continuous smelting:		
Noranda process	16-20	Noranda emissions from between the primary uptake hood and furnace mouth, from the mouth when in the rolled out position, around matte tapping, and at the port for feeding concentrates and fluxes.
Mitsubishi process	11	
Electric furnace	5 +	Fugitive emissions lower than most reverberatories; if not properly maintained, brickwork could be a source of emissions. Emissions may occur during slagging, matte tapping, converter slag return, around the electrodes, and the calcine handling.
Flash smelting:		
30% oxygen enriched	10-20	Fugitive emissions at launders and ladles and from leakage through the furnace walls and roof.
tonnage oxygen	70-80	
Hoboken Converter	8-9	This converter has no primary hood, so any emissions from the mouth of the converter are fugitive emissions; properly designed, operated, and maintained, there are minimal fugitive emissions. Fugitive emissions occur during the hot metal matte charging or hot blister metal pouring.

SOURCE: Timothy W. Devitt, *Control of Copper Smelter Fugitive Emissions*, PEDCo-Environmental, Inc., May 1980, p. 14

by returning the gas stream to the converters through an intermediate absorption tower. These plants are capable of 99.7 to 99.8 percent conversion efficiencies.⁷

The design of an acid plant is unique to each smelter. The key variables affecting the efficiency and economics of acid production are the total gas volume; and the SO₂ concentration, water vapor concentration, and free oxygen content of the treated gases. The physical dimensions and energy requirements of the acid plant are largely determined by the maximum volume and minimum concentration of SO₂ gas.⁸

There are several reasons why acid plants are so widely used by the U.S. copper industry. The technology is well proven and is the least expen-

sive method of smelter SO₂ control. Sulfuric acid is used in solution mining, and also is the most common form in which other industries consume sulfur; thus it can be a salable byproduct rather than a waste. However, non-leaching markets for sulfuric acid generally are a long way from the smelters in the United States, and the resulting transportation costs can turn the byproduct credit into a deficit. Moreover, it often is cheaper for industrial consumers to buy sulfur and produce the sulfuric acid themselves than to purchase acid produced elsewhere.⁹

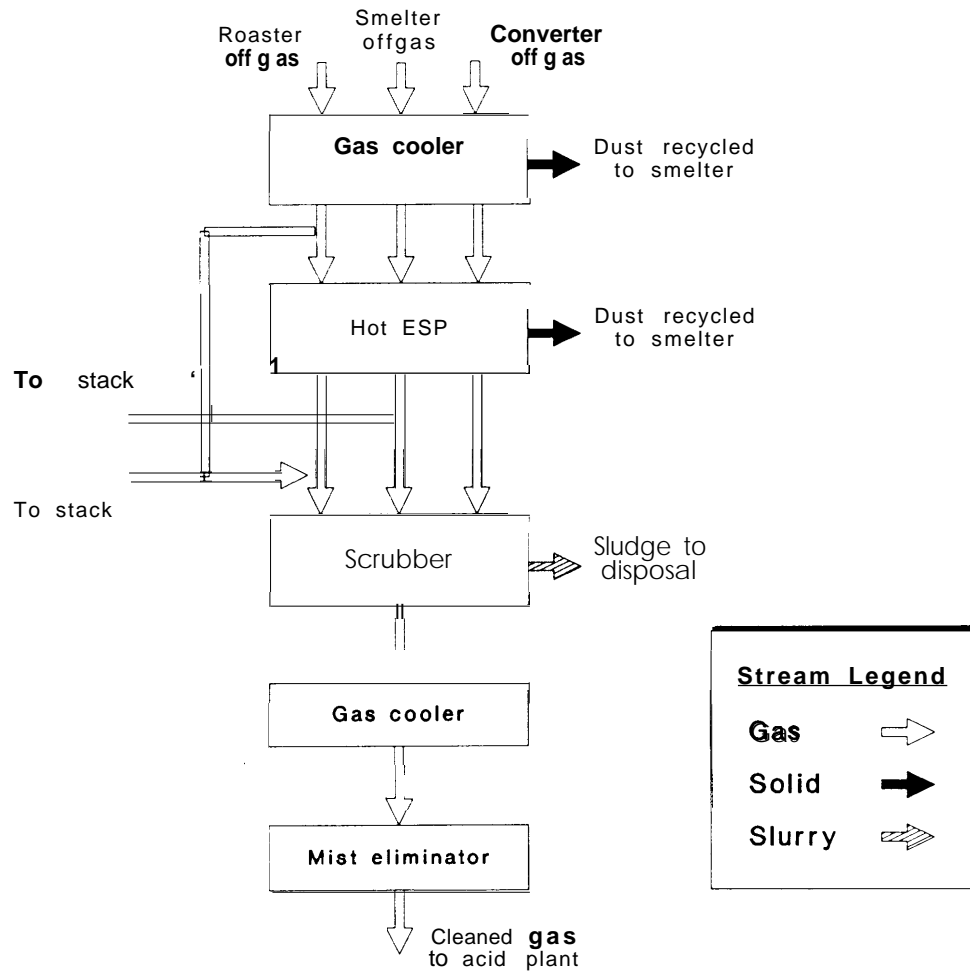
In some countries, such as Japan, a very high level of SO₂ control is achieved by copper smelters as part of a government policy to provide sulfuric acid for industrial development (see ch. 4). In less developed areas, such as the copper-producing countries of Africa and Latin America, there are

⁷Charles H. Pitt and Milton E. Wadsworth, *An Assessment of Energy Requirements in Proven and New Copper Processes*, report prepared for the U.S. Department of Energy, contract no. EM-78-S-07-1 743, December 1980.

⁸Ibid.

⁹Michael Rieber, *Smelter Emissions Controls, The Impact on Mining and the Market for Acid*, prepared for U.S. Department of the Interior, Bureau of Mines, March 1982.

Figure 8-2.-Gas Cleaning in Copper Smelting



SOURCE: Charles H. Pitt and Milton E. Wadsworth, *An Assessment of Energy Requirements in Proven and New Copper Processes*, report prepared for the U.S. Department of Energy, contract EM 78. S-07-1 743 Dec. 31, 1980

Box 8-A.—Alternative Byproducts From the Control of Strong SO₂ Emissions

Elemental Sulfur. The reduction of sulfur dioxide to elemental sulfur is technically complex and requires an extremely high concentration of SO₂ in the off gases. Therefore, elemental sulfur production is feasible only with the INCO flash furnace, which uses tonnage oxygen (rather than oxygen-enriched air) and has emissions of up to **75 to 80** percent SO₂. This conversion also requires large amounts of hydrocarbon fuel, such as coke, which reacts chemically with the SO₂ to form elemental sulfur. The fuel is relatively expensive and more than triples the energy requirement of the SO₂ control system.¹ However, elemental sulfur can be transported economically much greater distances than either sulfuric acid or liquid sulfur dioxide, and is more easily stored when demand is low.

Liquid Sulfur Dioxide. Liquid sulfur dioxide production also works best with a highly concentrated gas stream like that emitted by the INCO furnace. Liquid SO₂ has a very limited demand in the United States, but, owing to its relatively high price per unit weight, it can be shipped long distances. It is still extremely expensive to transport, however, because it requires special pressurized tank cars that usually return empty. The market is too small to justify cost saving measures such as unit trains or special ocean tankers.²

¹ D. A. Schultz, "Pollution Control and Energy Consumption at U.S. Copper Smelters," *Journal of Metals*, January 1978, p. 20.

² Michael Rieber, *Smelter Emissions Controls: The Impact on Mining and the Market for Acid* prepared for U.S. Department of the Interior, Bureau of Mines, March 1982.

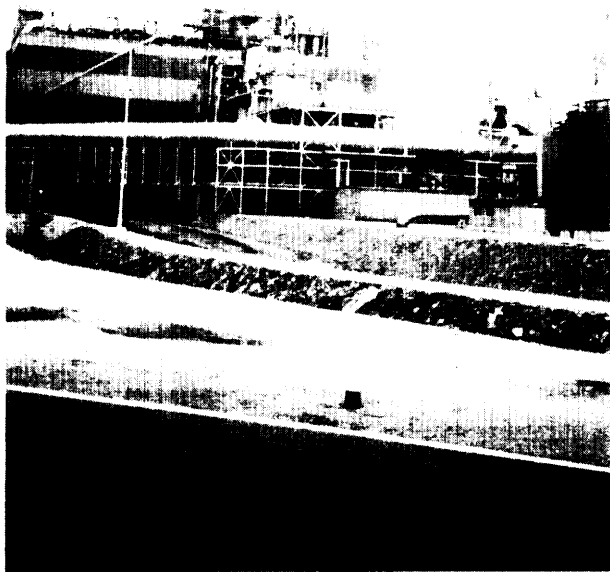


Photo credit: Robert Niblock

Acid plants entail extensive gas collection systems.

few industrial markets for acid, and SO_2 control is minimal (see figure 8-6, below).

It is important to note that not all of the SO_2 produced in a smelter is processed in the acid plant. Some of the sulfur dioxide gas is too weak to treat in the acid plant and some escapes as fugitive emissions. Gases from the acid plant itself contain unreacted sulfur dioxide and unabsorbed sulfur trioxide and usually are treated to remove acid mist before being vented to the atmosphere.

Weak Sulfur Dioxide Emissions

Weak gas streams, with an SO_2 concentration of less than 4 percent by volume, constitute a more difficult and costly problem than stronger streams. These include both smelter gases and fugitive emissions. For smelters, the three available control options are flue gas desulfurization,

modifying the furnace to produce stronger gas streams, and replacing the equipment with newer technology. All but two of the operating domestic smelters chose the third option.

In flue gas desulfurization (FGD), the SO_2 is chemically removed through reactions with lime, magnesium oxide, ammonia, or dimethylaniline (DMA, an organic liquid). Regenerative FGD systems upgrade the sulfur dioxide content of the gases so that they may be further treated in an acid plant. Non regenerative systems result in a waste product (scrubber sludge). Although FGD is a well proven technology in fossil-fueled powerplants, and the Environmental Protection Agency (EPA) considers it adequately demonstrated in nonferrous smelters, very few smelters have actually installed scrubbers.¹⁰ In early trials, smelters experienced frequent scaling and plugging problems with scrubbers. Phelps Dodge installed an experimental DMA system at their Ajo, Arizona smelter; it was operated intermittently and is no longer in use.¹¹ Currently, the White Pine, Michigan smelter is using gas scrubbers without an acid plant, and is in compliance with emission limitations.¹²

A broad range of reverberatory furnace modifications are available. The furnace can be sealed tightly to prevent infiltration of air and the subsequent dilution of the gases. oxygen-enriched smelting can increase the SO_2 content of the off gases while it reduces the overall volume of gas. Weak or intermittent gas streams can be blended with stronger gas streams to produce a stream amenable to SO_2 control. Supplemental sulfur can be burned in conjunction with a sulfuric acid plant to generate a supply of sulfur dioxide that can be used to beef up weaker gas streams.

Finally, reverberatory furnaces can be replaced with newer technology, resulting in the greatest improvements in sulfur capture. Although a complete smelter retrofit involves large capital costs

¹⁰A V Slack, "Application of Flue Gas Desulfurization in the Non-ferrous Metal Industry," *Sulfur Dioxide Control in Pyrometallurgy*, The Metallurgical Society of AIME, Chicago, Illinois, February 1981, p. 92.

¹¹Pitt and Wadsworth, *supra* note 7.

¹²Janice L. W. Jolly and Daniel Edelstein, "Copper," preprint from 1986 *Bureau of Mines Minerals Yearbook* (Washington, DC: U.S. Department of the Interior, 1987).

(see ch. 9), the newer furnaces comply more easily with air quality standards and are more efficient. Another alternative involves replacing or augmenting smelting with hydrometallurgical processes. Leaching and solvent extraction do not produce sulfur dioxide gas, but they can fall under water quality and waste disposal regulation. Moreover, only oxide ores and oxidized waste material currently can be leached economically.

The Pierce-Smith converter is the major source of fugitive emissions in a smelter building. Fugitives are emitted directly when the converter is rolled for the addition of matte (figure 8-3). They escape the primary hood (box 8-B) when it is moved to provide clearance for the overhead crane and matte ladle. Significant amounts of gases also escape from the hood during air injection (blowing). Moreover, the fan in the hood shuts down during charging, but, before the converter has completely rolled back to the vertical position and the hood and fan are fully operational, blowing resumes, allowing fugitives to escape.¹³

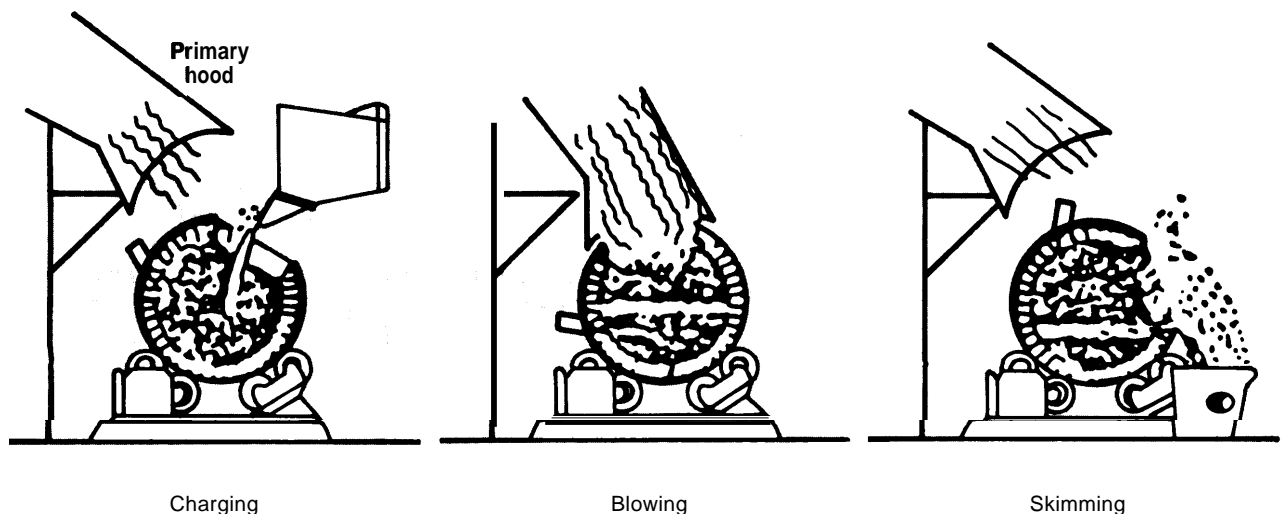
¹³Timothy W. Devitt, *Control of Copper Smelter Fugitive Emissions*, PEDCo-Environmental, Inc., May 1980, p. 14.



Photo credit: Manley Prim Photography, Tucson, AZ

Skimming from a converter.

Figure 8-3.—Copper Converter Operation



SOURCE: John O. Burckle et al., *Evaluation of an Air Curtain Hooding System for a Primary Copper Converter*, Vol. 1, Prepared for U S Environmental Protection Agency, Industrial Environmental Research Laboratory, by PEDCo Environmental, Inc., February 1984

Box 8-B.—Collecting Converter Gases

Converter gas streams are more difficult to collect than those from roasters and smelters. A hood is lowered to the converter mouth to capture the gases and particulate matter that are emitted while air is being blown into the matte. The primary hooding system on most converters consists of a fixed hood with a sliding gate located above and slightly away from the converter (see figure 8-3). During blowing, the gate is lowered to the converter mouth to help guide the emissions and reduce the intake of cool ambient air.

Primary hoods are not 100 percent efficient because the gate does not form a perfectly tight seal with the converter mouth. At plants where the gates were retrofitted rather than designed and installed as part of the original smelter, the gate often does not completely cover the converter mouth. Contact with the crane and ladles also can damage the hooding system, and preventive maintenance is required to repair leaks due to normal wear and tear.

A secondary hood that slips over the primary hood affords some additional emissions capture during the critical times of charging and skimming. Double hood systems have exhibited operational problems, however. They can become warped to the point that they no longer fit over the primary hood, and at times they do not supply enough draft or are too far from the mouth of the converter to be effective. }

¹Carl H. Billings, *Second Annual Report on Arizona Copper Smelter Air Pollution Control Technology*, State of Arizona, Bureau of Air Quality Control, April 1978, p. 40

Methods of capturing fugitive emissions from converters include secondary hoods, air curtains, ventilation systems, and alternative converter technologies. Air curtains use a row of nozzles to create a stream of air that captures around 90 percent of the gaseous emissions and particulate over the converter (see figure 8-4).¹⁴ As with primary hoods, however, contact with cranes and

¹⁴John O. Burckle, et al., *Evacuation of an Air Curtain Hooding System for a Primary Copper Converter, Volume I*, Prepared for U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, by PEDCo Environmental Inc., February 1984, p. 4.

ladles can damage or misalign air curtains. This sort of technology could be effective at fugitive emissions control if design changes could make it more adaptable to the smelter environment.

Another option for fugitive emissions control is a total building ventilation and collection system. Such a system did prevent high ambient air readings at monitoring stations around one smelter in which it was tried, but created dead spots inside the building where there were increased concentrations of SO₂ and elevated temperatures, largely due to inadequate fan capacity. Total ventilation may also create heating problems during cold spells as most of the heat is evacuated with the emissions.¹⁵

Alternative converter technologies include continuous reactors and the Hoboken converter. Continuous reactors theoretically combine roasting, smelting, and converting in one operation. In the Mitsubishi continuous reactor, the converter portion is enclosed and the potential for fugitives should be reduced substantially. The Noranda reactor both has a hood and typically is used in conjunction with a Pierce-Smith converter (see ch. 6).

Inspiration Consolidated Copper Company (ICCC) experimented with an induced draft Hoboken Converter, which was supposed to control emissions by maintaining a negative draft at the mouth at all times. Concentrations of 8 to 9 percent SO₂ were achieved in early tests—sufficient for treatment in an acid plant. Subsequently, however, ICCC experienced operational problems, fugitive emissions became progressively worse, and they replaced the converter.¹⁶

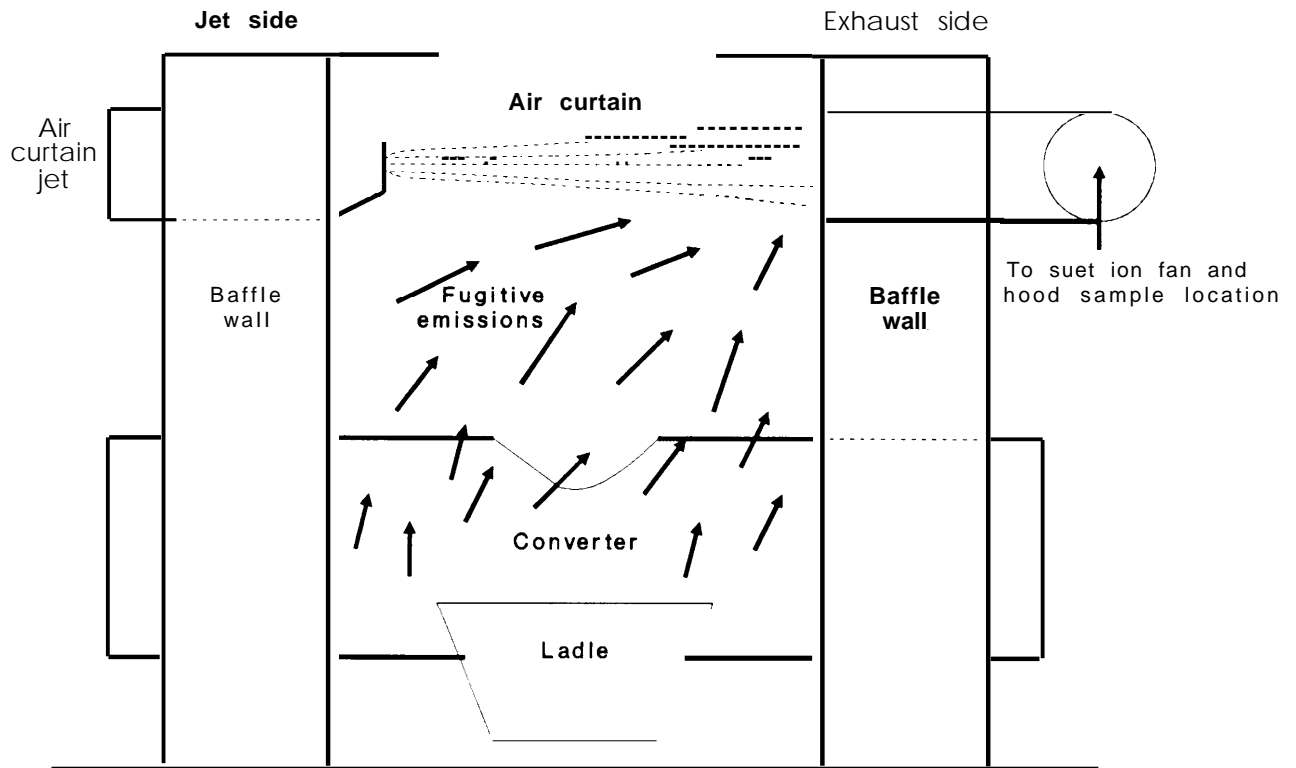
Costs and Benefits of Pollution Control

Control strategies have resulted in marked improvements in long term SO₂ levels in the past 15 years, with substantial benefits for public health and the environment. According to EPA statistics, copper smelters reduced their total sul-

¹⁵Carl H. Billings, *Third Annual Report on Arizona Copper Smelter Air Pollution Control Technology*, Arizona Bureau of Air Quality Control, April 1979, p. 42.

¹⁶Ibid.

Figure 8-4.-Air Curtain Control System



SOURCE John O Burckle et al., Evaluation of an Air Curtain Flooding System for a Primary Copper Converter, vol. 1, report prepared for U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, by PEDCO Environmental, Inc., February 1984.

fur dioxide emissions from 3.5 million tons in 1970 to **970,000** tons in 1983—a 72 percent reduction. The percent of input sulfur captured at domestic smelters is currently 90 percent.¹⁷

These gains were not easy. By the very nature of their operation, smelter and converter emissions are difficult and expensive—to capture and control. Before technological means of control became mandatory, smelters used supplemental and intermittent SO₂ controls.¹⁸ While these

¹⁷Duane Chapman, "The Economic Significance of Pollution Control and Worker Safety Costs For World Copper Trade," Cornell Agricultural Economics Staff Paper, Cornell University, Ithaca, New York, 1987.

¹⁸Supplemental control systems include the use of very tall stacks to disperse pollutants, thus diluting their ambient concentration. Intermittent control consists of monitoring the ambient weather conditions to identify when wind patterns and temperature inversions could trap the pollutants near the source instead of dispersing the plume. Under these conditions, production is cut back to the point necessary to reduce pollutant emissions to an acceptable ambient concentration,

methods resulted in lower overall SO₂ emissions, they also reduced production.¹⁹ When smelters had to install technological controls, many closed because the capital cost of retrofitting the smelter was too high. The General Accounting Office estimates that between 1970 and 1984, 44 percent of the reduced emissions from non-ferrous smelters (including lead and zinc operations) were due to improvements in control techniques, while 56 percent were due to decreased production.²⁰ (Smelters that closed during 1984 and 1985 had been responsible for over half of NAAQS violations.)

Although the need to replace reverb with other furnaces plus pollution control devices

¹⁹Rieber, supra note 9.

²⁰U.S. Congress, General Accounting Office, *Air Pollution, Sulphur Dioxide Emissions From Nonferrous Smelters Have Been Reduced*, April 1986, p.4.

brought social benefits and increased furnace efficiency, it also cost the domestic industry an enormous amount of money and contributed to the closure of significant domestic capacity.

The primary copper industry had capital investments totalling \$2.088 billion for air pollution control between 1970 and 1981, with average annual costs of \$3.074 billion.²¹ Furthermore, adding an acid plant to the production line increases operating costs without necessarily providing a byproduct credit. Present levels of control entail capital and operating costs of between 10 and 15 cents per pound of copper.²²

The capital cost of sulfur removal, which includes gas handling of a 4 percent sulfur dioxide gas stream and the sulfuric acid plant at a 50,000 tonne per year copper facility, has been estimated at \$560 per annual tonne of copper produced.²³ This is approximately 20 percent of the total capital costs of the facility. Both the capital investment and the operating cost for SO₂ removal decrease with increasing concentration of SO₂ in

²¹ Lawrence J. McDonnell, "Government Mandated Costs: The Regulatory Burden of Environmental, Health, and Safety Standards of U.S. Metals Production," paper prepared for the conference Public Policy and the Competitiveness of the U.S. and Canadian Metals Production, Golden, CO, January 1987.

²² Everest Consulting, *Air Pollution Requirements for Copper Smelters in the United States Compared to Chile, Peru, Mexico, Zaire and Zambia*, 1985.

²³ Jagdish C. Agarwal and Michael J. Loreth, "Preliminary Economic Analysis of SO₂ Abatement Technologies," *Sulfur Dioxide Control in Pyrometallurgy*, The Metallurgical Society of AIME, February 1981.

the gas stream because of lower costs associated with handling a smaller gas volume (see figure 8-5). Fugitive emissions are the most difficult and expensive to control because they are dilute, have a large volume, and are not easy to capture.

In comparison, copper smelters in Chile, Canada, Peru, Mexico, Zaire, Zambia and Japan—our major foreign competitors—are not faced with similar environmental regulations. In all but Japan, if smelter emissions are controlled at all, it is only to the extent that sulfuric acid is needed at an associated leaching project. Copper smelters in these countries capture between 0 and 35 percent of the input sulfur; on average only about one-fifth of the present level of U.S. control (see figure 8-6). Japanese smelters achieve 95 percent control as part of government policy to subsidize sulfuric acid production. Information regarding the costs of acid production in these countries is not available.²⁴ However, it is clear that domestic regulation puts U.S. producers at a competitive disadvantage.

Future capital investments in Chile, Peru, Mexico, Zaire, Zambia may be funded in part by the World Bank (see ch. 3). The World Bank requires environmental controls as a condition for financing, but they are less stringent than Clean Air Act standards, and compliance is not monitored.²⁵

²⁴ MacDonnell, *supra* note 21.

²⁵ Everest Consulting, *supra* note 22.

WATER QUALITY AND WASTE DISPOSAL

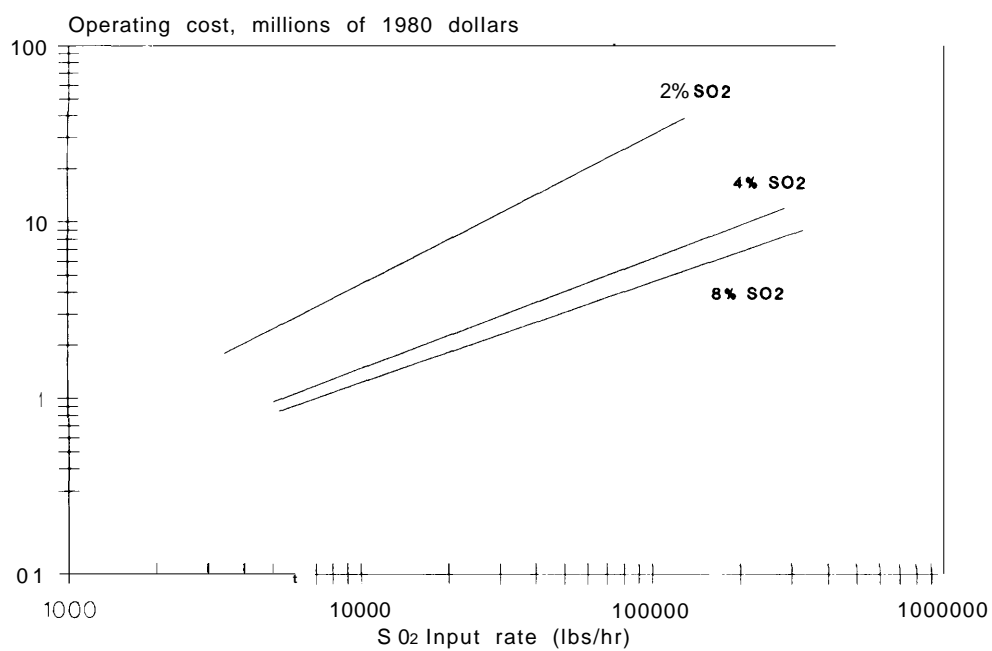
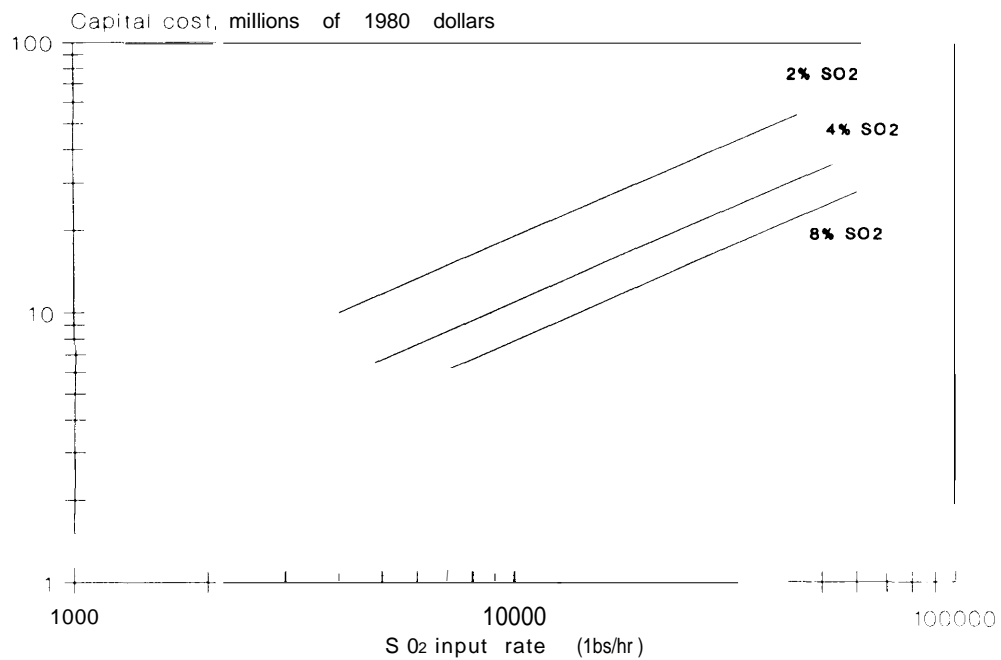
All aspects of copper production—from mining and leaching to milling, smelting, refining and electrowinning—have potential impacts on surface and groundwater quality (see figure 8-1).²⁶ Adverse water quality impacts are caused primarily by land disposal practices that fail to contain wastes, by run-on and run-off controls that are inadequate to prevent surface water from flow-

²⁶ surface waters include the various forms of water occurring on the surface of the earth, such as streams, rivers, ponds, lakes, etc. Groundwater is water that flows or seeps downward, saturating soil or rock and supplying springs or wells. The upper level of this saturated zone is called the water table. Aquifers are underground water sources large enough to be used for public water supplies.

ing through impoundments, or by groundwater infiltrating surface impoundments.²⁷ In addition, the large-scale land disturbances associated with open-pit mining may disrupt the natural flow of surface and groundwaters, and may lower the water table in the mine area. Lowering the water table may cause water shortages, land subsidence, and fracturing; the latter facilitates the transport of contaminants into and through an aquifer.

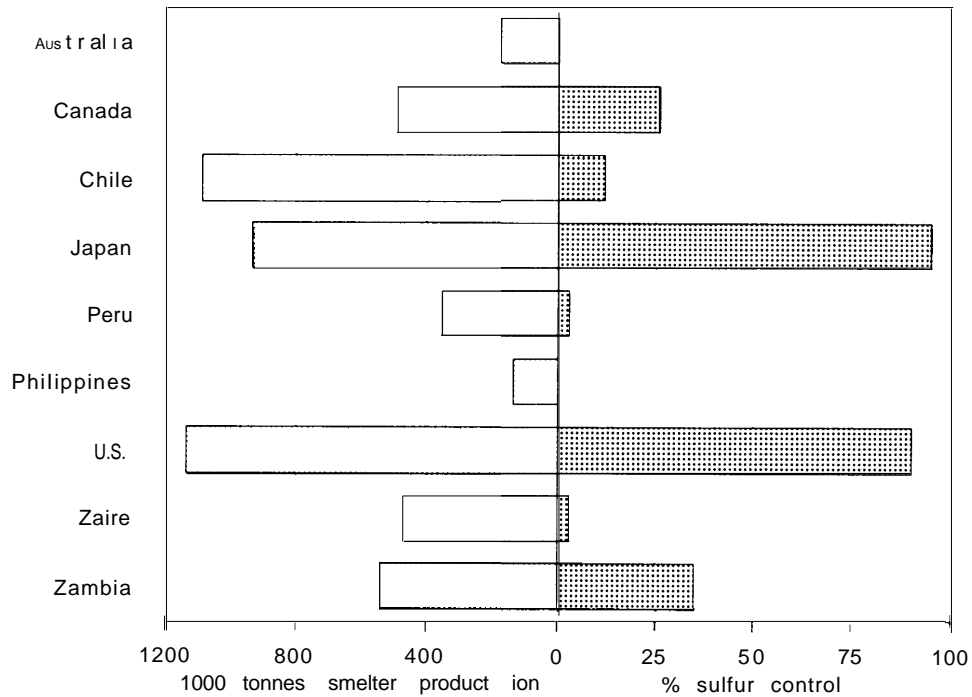
²⁷ SCS Engineers, *Summary of Damage Sites from the Disposal of Mining Wastes*, prepared for the U.S. Environmental Protection Agency, January 1984.

Figure 8-5.-Cost of SO₂ Removal with an Acid Plant



SOURCE: Jagdish C. Agarwal and Michael J. Loreth, "Preliminary Economic Analysis of SO₂ Abatement Technologies," *Sulfur Dioxide Control in Pyrometallurgy*, The Metallurgical Society of AIME, February 1981

Figure 8-6.-Sulfur Dioxide Control



SOURCE Duane Chapman, "The Economic Significance of Pollution Control and Worker Safety Costs for World Copper Trade," Cornell Agricultural Economics Staff Paper, Cornell University, Ithaca, New York, 1987.

The EPA administers four major legislative programs that could affect water quality control and waste disposal practices at domestic copper mining operations: 1) the Clean Water Act, which imposes effluent limitations on point sources (see table 8-4) and requires permits for the discharge of any effluent under the National Pollution Discharge Elimination System (NPDES); 2) the Resource Conservation and Recovery Act (RCRA), which regulates the generation, transport, and disposal of hazardous and solid wastes (see box 8-C); 3) Superfund, which assigns priorities for, and oversees the cleanup of, polluted sites; and 4) the Safe Drinking Water Act, which is designed to protect the quality of public drinking water supplies. In addition, new or substantially modified copper operations are subject to the National Environmental Policy Act of 1969 (N EPA), which requires Federal agencies to prepare an environmental impact statement (EIS) for any major Federal action (e.g., issuing a permit) that will signifi-

Table 8-4.—Effluent Limitations on Discharges from Mines, Mills, and Leach Operations^a

Effluent characteristic	Effluent limitations (mg/l)	
	Maximum for any one day	Average of daily values for 30 consecutive days
TSS	30.00	20.00
Cu	0.30	0.15
Zn	1.50	0.75
Pb	0.60	0.30
Hg	0.002	0.001
pH	6.0-9.0	6.0-9.0
Cd	0.10	0.05

^aLeaching Operations are expected to achieve zero discharge unless the annual precipitation exceeds the annual evaporation, in which case a volume of water equal to the amount exceeding annual evaporation may be discharged subject to NPDES limitations

SOURCE: *Ore Mining and Dressing Point Source Category Water Pollution Effluent Guidelines*, 40 CFR Ch.1 (7-1-85 edition)

icantly affect the environment. Tailings dams also are subject to Federal design standards to ensure public safety.

Although water quality control and waste management have not yet had the same finan-

Box 8-C.—The Resource Conservation and Recovery Act

Future regulation of mine wastes under the Resource Conservation and Recovery Act (RCRA) is of major concern to the domestic copper industry. Subtitle C of RCRA governs hazardous wastes, while subtitle D provides guidelines for non-hazardous solid and liquid wastes. In 1986, EPA decided that solid wastes from the mining and beneficiation of copper ores should not be regulated under Subtitle C of RCRA as hazardous, even though copper dump leach liquor, copper dump leach wastes, and tailings may exhibit hazardous characteristics of corrosiveness or Extraction Procedure (EP) toxicity.¹ The rationale for this decision was that the large volumes of mine waste would be very difficult to regulate under rules designed to manage much smaller amounts of industrial and municipal waste. Also, EPA reasoned that Subtitle C does not allow considerations of environmental necessity, technological feasibility, and economic practicality, which are important given the magnitude of mine waste.²

The cost of mine waste management under Subtitle C of RCRA would result in further closures of domestic mines and mills. EPA believes that concerns about actual and potential releases of hazardous contaminants from mine wastes can be addressed adequately by designing a regulatory program specific to such wastes under the more flexible Subtitle D solid waste management authority. Subtitle D gives EPA the authority to set waste management standards intended to protect surface and groundwater quality and ambient air quality. At the same time, it allows consideration of the varying geologic, hydrologic, climatic, population and other circumstances under which different waste management practices assure reasonable environmental protection.³

Critics of this approach argue that Subtitle D regulations do not fully address mine waste concerns, especially for hazardous wastes. In addition, based on information supplied largely by the mining industry, EPA is uncertain whether current waste management practices can prevent damage from seepage or sudden leaks.⁴

¹ The EP toxicity tests are an analytical technique used by EPA to predict the leaching potential of wastes.

² U.S. Environmental Protection Agency (EPA), *Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden from Uranium Mining and Oil Shale*, Report to Congress, December 1985, p. ES-13.

³ Non-Coal Mining Wastes To Be Regulated Under RCRA, But Not All Hazardous, EPA Says, *Environment Reporter*, July 4, 1986, pp 355-356.

⁴ Regulatory Determination for Wastes from the Extraction and Beneficiation of Ores and Minerals, *Federal Register*, July 3, 1986.

cial or capacity impact on the domestic copper industry as air pollution control, their costs are not insignificant. The U.S. nonferrous ore mining and dressing sector had a total capital investment of \$667 million in water pollution control between 1970 and 1981, with average annual costs of \$708 million.²⁸ Copper operations handle much larger amounts of material than other metal mining industries and generate considerably more solid waste, and a large share of this cost can be assigned to the domestic copper industry—perhaps as much as half. Data on foreign water pollution control practices were not available.

Pollutants of Concern

The mining and beneficiation of copper ore produces enormous volumes of liquid and solid

²⁸ MacDonnell, *supra* note 21.

waste. The EPA estimates that, between 1910 and 1981, all types of metallic ore mining and beneficiation in the United States generated a cumulative total amount of waste of more than 40 billion tonnes. Copper production accounts for roughly half of this total. In 1980, when U.S. copper mine production was 1 million tonnes, the domestic industry generated an estimated 282 million tonnes of mine waste, 241 million tonnes of tailings, and 200 million tonnes dump leach wastes.²⁹

Most of the copper mined in the United States comes from sulfide ores such as chalcopyrite and bornite—mineral compounds characterized by the linkage of sulfur with the metal(s) (see ch. 5).

²⁹ U. S. Environmental Protection Agency (EPA), *Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden from Uranium Mining, and Oil Shale*, Report to Congress, December 1985, p. ES-13.

Mining exposes the sulfides to water and air, causing a reaction that forms sulfuric acid and iron. The acidic effluents can dissolve and transport heavy and toxic metals from the solid waste or surrounding ground. Arsenic, lead, and cadmium are the metals of concern most commonly associated with copper ores. These toxic metals can accumulate in the environment and concentrate in the food chain, reaching levels that are toxic to both human and aquatic life. Removal and fracturing of rock and soil during mining also speeds up normal weathering processes and increases the load of sediments and fine solids transported by wind and water.

The EPA conducted a study to determine whether mine waste facilities leak and, if they do, whether they release contaminants of concern in significant quantities. Surface and groundwaters were monitored at eight active metal mine sites. Results indicated that constituents from impoundments do enter groundwater at most sites, but significant increases in concentrations of hazardous constituents were rarely demonstrated. so

On the other hand, court cases show that runoff and seepage have caused surface and groundwater contamination at active, inactive, and abandoned mine sites. Much of the damage was caused by outmoded disposal practices, but the relatively even distribution among the three types of facility status indicates that the problem is not associated solely with abandoned or inactive mine sites.³¹ Some sites may have been active for a long time, however, and while even there the problematic disposal practices are no longer in use, their effects may continue.

The potential for contamination of surface and groundwaters due to the activities of the copper industry varies widely depending on a variety of site-specific factors. The considerations discussed in box 8-D, and the chance that potential problems may not be identified by the current RCRA characterizations of wastes, led the EPA to believe that entirely different criteria may more appropriately identify the mining wastes most likely to be of concern.³²

³⁰Regulatory Determination for Wastes from the Extraction and Beneficiation of Ores and Minerals, Federal Register, July 3, 1986.

³¹SCS Engineers, *supra* note 27.

³²Federal Register, *supra* note 30.

Waste Management Practices

In the great majority of cases, potential adverse impacts from copper wastes can be controlled to acceptable levels with established waste management practices (see figure 8-7).

These practices can be summarized in three main categories: 1) minimization, collection, and treatment of mine drainage, mill process water, and contaminated surface drainage; 2) handling, storage, and ultimate disposal of tailings and waste rock; and 3) reclamation of the site to minimize long-term environmental effects once active mining has ceased.³³ Waste reprocessing and utilization is a fourth method that could offer many advantages over disposal, but the enormous volumes of waste preclude this from being a viable alternative to disposal.

Collection and Treatment of Liquid Wastes

Disposal of liquid wastes is rarely a problem as most water can be treated (if necessary to remove contaminants that would interfere with its use) and recycled for drilling, dust control, or process water at the mill. Indeed, such recycling can augment water supplies in the arid and semi-arid Southwest. Water containing relatively high concentrations of soluble metals can be used in the flotation circuits, which will precipitate the metals. Total suspended solids (including metals) in wastewater are controlled by building sediment control ponds, in which the water is held long enough for most of the sediment to settle. Sedimentation ponds must be designed with respect to predicted frequency and volume of discharge; a series of settling ponds can be used to improve the entrapment of sediment.

Mine Water.—Water can accumulate in surface mines and underground shafts due to hydraulic backfill operations; groundwater seepage into the mine; water use for machine operations including drilling, dust suppression, cooling, and air conditioning; sanitation and drinking water; and direct rainfall. Volumes vary widely depend-

³³Alan v. Bell, "Waste Controls at Base Metal Mines, *Environmental Science and Technology*, vol. 10, No. 2, February 1976, pp. 130-135.

Box 8-D.—Factors Affecting the Potential for Contamination

The Location of the Site.—Sites well removed from urban areas, drinking water supplies, surface waters, and sensitive ecosystems are not likely to pose high risks. Most active U.S. copper operations are in sparsely populated, arid areas where the transport of contaminants is limited by the scant annual precipitation.

The Climate.—Surface infiltration to groundwater is limited in arid and semiarid regions with little surface water. Almost 80 percent of copper sites are located in areas with a net annual recharge of less than two inches.¹ However, heavy storms could cause some leaching of the waste and result in acid flushes to the surrounding area.

The Hydrogeology of the Site.—The geologic structure of subsurface and related surface water systems may prevent contamination by effluents. For example, aquifers may be protected from effluents by thick layers of alluvium deposits or an impervious clay cap. EPA studies indicate that 70 percent of all mine waste sites (including copper) have groundwater depths greater than thirty feet, so there is time for the soil to mitigate any seepage that might occur. Other formations such as bedrock may divert effluents.

The Buffering Capacity of Soil.—Some copper ores in the southwestern United States are embedded in host rock of sedimentary limestone (calcium carbonate, CaCO_3 , is the chief constituent of limestone). As the effluent passes over or through limestone formations, it is partially neutralized, the pH increases, and some of the metals will precipitate out of the solution. The buffering capacity of limestone degrades over time. Other copper ores are formed in acid igneous deposits in which calcareous minerals are rare and acid formation potential is correspondingly high.

Removal Mechanisms in Surface Waters.—Alkalinity is described as the ability of water to neutralize acid. Bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) from adjacent limestone and feldspar formations are the principal sources of alkalinity in most surface waters. Alkalinity also tends to precipitate metals. Conditions may arise later that will re-solubilize the metals, however, and they can become a source of low level, nonpoint pollution for years to come. The real extent of the pollution is determined by the volume and velocity of the receiving waters. As with buffering by soils, the alkalinity of surface waters is finite.²

¹Recharge is the flow of water into subsurface areas, either from infiltration by precipitation or transport from adjacent groundwaters.

²Harry W. Martin and William R. Mills, *Water Pollution Caused by Inactive Ore and Mineral Mines—A National Assessment*, prepared for the EPA, December 1976.



Photo credit Jenifer Robison

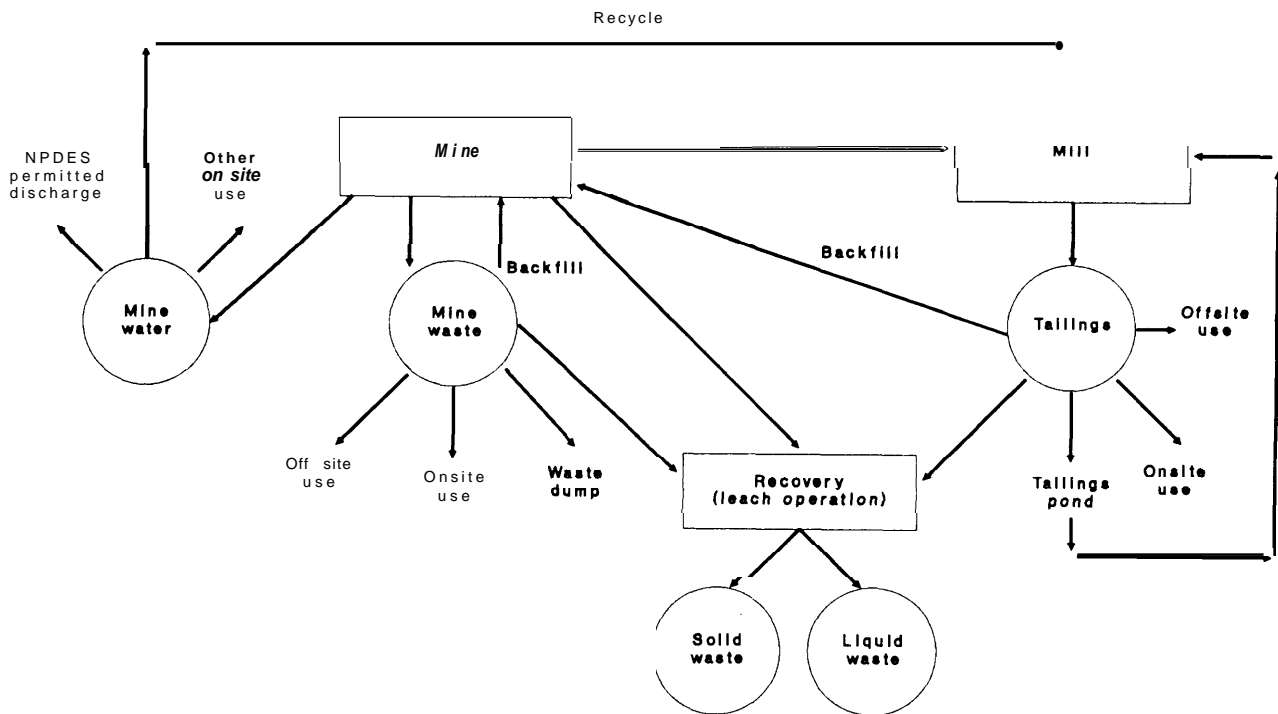
The arid climate, low population density, and other features of the Southwest mitigate the potential for surface and groundwater impacts from copper mining.

ing on mining methods, the climate, and the hydrogeological characteristics of the region.³⁴ Excess water usually is stored in natural drainage areas or in surface impoundments where it evaporates or is later used as process water.

Mill Process Water.—Water use in froth flotation is high (in Arizona, about 126,000 gallons per ton of copper produced); around 80 percent is recycled. Occasionally, a buildup of reagents in the process water will interfere with flotation, and it becomes necessary to discharge and replace the water. Any discharge is required to meet effluent limitations.

³⁴*Ibid.*

Figure 8-7.-Wastes and Management Practices



SOURCE: U.S. Environmental Protection Agency, *Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden from Uranium Mining and Oil Shale*, report to Congress, December 1985.



Photo credit: John E. Robison

Sediment control pond

Smelting and Refining.—Guidelines are being developed for effluents discharged from primary copper smelters, electrolytic copper refineries, and metallurgical acid plants. These limitations aim to control the amount of arsenic, cadmium,

copper, lead, zinc, and nickel in effluents; the pH of the discharge; and the concentration of total suspended solids. Treatment of wastewater from these sources is similar to that described above for mines and mills.

Leachate.—The seepage and leaking of sulfuric acid solutions could contaminate both surface and groundwater. However, this potential is offset by the miner's interest to collect as much of the copper-bearing leachate as possible. Leachate collection systems include hydraulic draws that exploit the natural slopes of the area, sumps located beneath the heap/dump, or a more sophisticated pumping system with secondary leachate collection to control contamination. Older operations generally do not have protective liners, and experience some loss of leachate. New leaching operations use impermeable membranes to confine leach solutions and channel them to a collection pond.³⁵

³⁵Stephen F. Walsh, "The San Manuel Oxide Open Pit Project," Presented to the Arizona Conference of AIME, Dec. 9, 1985.

Handling and Storage of Solid Wastes

As noted previously, solid wastes are generated during mining and milling, as well as smelting and converting. The primary pollution problem is the potential for sulfide minerals to form sulfuric acid, which in turn is capable of leaching metals from the wastes and the surrounding formations and transporting them to surface and groundwater systems.

Mine Waste.—Copper mining generates large volumes of waste rock and dirt, either from the material overlying the deposit (overburden), rock removed from underground mines while sinking shafts, ore that is too low in grade to be commercially valuable, and the rock interbedded with the ore body.³⁶ This distinguishes mining from many other process industries where wastes are a relatively small portion of the total materials used to produce a final product. Indeed, larger mines handle more material and generate more waste than many entire industries.³⁷

Although mine waste makes up the largest fraction of total solid waste from copper production, it has fewer stability and environmental problems than other solid wastes.³⁸ The waste typically is dumped in a pile near the mine site by the truck-

³⁶U.S. EPA, *supra* note 29.

³⁷Federal Register, *supra* note 30.

³⁸C. W. Center et al., *Development of Systematic Waste Disposal Plans for Metal and Nonmetal Mines*, Goodson and Associates, Inc., Aurora, Colorado, Prepared for the Bureau of Mines, June 1982, p. 14.

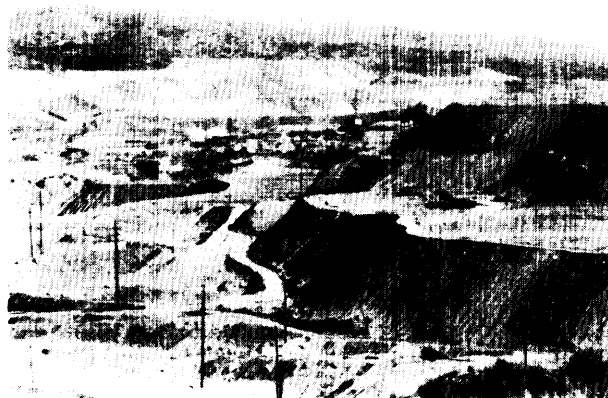


Photo credit Jenifer Robison

Copper mining generates large volumes of waste rock and dirt.

load. This usually produces steep slopes and some segregation of particle sizes, with the larger sizes relegated to the bottom of the coarse material. There may be some deliberate segregation of the waste to stockpile low grade ore for leaching operations.

Leach Waste.—Once leaching is discontinued, the heap/dump becomes leach waste, which can release acidic effluents, toxic metals, and total dissolved solids to the surrounding area. If the leach pile is in a recharge area, groundwater contamination could occur. The liners used in new leaching dumps continue to provide groundwater protection after closure, but older, unlined dumps may degrade surface and groundwater if steps are not taken to contain or prevent seepage.

Tailings.—Tailings differ from mine and leach waste in that they are very fine and they retain a certain amount of water after disposal. Fine particle sizes tend to liberate more contained toxics at a faster rate than coarser wastes. If future advances in processing include grinding ore more finely to increase metal recovery, tailings disposal will become even more complicated.

Seasonal or intermittent releases due to heavy rainfall and continuous seepage from groundwater infiltration are the most common mechanisms of tailings transport. Seepage can flush sulfates, dissolved solids, trace metals, and organics into groundwater. In older tailings, heavy rains can oxidize pyritic minerals and form an acidic effluent that is capable of mobilizing residual metals. Arsenic, cadmium, and lead are the toxics most frequently released from tailings ponds, although other trace metals such as copper, gold, silver, and zinc also may be released.³⁹

Miscellaneous Sludges and Dusts.—In this group of wastes, the sludges generated by sulfide precipitation (followed by sedimentation) are of greatest concern; EPA believes these will be classified as hazardous under RCRA, and considers the potential control costs achievable.⁴⁰ Other

³⁹SCS Engineers, *supra* note 27.

⁴⁰Nonferrous Metals Manufacturing Point Source Category: Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards; Final Rule, Federal Register, vol. 49, No. 47, Mar. 8, 1984.



Photo credit: Jenifer Robison

Copper tailings have a much finer texture than mine wastes.

miscellaneous wastes include sludges from acid plants (blowdown) and dusts from converters and reverberatory furnaces. Volubility tests have found these can leach copper, lead, zinc, and cadmium. They also contain antimony, arsenic, chromium, mercury, nickel, selenium, and silver. Slimes recovered from electrorefining cells tend to be rich in selenium, tellurium, arsenic, gold, silver, and platinum. The precious metals are recovered from the slime, but significant leaching of hazardous constituents from electrolytic refining lagoon sediments is also possible. These sediments settle from a combined slurry composed of effluents from spent electrolyte as well as contact cooling of furnaces, spent anode and cathode rinse water, plant washdown, and wet air pollution control.

Reclamation

Reclamation of tailings and mine waste dumps attempts to restore the area to a productive land use after closure and to provide long-term environmental protection. The land use is usually restricted to a self-sustaining vegetative cover that protects the surface from erosion⁴¹ Because most tailings transport mechanisms depend either directly or indirectly on water, reclamation techniques often focus on controlling and diverting water.

⁴¹ Richard C. Barth, "Reclamation Technology for Tailings Impoundments Part 1: Containment," *Mineral and Energy Resources*, vol. 29, No. 1, January 1986, p. 2.

Tailings transport due to wind erosion also can be a serious problem, especially when the tailings are inactive and dry out. Ambient air standards for total suspended particulate have been violated due to the heavy loading of tailings in the atmosphere.⁴² This erosion can be controlled by watering the tailings, maintaining a vegetative cover, applying a chemical sealant, or covering the tailings with waste rock or slag. In arid climates, waste rock covers are more frequently used because revegetation is difficult and expensive.

One reclamation technique common to all tailings and waste dumps is the application of a layer of topsoil or alluvial material to protect seedlings from glare and supply essential nutrients and microorganisms. This technique can be expensive; some topsoiling efforts have exceeded **\$65,000** per acre. Asarco has managed to top-

⁴²George J. Schewe, *Monitoring and Modeling Analyses of the Kennecott Corporation Smelter in McGill, Nevada*, PEDCo Environmental Inc Cincinnati, Ohio, March 1981,

soil their Arizona tailings successfully for an average cost of \$2,500 per acre.⁴³

Waste Reprocessing and Utilization

Tailings may be reprocessed to recover additional metals. This method may be particularly rewarding when dealing with older tailing piles from much less efficient beneficiation processes. Tailings also may be used onsite for mine backfill. There has been extensive research into the possibility of upgrading tailings to a salable product such as building materials (e.g., glass and bricks). However, tailings often are unsuitable for such materials because they are too fine, have poor drainage properties, and can be thixotropic (turn liquid when shaken).⁴⁴

⁴³Stuart A. Bengson, "Asarco's Revegetation of Mill Tailings and Overburden Wastes from Open Pit Copper Mining operations in Arizona," paper presented at the National Meeting for the American Society for Surface Mine Reclamation, Oct. 8-10, 1985, Denver, CO.

⁴⁴C.G. Down and John Stocks, "Positive Uses of Mill Tailings," *Mining Magazine*, September 1977 pp. 213-223