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EPA Office of Compliance Sector Notebook Project

Profile of the Metal Mining Industry

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Office of Compliance
Office of Enforcement and Compliance Assurance
U.S. Environmental Protection Agency
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EPA/310-R-95-009.	Motor Vehicle Assembly Industry	Suzanne Childress	564-7018
EPA/310-R-95-010.	Nonferrous Metals Industry	Jane Engert	564-5021
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LIST OF ACRONYMS

AFS - AIRS Facility Subsystem (CAA database)
AIRS - Aerometric Information Retrieval System (CAA database)
BIFs - Boilers and Industrial Furnaces (RCRA)
BOD - Biochemical Oxygen Demand
CAA - Clean Air Act
CAAA - Clean Air Act Amendments of 1990
CERCLA - Comprehensive Environmental Response, Compensation and Liability Act
CERCLIS - CERCLA Information System
CFCs - Chlorofluorocarbons
CO - Carbon Monoxide
COD - Chemical Oxygen Demand
CSI - Common Sense Initiative
CWA - Clean Water Act
D&B - Dun and Bradstreet Marketing Index
ELP - Environmental Leadership Program
EPA - United States Environmental Protection Agency
EPCRA Emergency Planning and Community Right-to-Know Act
FIFRA - Federal Insecticide, Fungicide, and Rodenticide Act
FINDS - Facility Indexing System
HAPs - Hazardous Air Pollutants (CAA)
HSDB - Hazardous Substances Data Bank
IDEA - Integrated Data for Enforcement Analysis
LDR - Land Disposal Restrictions (RCRA)
LEPCs - Local Emergency Planning Committees
MACT - Maximum Achievable Control Technology (CAA)
MCLGs - Maximum Contaminant Level Goals
MCLs - Maximum Contaminant Levels
MEK - Methyl Ethyl Ketone
MSDSs - Material Safety Data Sheets
NAAQS - National Ambient Air Quality Standards (CAA)
NAFTA - North American Free Trade Agreement
NCDB - National Compliance Database (for TSCA, FIFRA, EPCRA)
NCP - National Oil and Hazardous Substances Pollution Contingency Plan
NEIC - National Enforcement Investigation Center
NESHAP - National Emission Standards for Hazardous Air Pollutants

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LIST OF ACRONYMS (CONT'D)

NO_X - Nitrogen Oxide
NOV - Notice of Violation
NPDES - National Pollution Discharge Elimination System (CWA)
NPL - National Priorities List
NRC - National Response Center
NSPS - New Source Performance Standards (CAA)
OAR - Office of Air and Radiation
OECA - Office of Enforcement and Compliance Assurance
OPA - Oil Pollution Act
OPPTS - Office of Prevention, Pesticides, and Toxic Substances
OSHA - Occupational Safety and Health Administration
OSW - Office of Solid Waste
OSWER - Office of Solid Waste and Emergency Response
OW - Office of Water
P2 - Pollution Prevention
PCS - Permit Compliance System (CWA Database)
POTW - Publicly Owned Treatments Works
RCRA - Resource Conservation and Recovery Act
RCRIS - RCRA Information System
SARA - Superfund Amendments and Reauthorization Act
SDWA - Safe Drinking Water Act
SEPs - Supplementary Environmental Projects
SERCs - State Emergency Response Commissions
SIC - Standard Industrial Classification
SO_2 - Sulfur Dioxide
SX/EW - Solvent Extraction/Electrowinning
TRI - Toxic Release Inventory
TRIS - Toxic Release Inventory System
TRIS - Toxic Chemical Release Inventory System
TSCA - Toxic Substances Control Act
TSS - Total Suspended Solids
UIC - Underground Injection Control (SDWA)
UST - Underground Storage Tanks (RCRA)
VOCs - Volatile Organic Compounds

METAL MINING
(SIC 10)

I. INTRODUCTION TO THE SECTOR NOTEBOOK PROJECT

I.A. Summary of the Sector Notebook Project

Environmental policies based upon comprehensive analysis of air, water, and land pollution are an inevitable and logical supplement to traditional single-media approaches to environmental protection. Environmental regulatory agencies are beginning to embrace comprehensive, multi-statute solutions to facility permitting, enforcement and compliance assurance, education/outreach, research, and regulatory development issues. The central concepts driving the new policy direction are that pollutant releases to each environmental medium (air, water, and land) affect each other, and that environmental strategies must actively identify and address these inter-relationships by designing policies for the "whole" facility. One way to achieve a whole facility focus is to design environmental policies for similar industrial facilities. By doing so, environmental concerns that are common to the manufacturing of similar products can be addressed in a comprehensive manner. Recognition of the need to develop the industrial "sector-based" approach within the EPA Office of Compliance led to the creation of this document.

The Sector Notebook Project was initiated by the Office of Compliance within the Office of Enforcement and Compliance Assurance (OECA) to provide its staff and managers with summary information for eighteen specific industrial sectors. As other EPA offices, States, the regulated community, environmental groups, and the public became interested in this project, the scope of the original project was expanded. The ability to design comprehensive, common sense environmental protection measures for specific industries is dependent on knowledge of several inter-related topics. For the purposes of this project, the key elements chosen for inclusion are: general industry information (economic and geographic); a description of industrial processes; pollution outputs; pollution prevention opportunities; Federal statutory and regulatory framework; compliance history; and a description of partnerships that have been formed between regulatory agencies, the regulated community, and the public.

For any given industry, each topic listed above could alone be the subject of a lengthy volume. However, in order to produce a manageable document, this project focuses on providing summary information for each topic. This format provides the reader with a synopsis of each issue, and references where more in-depth information is available. Text within each profile was researched from a variety of sources, and was usually condensed from more detailed sources pertaining to specific topics. This approach allows for a wide coverage of activities that can be further explored based upon the citations and references listed at the end of this profile. As a check on the information included, each notebook went through an external review process. The Office of Compliance appreciates the efforts of all those that participated in this process and enabled us to develop more complete, accurate, and up-to-date summaries. Many of those who reviewed this notebook are listed as contacts in Section IX and may be sources of additional information. The individuals and groups on this list do not necessarily concur with all statements within this notebook.

I.B. Additional Information

Providing Comments

OECA's Office of Compliance plans to periodically review and update the notebooks and will make these updates available both in hard copy and electronically. If you have any comments on the existing notebook, or if you would like to provide additional information, please send a hard copy and computer disk to the EPA Office of Compliance, Sector Notebook Project, 401 M St., SW (2223-A), Washington, DC 20460. Comments can also be uploaded to the Enviroene Bulletin Board or the Enviroene World Wide Web for general access to all users of the system. Follow instructions in Appendix A for accessing these data systems. Once you have logged in, procedures for uploading text are available from the on-line Enviroene Help System.

Adapting Notebooks to Particular Needs

The scope of the existing notebooks reflect an approximation of the relative national occurrence of facility types that occur within each sector. In many instances, industries within specific geographic regions or States may have unique characteristics that are not fully captured in these profiles. For this reason, the Office of Compliance encourages State and local environmental agencies and other groups to supplement or re-package the information included in this notebook to include more specific industrial and regulatory information that may be available. Additionally, interested States may want to supplement the "Summary of Applicable Federal Statutes and Regulations" section with State and local requirements. Compliance or technical assistance providers may also want to develop the "Pollution Prevention" section in more detail. Please contact the appropriate specialist listed on the opening page of this notebook if your office is interested in assisting us in the further development of the information or policies addressed within this volume.

If you are interested in assisting in the development of new notebooks for sectors not covered in the original eighteen, please contact the Office of Compliance at 202-564-2395.

Because this profile was not intended to be a stand-alone document concerning the metal mining industry, appended is a full reference of additional EPA documents and reports on this subject, as listed in the March edition of the Federal Register.

II. INTRODUCTION TO THE METAL MINING INDUSTRY

This section provides background information on the size, geographic distribution, employment, production, sales, and economic condition of the metal mining industry. The type of facilities described within the document are also described in terms of their Standard Industrial Classification (SIC) codes.

II.A. Introduction, Background, and Scope of the Notebook

The metal mining industry includes facilities engaged primarily in exploring for metallic minerals, developing mines, and ore mining. These ores are valued chiefly for the metals they contain, which are recovered for use as constituents of alloys, chemicals, pigments, or other products. The industry sector also includes ore dressing and beneficiating operations. The categorization corresponds to the Standard Industrial Classification (SIC) code 10, published by the Department of Commerce to track the flow of goods and services within the economy.

The SIC 10 group consists of the following three-digit breakout of industries:

SIC 101 - Iron Ores
SIC 102 - Copper Ores
SIC 103 - Lead and Zinc Ores
SIC 104 - Gold and Silver Ores
SIC 106 - Ferroalloy Ores, Except Vanadium
SIC 108 - Metal Mining Services
SIC 109 - Miscellaneous Metal Ores.

Although the group includes all metal ore mining, the scope of mining industries with a significant domestic presence is concentrated in iron, copper, lead, zinc, gold, and silver. These represent the most common hardrock minerals mined domestically, and comprise an essential sector of the nation's economy by providing basic raw materials for major sectors of the U.S. economy. In addition, the extraction and beneficiation of these minerals generate large amounts of wastes. For these reasons, this profile's focus is limited to the above-stated sectors of the SIC 10 metal mining industry.

While such metals as molybdenum, platinum, and uranium are also included in SIC code 10, mining for these metals does not constitute a significant portion of the overall metal mining industry, nor of the waste generation in mining processes; these metals are therefore excluded from this profile.

In the global market, the U.S. is a major producer of iron, copper, lead, zinc, gold, and silver. In 1993, domestic mines were responsible for six percent of iron ore production, 13 percent of copper ore production, 13 percent of lead production, eight percent of zinc production, 14 percent of gold production, and 11 percent of silver production. Despite an extraordinary wealth of domestic metal sources, with the exception of gold, the U.S. is a net importer of all the above-mentioned metals.

Regulations pertaining to the industry are numerous, but an emphasis is placed on point source discharges to waters, regulated by the Clean Water Act. These industries also face existing and future regulation under the Clean Water Act, Comprehensive Environmental Response, Compensation and Liability Act, and the Clean Air Act. Unlike manufacturing facilities, facilities involved in mining metals are not currently required to report chemical releases and transfers to the Toxic Release Inventory (TRI) Public Release Database under the Emergency Planning and Community Right-To-Know Act of 1986. As a result, TRI data is not available as a source of information on chemical releases in the metal mining industry; alternative sources of data have been identified for purposes of this profile.

II.B. Characterization of the Metal Mining Industry

The metal mining industry is predominantly located in the Western States, where most copper, silver, and gold mining occurs. Iron ore production is centered in the Great Lakes region, while zinc mining occurs in Tennessee and lead mining in Missouri. Large companies tend to dominate mining of such metals as copper, silver, and gold, while more diverse mine operators may be involved in mining lead, zinc, and iron metals. Metals generated from U.S. mining operations are used domestically in a wide range of products, including automobiles, electrical and industrial equipment, jewelry, and photographic materials. Metal mine production has remained somewhat stagnant over recent years, and metals exploration has declined, although future production is expected to climb as a result of continued industrial manufacturing and a growing economy.

The following exhibit depicts the proportion of metal mining production within the entire mining industry.

Exhibit 1
Total Mine Production - USA, in Billions of Dollars

Source: Randol Mining Directory 1994/95.

II.B.1. Industry Size and Distribution

Variation in facility counts occur across data sources due to many factors, including reporting and definition differences. This document does not attempt to reconcile these differences, but rather reports the data as they are maintained by each source.

Geographic Distribution

Though mining operations are performed throughout the U.S., the concentration of metal mining is located in the Western region of the country. Copper, gold, and silver deposits are primarily found in Utah, Montana, Nevada, California, and Arizona. Zinc is mined primarily in Alaska, Missouri, New York, and Tennessee. Lead deposits are mined primarily in Missouri, Alaska, Colorado, Idaho, and Montana, while Minnesota and Michigan are the primary sources of domestic iron ore production. The U.S. Bureau of Mines lists 482 active mines in its 1994 Mineral Commodity Summaries. (See Exhibits 2, 3, and 4). Exhibit 5 illustrates the number of facilities performing metal-specific operations by State.

Exhibit 2
Geographic Distribution of Industry

Source: Based on U.S. Bureau of Mines 1992 and 1994 Data.

Exhibits 3 & 4
Metal-Producing Areas

Exhibit 5
Number of Facilities per State

Type of Facility/ Total Number	States and Number of Mines
Iron Ore (22)	MI-2; MN-7; MT-1; SD-1; TX -2; UT-2
Silver (150)	AK-15; AZ-15; CA-14; CO-4; ID-12; MI-1; MT-9; NV-1; NY-1; OR-1; SC-3; SD-4; UT-4; WA-4
Gold (212)	AK-13; AZ-14; CA-19; CO-7; ID-11; MT-9; NM-5; NV-61; OR-2; SC-4; SD-5; WA-4; UT-2
Lead (23)	AK-2; AZ-1; CO-2; ID-1; IL-1; MO-7; MT-2; NM-2; NY-2; TN-2; WA-1
Zinc (25)	AK-3; CO-1; ID-2; MO-4; MT-1; NY-2; TN-10; WA-1
Copper (50)	AZ-16; CO-2; ID-3; MI-3; MO-2; MT-3; NM-9; NV-1; OR-1; UT-1

Source: U.S. Bureau of Mines 1992 and 1994 Data.

Metals mined under SIC 10 are used for a wide variety of products, and are the primary raw materials used in many industrial applications. As noted in a series of Technical Resource Documents prepared by EPA's Office of Solid Waste, copper is essential to the electronics and construction industry; iron ore provides the base material for the steel, automotive, and transportation industries; gold is used primarily in jewelry and the decorative arts, but is also used in the electronics industry and in dentistry. Gold also serves as an important investment vehicle and reserve asset. All of these metals are essential to the operation of a modern economy. Exhibit 6 provides a more detailed list of the uses for these metals.

Exhibit 6
Major Uses for Selected Metal Minerals

Commodity	Number of Mines	Major Uses	Total U.S. Production (metric tons)
Copper	50	Building construction, electrical and electronic products, industrial machinery and equipment, transportation equipment, and consumer and general products	1,765,000
Gold	212+	Jewelry and arts, industrial (mainly electronic), dental	329
Iron Ore	22	Steel	55,593,000
Lead	23	Transportation (batteries, fuel tanks, solder, seals, and bearings); electrical, electronic, and communications uses	398,000
Silver	150	Photographic products, electrical and electronic, electroplated ware, sterling ware, and jewelry	1,800
Zinc	25	Galvanizing, diecast alloys, brass, and bronze	524,000

Source: U.S. Bureau of Mines, Mineral Commodity Summaries 1994, and Minerals Yearbook, Volume I: Metals and Minerals, 1992.

II.B.2. Economic Trends

The estimated U.S. metal mine production value for 1993 was $12.15 billion, accounting for less than one percent of gross national product. In 1993, the total employment in the metal mining industry stood at nearly 50,000 according to the National Mining Association (See Exhibit 7 for the distribution of employment by facility size). Motor vehicle manufacturing helped support demand for materials such as steel (an iron alloy), copper, lead, and zinc. However, mining production volumes remained relatively stagnant. In some cases, ore production was down (lead - four percent; iron ore - one percent; zinc - four percent; silver - six percent). The other principal metal ore industries, copper and gold, remained even with 1992 production levels. Metals production in general is expected to increase, due to anticipated continued growth in the motor vehicle industry.

Exhibit 7
Facility Size Distribution

Type of Facility*	Facilities w/ 1 - 9 employees	Facilities w/ 10 - 99 employees	Facilities w/ 100 + employees	Total
SIC 1021 - Copper	102	30	24	156
SIC 1031 - Lead and Zinc	40	8	16	64
SIC 1041 - Gold	586	122	53	761
SIC 1011 - Iron	81	14	11	106
SIC 1044 - Silver	73	9	2	84

Source: Dun and Bradstreet, 1993.

**Note: Sources define the term "facility" differently, which causes the apparent disparity between those totals cited above and those accounted for by the U.S. Bureau of Mines. Represented in these facility numbers are recreational mine operators predominantly located in Alaska, California, and Montana.*

A preliminary evaluation of 1992 survey responses from 36 Canadian and 25 U.S. mineral companies operating in the U.S. suggests that the average corporate exploration budget was reduced by more than one-half from 1991 levels. Metal exploration in the U.S. during 1992 appears to have declined on an average company basis by more than 60 percent. Although specific gold and copper deposits continue to command attention, most U.S. programs have been curtailed. The BLM estimated that 75 percent of company claims were dropped during 1993 (Federal mining law grants sole mineral rights to a prospector if there is a discovery of economic value; prior to such a discovery, a "claim" is honored if the prospector maintains an actual presence on site and completes a progressive amount of developmental work per year).

The number of companies that have shifted portions of their exploration budgets to Latin America is growing. More than 250 companies, about 10 percent of the North American mining exploration industry, are now active in Latin America, especially Mexico and Chile. Among the forces driving U.S. companies abroad is the recent privatization of world-class mineral deposits, the presence of rich overseas ore deposits, depletion of prime domestic ore sources, labor costs, and the lack of significant regulatory pressure in the developing world.

The U.S. economy's slow but steady growth rate of the last several years is expected to spur demand in major domestic materials-consuming industries, such as the auto industry. In addition, developing economies in South America and Asia have had higher consumption of mineral materials as political regimes have liberalized their economies to meet demands for higher standards of living.

The following exhibit illustrates production values in 1993 for various metal mining industry sectors.

Exhibit 8
Metal Mine Production - USA, in Billions of Dollars

Source: Randol Mining Directory 1994/95.

Following is a brief summary of current trends in domestic mining industries. Much of the information presented is based on a report prepared by EPA's Office of Research and Development.

Iron

In 1993, domestic production of iron ore remained at approximately the same level as that of 1992. The value of usable ore shipped from mines in Minnesota, Michigan, and six other States in 1993 was estimated at $1.7 billion. Iron ore was produced domestically by 16 companies operating 22 mines, 16 concentration plants, and 10 pelletizing plants. The mines included 19 open pits and one underground operation. Nine of these mines, operated by six companies, accounted for the vast majority of the output.

The U.S. steel industry was the primary consumer of iron ore, accounting for 98 percent of domestic iron ore consumption in 1992. Domestic demand for iron ore has fallen behind that for iron and steel due to changes in industrial processes, including the increased use of scrap (especially by mini-mills) and the use of imported semi-finished steel. Twelve percent of domestic iron consumption in 1993 was imported. While world consumption of iron ore increased slightly, prices declined for the third consecutive year.

Copper

World copper production remained at approximately the same level in 1993 as in 1992, while world consumption of refined copper declined. However, refined copper demand in the U.S. and Canada ran counter to the world trend. Domestic demand for copper rose by approximately eight percent in 1993; the U.S. imported six percent of its copper needs in 1993. Consumption was expected to increase in 1994 to more than 2.4 million tons, up from the previous year's 2.3 million tons. Domestic brass mills (a mixture of copper and zinc) ran at capacity.

Copper was recovered at 50 mines in 1993, and the top 15 mines accounted for more than 95 percent of production. The primary end uses for copper are building construction (42 percent), electrical and electronic products (24 percent), industrial machinery and equipment (13 percent), transportation equipment (11 percent), and consumer and general products (10 percent).

According to Standard & Poor's, the copper mining industry is dominated by three producers (ASARCO Incorporated, Cyprus Amax Mining Company, and Phelps Dodge), which are financially viable operations. However, not all copper mining firms are as healthy financially. From 1989 to 1992, the industry was characterized by decreasing operating revenues and net income, while short and long-term liabilities increased for some companies. With the recent economic recovery, however, the overall outlook for the copper industry is financially secure.

Lead

The U.S. imported 15 percent of its lead needs in 1993. Transportation is the major end use for lead, with approximately 83 percent being used to produce batteries, fuel tanks, solder, seals, and bearings. Electrical, electronic, and communications uses, ammunition, TV glass, construction, and protective coatings accounted for more than nine percent of lead consumption.

According to the U.S. Bureau of Mines, U.S. lead production has remained relatively constant through 1994, while prices for lead continued an upward trend that began in 1993. Consumption of lead in the U.S. increased in 1994, due to greater demand for original equipment batteries in the automotive industry. This trend is expected to continue.

Zinc

In 1993, the U.S. imported 26 percent of its zinc needs. Domestically, 25 zinc mines produced 99 percent of the output; Alaska's Red Dog Mine accounted for nearly one-half of the total. Zinc's main use has traditionally been to provide corrosion protection through galvanization for iron and steel. In 1991, the largest consumers of zinc were the construction (43 percent), transportation (20 percent), machinery (12 percent), and electrical (12 percent) sectors.

Domestic mine production increased substantially in 1994 in response to domestic demand, according to the U.S. Bureau of Mines. The largest growth occurred in the galvanizing and brass and bronze industries, due to increased automobile production. Exports of zinc concentrates were up slightly in 1994.

Gold

Domestic gold mines continue to produce at record levels, maintaining the U.S. position as the world's second largest gold-producing nation (12 percent of world resources), after the Republic of South Africa. The U.S was a net exporter of gold in 1993. Gold was produced at 200 lode mines and numerous placer mines (see discussion below for definition of lode and placer mines). Twenty-five mines yielded 75 percent of the gold produced. Estimated end-uses for 1993 were as follows: jewelry and arts (70 percent); industrial (mainly electronic; 23 percent); and dental (seven percent).

The gold mining industry is dominated by a few firms that are gaining an increasing portion of the market share and that remain financially strong. Smaller firms have seen decreasing operating revenues and net incomes, and may have greater difficulty in the future meeting short-term debt. The trend in gold exploration activities continues to be toward Latin American nations, where favorable geology and liberalized mining regulations hold the promise for greater long-term success and reduced risk to investment capital.

Silver

Continuing the trend begun in 1991, several large domestic silver producers halted mining operations in 1993 due to the continuing low price of silver. As a result, U.S. mine production of silver declined for the fourth consecutive year, and three major silver producers had negative net income. Silver prices have recently begun to rise, however; with the prospect of continued higher prices, some companies are considering resuming operations at currently inactive mines.

The U.S. is a net importer of silver. One hundred and fifty mines in 14 States mined silver in 1993. However, Nevada, Idaho, Arizona, and Montana accounted for 74 percent of all domestic production. Estimated end-uses for 1993 were as follows: photographic products (50_percent); and electrical and electronic products (20 percent).

III. Industrial Process Description

This section describes the major industrial processes within the metal mining industry, including the materials and equipment used, and the processes employed. The section is designed for those interested in gaining a general understanding of the industry, and for those interested in the inter-relationship between the industrial process and the topics described in subsequent sections of this profile -- pollutant outputs, pollution prevention opportunities, and Federal regulations. This section does not attempt to replicate published engineering information that is available for this industry. Refer to Section IX for a list of available reference documents.

This section describes commonly used production processes, associated raw materials, the byproducts produced or released, and the materials either recycled or transferred off-site. This discussion, coupled with schematic drawings of the identified processes, provide a concise description of where wastes may be produced in the process. This section also describes the potential fate (air, water, land) of these waste products.

III.A. Industrial Processes in the Metal Mining Industry

Much of the following information has been presented previously in reports and issue papers drafted in support of various EPA offices, including the Office of Solid Waste, the Office of Pollution Prevention and Toxics, and the Office of Enforcement and Compliance Assurance. For a complete listing of reference documents, please see Section IX.

Metals are mined from two types of deposits. The first, lode deposits, are concentrated deposits that are fairly well-defined from surrounding rock. Iron, copper, lead, gold, silver, and zinc are mined mainly from lode deposits. The second type of deposits, placer deposits, occur with sand, gravel, and rock; they are usually deposited by flowing water or ice, and contain metals that were once part of a lode deposit. Only a small percentage of domestic gold and silver is derived from placer deposits.

There are three general approaches to mining metals:

Surface or **open-pit mining** requires extensive blasting, as well as rock, soil, and vegetation 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 milling and beneficiating plants for concentrating the ore, and smelting, and/or refining. Open pit mining is the primary domestic source of iron, copper, gold, and silver.

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 removed to the surface, crushed, concentrated, and refined. While underground mines do not create the volume of overburden waste 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. In the U.S., only lead, antimony, and zinc are solely underground operations.

Solution or fluid mining entails drilling into intact 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. This method of mining is used in some parts of Arizona, Nevada, and New Mexico to recover copper.

Historically, the primary mining method has been underground mining. However, with the advent in recent decades of large earth moving equipment, less expensive energy sources, and improved extraction and beneficiation technologies, surface mining now prevails in most industry sectors. Open-pit mining is generally more economical and safer than underground mining, especially when the ore body is large and the overburden (surface vegetation, soil, and rock) relatively shallow. In fact, the lower cost of surface mining has allowed much lower-grade ores to be exploited economically in some industry sectors.

Metal mining processes include extraction and beneficiation steps during production. Extraction removes the ore from the ground, while beneficiation concentrates the valuable metal in the ore by removing unwanted constituents. Often, more than one metal is targeted in beneficiation processes. For example, silver is often beneficiated and recovered with copper. The beneficiation method selected varies with mining operations and depends on ore characteristics and economic considerations.

The following sections provide more detail on extraction methods and beneficiation processes, as they relate to the mining of each metal.

Extraction Processes

As described in a report drafted for EPA's Office of Pollution Prevention and Toxics, extraction involves removing any overburden, then drilling, blasting, and mucking the broken ore and waste rock.

Mobile rigs drill holes in rock, which can then be filled with explosives for blasting waste rock and ore. Potential pollutants involved in this step in the mining process include the fuel, lubricants, and hydraulic oils consumed by the rigs; fuels and oils typically contain such constituents as benzene, ethylbenzene, and toluene.

Explosives (usually a mixture of ammonium nitrate and fuel oil) are used to break up the rock. Other explosives, including trinitrotoluene (TNT) and nitroglycerine, may also be used.

Mucking is the process of removing broken ore from the mine, using a variety of loading and hauling equipment to transport ore to a mill for beneficiation. Depending on ore volume, trucks, rail cars, conveyers, and elevators may all be required to haul ore. Equipment involved in this step of the mining process uses hydraulic fluid (containing glycol ethers); batteries (containing sulfuric acid, lead, antimony, and arsenic); and lubricants and fuel (containing petroleum hydrocarbons).

Beneficiation Methods

Ore beneficiation is the processing of ores to regulate the size of the product, to remove unwanted constituents, or to improve the quality, purity, or grade of a desired product. Under regulations drafted pursuant to the Resource Conservation and Recovery Act (40 CFR §261.4), beneficiation is restricted to the following activities: crushing; grinding; washing; dissolution; crystallization; filtration; sorting; sizing; drying; sintering; pelletizing, briquetting; calcining to remove water and/or carbon dioxide; roasting, autoclaving, and/or chlorination in preparation for leaching; gravity concentration; magnetic separation; electrostatic separation; flotation; ion exchange; solvent extraction; electrowinning; precipitation; amalgamation; and heap, dump, vat, tank, and *in situ* leaching.

The most common beneficiation processes include gravity concentration (used only with placer gold deposits); milling and floating (used for base metal ores); leaching (used for tank and heap leaching); dump leaching (used for low-grade copper); and magnetic separation. Typical beneficiation steps include one or more of the following: milling; washing; filtration; sorting; sizing; magnetic separation; pressure oxidation; flotation; leaching; gravity concentration; and agglomeration (pelletizing, sintering, briquetting, or nodulizing).

Milling extracted ore produces uniform-sized particles, using crushing and grinding processes. As many as three crushing steps may be required to reduce the ore to the desired particle size. Milled ore in the form of a slurry is then pumped to the next beneficiation stage.

Magnetic separation is used to separate iron ores from less magnetic material, and can be classified as either high- or low-intensity (requiring as little as 1,000 gauss or as much as 20,000). Particle size and the solids content of the ore slurry determine which type of magnetic separator system is used.

Flotation uses a chemical reagent to make one or a group of minerals adhere to air bubbles for collection. Chemical reagents include collectors, frothers, antifoams, activators, and depressants; the type of reagent used depends on the characteristics of a given ore. These flotation agents may contain sulfur dioxide, sulfuric acid, cyanide compounds, cresols, petroleum hydrocarbons, hydrochloric acids, copper compounds, and zinc fume or dust.

Gravity concentration separates minerals based on differences in their gravity. The size of the particles being separated is important, thus sizes are kept uniform with classifiers (such as screens and hydrocyclones).

Thickening/filtering removes most of the liquid from both slurried concentrates and mill tailings. Thickened tailings are discharged to a tailings impoundment; the liquid is usually recycled to a holding pond for reuse at the mill. Chemical flocculants, such as aluminum sulfate, lime, iron, calcium salts, and starches, may be added to increase the efficiency of the thickening process.

Leaching is the process of extracting a soluble metallic compound from an ore by selectively dissolving it in a solvent such as water, sulfuric or hydrochloric acid, or cyanide solution.

The desired metal is then removed from the "pregnant" leach solution by chemical precipitation or another chemical or electrochemical process. Leaching methods include "dump," heap," and "tank" operations. Heap leaching is widely used in the gold industry, and dump leaching in the copper industry.

The following exhibit summarizes the various processes used within each mining sector, and the primary wastes associated with those processes.

Exhibit 9
Sector-Specific Processes and Wastes/Materials

Sector	Mining Type	Beneficiation/Processing	Primary Wastes/Materials
Gold-Silver	• Surface • Underground • *In Situ* (experimental)	• Cyanidation • Elution • Electrowinning/zinc precipitation • Milling • Base metal flotation • Smelting • Amalgamation (historic)	• Mine water * • Overburden/waste rock • Spent process solutions • Tailings • Spent Ore
Gold Placer	• Surface	• Gravity separation •Roughing, cleaning, fine separation • Some magnetic separation	• Mine water* • Overburden/waste rock • Tailings
Lead-Zinc	• Underground (exclusively)	• Milling • Flotation • Sintering • Smelting	• Mine water* • Overburden/waste rock • Tailings • Slag
Copper	• Surface • Underground • *In Situ*	• Milling • Flotation • Smelting • Acid leaching • SX/EW recovery • Iron precipitation/smelting	• Mine water* • Overburden/waste rock • Tailings • Slag • Spent ore • Spent leach solutions
Iron	• Surface (almost exclusively) • Underground	• Milling • Magnetic separation • Gravity separation • Flotation • Agglomeration • Blast furnace	• Mine water* • Overburden/waste rock • Tailings • Slag

** Note: Mine water is a waste if it is discharged to the environment via a point source*
Source: U.S. EPA, Office of Solid Waste, Technical Document, Background for NEPA Reviewers: Non-Coal Mining Operations.

Below is a more detailed discussion of the various beneficiation methods and processes used for each of the sectors presented in the table above.

Iron Ore

Typical beneficiation steps applied to iron ore include: milling, washing, sorting, sizing, magnetic separation, flotation, and agglomeration. Milling followed by magnetic separation is the most common beneficiation sequence used, according to the American Iron Ore Association. Flotation is primarily used to upgrade the concentrates generated from magnetic separation, using frothers, collectors, and antifoams.

Steel mills generally agglomerate or pelletize the iron ore concentrates to improve blast furnace operations that utilize iron ore. Pelletizing operations produce a moist pellet (often using clay as a binder), which is then hardened through heat treatment. Agglomeration generates by-products in the form of particulates and gases, including compounds such as carbon dioxide, sulfur compounds, chlorides, and fluorides. These emissions are usually treated using cyclones, electrostatic precipitators, and scrubbing equipment. These treatment technologies generate iron-containing effluent, which is recycled into the operation. Agglomeration produces large volumes of sulfur dioxide and nitrogen dioxide.

Copper

Copper is commonly extracted from surface, underground, and, increasingly, from *in situ* operations. According to the U.S. Bureau of Mines, surface mining accounted for 83 percent of copper production in 1992, with underground mining accounting for the remainder. *In situ* mining is the practice of percolating dilute sulfuric acid through ore to extract copper, by pumping copper-laden acid solutions to the surface for solvent extraction/electrowinning (SX/EW). This leaching operation uses both ammonium nitrate and sulfuric acid.

Beneficiation of copper 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. 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/electrowinning is generally used for the other half. Often, more than one metal is the target of beneficiation activities (silver, for example, is often recovered with copper).

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 or 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 and its use is still being piloted.

Dump leaching is a method of treating copper ore that has been extracted from a deposit, and refers to the leaching of oxide and low-grade sulfide ore on (typically) unlined surfaces. These operations involve the application of leaching solution, collection of pregnant leach solution (PLS), and the 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.

The solvent extraction process is a two-stage method; in the first stage, low-grade, impure leach solutions containing copper, iron, and other base-metal ions are fed to the extraction stage mixer-settler. In the mixer, the aqueous solution contacts an active organic extractant in an organic diluent (usually kerosene), forming a copper-organic complex; impurities are left behind in the aqueous phase. The barren aqueous solution, called raffinate, is typically recirculated back to the leaching units while the loaded organic solution is transferred from the extraction section to the stripping section. In the second stage, the loaded organic solution is stripped with concentrated sulfuric acid solution to produce a clean, high-grade solution of copper for electrowinning. Electrowinning is the method used to recover copper from the electrolyte solution produced by solvent extraction.

Exhibits 10 and 11 illustrate a typical dump leach operation and a representative solution-based process for recovering copper from ore. Variations exist in exact methods and processes used at each operation.

Exhibit 10
Copper Dump Leach Operation

Exhibit 11
Representative Hydrometallurgical Recovery of Copper

Source: Technical Resource Document: Extraction and Beneficiation of Ores and Minerals, Volume 4, Copper, August 1994 U.S. EPA.

Lead and Zinc

Beneficiation of lead and zinc ores includes crushing and grinding; filtration; sizing; flotation; and sintering of concentrates. Flotation is the most common method for concentrating lead-zinc minerals. Ore may be treated with conditioners during or after milling to prepare the ore pulp for flotation. Common conditioners may include lime, soda ash, caustic soda, or sulfuric acid. The conditioned ore is then slurried in fresh or salt water with chemical reagents to beneficiate the ore. Several separate flotation steps may be needed to concentrate individual metal values from the ore. Reagents used in the flotation processes typically include such chemicals as sulfur dioxide, zinc sulfate, coal tar, copper sulfate, and sodium or calcium cyanide.

Lead and zinc mineral concentrates that will be smelted and refined may require sintering, typically performed at the smelter site. Sintering partially fuses the ore concentrates into an agglomerated material for processing, and involves several steps. First, ore concentrates are blended with moisture and then fired (sintered) and cooled. During cooling, the sinter is crushed, graded, and further crushed to produce a smaller sinter product. By-products of the roasting and sintering processes include sulfur dioxide, nitrogen dioxide, and carbon monoxide. Residues generated also include dust and primary lead process water.

Gold and Silver

Three principal techniques are used to process gold and silver ore: cyanide leaching, flotation of base metal ores followed by smelting, and gravity concentration. According to the U.S. Bureau of Mines, cyanide leaching generated 88 percent of all domestic lode gold in 1991, and 38 percent of silver. Processing of base metal ores produced 11 percent of the gold; over half of the silver produced in 1991 was from smelting concentrates produced by flotation of silver and base metal ores. Gravity concentration is used primarily by gold and silver placer operations.

Cyanide leaching is a relatively inexpensive method of treating gold ores and is the chief method in use. In this technique, sodium or potassium cyanide solution is either applied directly to ore on open heaps or is mixed with a fine ore slurry in tanks; heap leaching is generally used to recover gold from low-grade ore, while tank leaching is used for higher grade ore.

Compared to tank leaching, **heap leaching** has several advantages, including simplicity of design, lower capital and operating costs, and shorter start-up times. Depending on the local topography, a heap or a valley fill method is typically employed. The size of heaps and valley fills can range from a few acres to several hundred. Heap leaching may involve any or all of the following steps:

- Preparation of a pad with an impervious liner. Some liners may simply be compacted soils and clays, while others may be of more sophisticated design, incorporating clay liners, french drains, and multiple synthetic liners.
- Placement of historic tailings, crushed ore, or other relatively uniform and pervious material on the uppermost liner to protect it from damage by heavy equipment or other circumstances.
- Crushing and/or agglomerating the ore.
- Placing the ore on the pad(s).
- Applying cyanide solution using drip, spray, or pond irrigation systems, with application rates generally between 0.5 and 1.0 pounds of sodium cyanide per ton of solution. This is known as the barren solution because it contains little or no gold.
- Collecting the solution via piping laid on the liner, ditches on the perimeter of the heap, or pipes/wells laid through the heap into sumps at the liner surface. The recovered pregnant solution, now laden with gold (and silver), may be stored in ponds or routed directly to tanks for gold recovery, or it may be reapplied to the heap for additional leaching.

- Recovering the gold from the pregnant solution (typically containing between 1 and 3 ppm of gold).

The leaching cycle can range from weeks to several months, depending on permeability, size of the pile, and ore characteristics. The average leach cycle is approximately three months.

Recovery of gold from the pregnant solution is accomplished using carbon adsorption or, less commonly, by direct precipitation with zinc dust. These techniques may be used separately or in a series with carbon adsorption followed by zinc precipitation. Both methods separate the gold-cyanide complex from other remaining wastes. Carbon adsorption involves pumping the pregnant solution into a series of activated carbon columns, which collect gold from the cyanide leachate. The precious metals are then stripped from the carbon by elution with the use of a boiling caustic cyanide stripping solution, or similar solution. Gold in the pregnant eluate solution may be electrowon or zinc precipitated.

Although carbon adsorption/electrowinning is the most common method of gold recovery domestically, zinc precipitation is the most widely used method for gold ore containing large amounts of silver. In zinc precipitation, pregnant solution (or the pregnant eluate stripped from carbon) is filtered and combined with metallic zinc dust resulting in a chemical reaction which generates a gold precipitate. The solution is then forced through a filter that removes the gold.

The following exhibit illustrates a typical gold heap leach operation using zinc precipitation; variations exist in exact processes and methods used at each operation.

Exhibit 12
Gold Heap Leaching Operation

Source: U.S. EPA, Office of Enforcement and Compliance Assurance.

To prepare for **tank leaching**, ore is ground to expose the metal values to the cyanide. Finely ground ore is slurried with the leaching solution in tanks. The resulting gold-cyanide complex is then adsorbed on activated carbon. The pregnant carbon then undergoes elution, followed either by electrowinning or zinc precipitation, as described previously. The recovery efficiencies attained by tank leaching are significantly higher than for heap leaching. The tank leaching process may occur over a series of days, rather than the weeks or months required in heap leaching.

After heap leaching and rinsing, the spent ore becomes waste and is left as is or is deposited in disposal areas similar to those used for waste rock. Spent ore may contain wastewater from rinsing the ore, residual cyanide, metal-cyanide complexes, and small quantities of heavy metals. Tailings produced from tank leaching may contain arsenic, barium, chloride, nitrate, sodium, and sulfate. Cyanide residues may require destruction using alkaline chlorination, ozone, or hydrogen peroxide addition.

Gravity concentration, a beneficiation method used mostly in placer mines, involves passing a slurry of ore and water over a series of riffles to catch heavier gold particles. Amalgamation, or wetting metallic gold with mercury to form an amalgam, is another recovery technique used in placer operations. Its high cost, inefficiency for large-scale mining operations, and environmental and safety considerations have greatly restricted amalgamation's previous widespread use.

Chemical Usage

The following exhibit lists the chemicals used in greatest volume in the metal mining processes for several of the main commodities. While volume does not necessarily correlate with potency, this data indicates which chemicals are present in greatest quantity, and to which chemicals mine workers may be most frequently exposed. Although it does not appear in the chart below, cyanide is also consumed in massive quantities by the gold industry. In 1990 alone, Dow Chemical supplied over 160 million pounds of reagent-grade cyanide for use in gold mining, according to the *Chicago Tribune* (February 2, 1992, p.27).

Exhibit 13
Chemicals Used in High Volume

Type of Mine	Chemical Name	Volume/ Mass at Mine Site

Iron Ore	Acetylene	5,577,726 gallons
	Argon	15,892,577 gallons
	Diesel Fuel	3,417,487 gallons
	Nitrogen	9,398,026 gallons
Lead/Zinc	Acetylene	1,021,795 gallons
	Calcium Oxide	932,129 lbs.
	Diesel Fuel No. 2	1,640,271 gallons
	Propane	171,733 lbs.; 1,015,962 gallons
	Sulfur Dioxide*	1,843,080 lbs.

Exhibit 13 (cont'd)
Chemicals Used in High Volume

Type of Mine	Chemical Name		Volume/ Mass at Mine Site
Copper	Acetylene		10,909,868 gallons
	Calcium Oxide		512,620,243 lbs.
	Chlorine**		17,242,059 lbs.; 138,015 gallons
	Coal		2,375,684,593 lbs.
	Copper ore concentrate**		24,000,000 lbs.
	Copper Slag		10,833,500 lbs.
	Diesel Fuel No. 2		47,301,433 gallons
	Limestone		154,280,000 lbs.
	Natural Gas		8.6 x 10^12 gallons
	Nitrogen		189,315,331 gallons
	Pyrites		38,400,000 lbs.
	Sulfuric Acid**		82,907,916 lbs.; 5,772 gallons
Gold	Acetylene		829,460 lbs.; 2,033,041 gallons
	Calcium Oxide		58,394,968 lbs.
	Chlorine**		66,090,022 lbs.; 165 gallons
	Diesel Fuel No. 2		13,425,408 gallons
	Propane		1,218 lbs.; 2,743,927 gallons

	Sulfuric Acid**	1,800,501 lbs.

Source: NIOSH 1990/91
* Proposed TRI chemical
** Current TRI chemical

III.B. Mining Process Pollution Outputs

The extraction and beneficiation of metals produce significant amounts of waste and byproducts. Total waste produced can range from 10 percent of the total material mined to well over 99.99 percent. The volume of total waste can be enormous: in 1992, gold mining alone produced over 540 million metric tons of waste. The following exhibit provides further detail on the volume of product and waste material generated from metal mineral mining.

Exhibit 14
Volume of Waste Generated for Selected Metals

Commodity	Number of Mines	Total Commodity Produced (1,000 mt)	Tailings Generated (1,000 mt)	Other Waste Handled (1,000 mt)
Copper	50	1,765	337,733	393,332
Gold	+212	0.329	247,533	293,128
Iron Ore	22	55,593	80,204	106,233
Lead	23	398	6,361	--
Silver	150	1.8	2,822	--
Zinc	25	524	4,227	--

Source: U.S. Bureau of Mines, Mineral Commodity Summaries 1994 and Minerals Yearbook, Volume I: Metals and Minerals, 1992.

The industry (including non-metallic minerals) is estimated to have generated 50 billion metric tons of waste through 1985, and currently generates approximately one billion metric tons annually. It is important to note, however, that virtually none of this annual production related to extraction and beneficiation is classified as RCRA hazardous waste. Exhibit 15 summarizes some of the potential effects of industrial mining on the environment.

Exhibit 15
Steps in the Mining Process and Their Potential Environmental Impacts

Mining Process	Process Wastes	Air Emissions	Other Waste	Land, Habitat, Wildlife
Site Preparation	Erosion due to removal of vegetation	Exhaust from construction vehicles; fugitive dust	Run-off sediment	Deforestation and habitat loss from road and site construction
Blasting/ Excavation	Acid Rock Drainage (ARD); erosion of sediments; petroleum wastes from trucks	Dust blown to surrounding area; exhaust from heavy machinery	Non-reused overburden; waste rock	Loss of habitat; increase in erosion; loss of plant population from dust and water pollution; reduction in localized groundwater recharge resulting from increased runoff; loss of fish population from water pollution; nearby structural damages from vibration and settling; competition for land use
Crushing/ Concentration	Acid Rock Drainage (ARD) from tailings	Dust created during transportation	Additional waste rock; tailings	

Exhibit 15(cont'd)
Steps in the Mining Process and Their Potential Environmental Impacts

Mining Process	Process Wastes	Air Emissions	Other Waste	Land, Habitat, Wildlife
Leaching	ARD; water pollution from ruptures in pipes or ponds holding leach solution		Sludges from neutralization of contaminated water	Loss of plant, fish, and water fowl population from water pollution

Source: Mining Support Package,. Draft, U.S. EPA, April 1994.

Wastes

Several wastes are created when metal ores are extracted from the earth. The first is overburden and waste rock, which is soil and rock removed in order to access an ore or mineral body. Overburden typically includes surface soils and vegetation, while waste rock also includes rock removed while sinking shafts, accessing or exploiting the ore body, and rock embedded within the ore or mineral body.

Most overburden and waste rock are disposed of in piles near the mine site, although approximately nine percent is backfilled in previously excavated areas, and nearly four percent is used off-site for construction. Waste rock dumps are generally constructed on unlined terrain, with underlying soils stripped, graded, or compacted depending on engineering considerations. Drainage systems may be incorporated into dump foundations to prevent instability due to foundation failures from groundwater saturation, and may be constructed of gravel-filled trenches or gravel blankets.

Tailings are a second type of common mining waste. Most beneficiation processes generate tailings, which contain a mixture of impurities, trace metals, and residue of chemicals used in the beneficiation process. Tailings usually leave the mill as a slurry consisting of 40 to 70 percent liquid mill effluent and 30 to 60 percent solids; liquids are commonly re-used in milling processes. Most mine tailings are disposed in on-site impoundments. Design of the impoundment depends on natural topography, site conditions, and economic factors; generally it is economically advantageous to use natural depressions to contain tailings. Impoundments are designed to control the movement of fluids both vertically and horizontally.

In some cases, tailings are dewatered or dried and disposed in piles; this minimizes seepage volumes and the amount of land required for an impoundment. However, dry disposal methods can be prohibitively expensive due to additional equipment and energy costs.

Slurried tailings are sometimes disposed of in underground mines as backfill to provide ground or wall support. This decreases the above-ground surface disturbance and can stabilize mined-out areas. Subaqueous tailings disposal, practiced primarily in Canada, is the placement of tailings below a permanent water surface such as a lake or ocean; it is used primarily to minimize the acid-generating potential of tailings by preventing sulfide ore from oxidizing. This disposal method is not currently practiced commercially in the United Stated.

Water

Water removed from a mine to gain or facilitate access to an ore body is known as mine water. Mine water can originate from precipitation, from flows into pits or underground workings, and/or from groundwater aquifers that are intercepted by the mine. Mine water is only a waste if it is discharged to the environment via a point source. Mine water can be a significant problem at many mines, and enormous quantities may have to be pumped continuously during operations. When a mine closes, removal of mine water generally ends. However, underground mines can then fill and mine water may be released through adits or fractures that reach the surface. Surface mines that extend below the water table fill to that level when pumping ceases, either forming a lake in the pit or inundating and saturating fill material. Pumped mine water is typically managed in on-site impoundments. Collected water may be allowed to infiltrate/evaporate, used as process water or for other on-site applications such as dust control, and/or discharged to surface water, subject to permit requirements.

Acid drainage is a potentially severe pollution hazard associated with mining, and can be difficult to predict. It occurs when pyrite and other sulfide minerals, upon exposure to oxygen and water, oxidize to create ferrous ions and sulfuric acid. Catalyzed by bacteria, the ferrous ions react further with oxygen, producing hydrated iron oxide, known as "yellowboy." This combination of yellowboy and sulfuric acid may contaminate surrounding soil, groundwater, and surface water, producing water with a low pH. When this reaction occurs within a mine it is called Acid Mine Drainage (AMD). When it occurs in waste rock and tailings piles it is often known as Acid Rock Drainage (ARD), although AMD is the most widely used term for both.

AMD is a significant problem at many abandoned mine sites: a 1993 survey by the U.S. Forest Service (*Acid Mine Drainage from Mines on National Forests, A Management Challenge*) estimates that 5,000 to 10,000 miles of domestic streams and rivers are impacted by acid drainage. Acid drainage can lower the pH of surrounding water, making it corrosive and unable to support many forms of aquatic life; vegetation growing along streams can also be affected. Mine water can also carry toxic, metal-bearing sediment into streams, which can kill waterborne plant and animal species. In extreme cases, acid drainage can kill all living organisms in nearby streams. Humans may also increase disease risks by consuming drinking water and fish tissue with a heavy metal content.

According to the 1994 *Technical Document/ Background for NEPA Reviewers: Non-Coal Mining Operations,* prepared by EPA's Office of Solid Waste (OSW), acid drainage can pose significant threats to surface and groundwater quality and resources during active mining and for decades after operations cease. Although mines that began operating after 1978 are required to treat their effluent water, the need for water treatment may persist for decades after mining operations have ceased. Abandoned mines and refuse piles can produce acid damage for over 50 years. According to EPA's hardrock mining strategy framework, for example, "negative changes in geochemistry over time can occur when the materials' environment changes (e.g., going from a reducing environment to an oxidizing one) or buffering capacity is exceeded (such as when the total neutralizing capacity of a rock mass is exceeded by acid generation). When these conditions are present, a facility can close in full environmental compliance, only to have a severe problem show up decades later." Because remediating acid drainage is so damaging and costly, predictive tools, design performance, financial assurance, and monitoring have become increasingly important.

Acid leaching operations are an additional source of water pollution. The leaching process itself resembles acid drainage, but it is conducted using high concentrations of acids to extract metals from ore. Since acid leaching produces large volumes of metal-bearing acid solutions, it is vital that leach dumps and associated extraction areas be designed to prevent releases. Most environmental damage associated with acid leaching is caused by leakage, spillage, or seepage of the leaching solution at various stages of the process. Potential problems include: seepage of acid solutions through soils and liners beneath leach piles; leakage from solution-holding ponds and transfer channels; spills from ruptured pipes and recovery equipment; pond overflow caused by excessive runoff; and ruptures of dams or liners in solution-holding ponds. Cyanide leaching solution processes carry a similar potential for damage as a result of leakages, spills, overflows, and ruptures.

Solution ponds associated with leaching operations are potential sources of acid and metal releases to ground and surface water. Ponds associated with precious metal leaching operations and newer copper facilities are generally lined with synthetic materials (although liners are often susceptible to failure). At older copper sites, solution ponds may be unlined or lined only with natural materials. Leakage, run-off from precipitation, and the like, may cause contamination of ground and surface waters.

Air

Substantial air pollution can occur at mining sites during excavation and transportation. Fugitive dust may be a significant problem at some sites, depending on site conditions and management practices, and is created at many stages of the mining process. The inherent toxicity of the dust depends on the proximity of environmental receptors and type of ore being mined; high levels of arsenic, lead, and radionuclides in windblown dust tend to pose the greatest risk, according to EPA's 1995 hardrock mining framework strategy. Sources of dust may be from road traffic in the mine pit and surrounding areas, rock crushers located in pits and in mills, and tailings ponds.

Dust control methods aim to reduce amounts and concentrations of dust produced and to minimize human exposure to remaining dust. The most important element of dust control at underground mines is a properly designed ventilation system. Water sprays are also used during ore transportation and crushing, and can greatly reduce dust levels at the site. Dust suppressants, such as lignin sulfonates and magnesium chloride, can stabilize solid piles or tailing areas that might otherwise become airborne in windy conditions. After mine closure, revegetation or other stabilizing methods may be used for dust control.

Exhaust fumes from diesel engines and blasting agents may also be serious hazards at underground mines. These exhausts produce carbon monoxide and nitrogen oxide gas, which collect in underground areas. Ventilation and monitoring are important steps taken to reduce the potential harm these fumes may cause workers.

The following exhibit, derived from EPA's OSW 1994 *Technical Document/Background for NEPA Reviewers: Non-Coal Mining Operations*, describes the various measures mining operators may take to mitigate potential environmental impacts of waste products generated through different phases of the extraction and beneficiation processes.

Exhibit 16
Potential Mine Waste Mitigation Measures

Mining Waste Product	Mitigation Measures
Extraction - Mine Workings	• Evaporation and re-use of mine water in processing operations • Run-on and runoff control measures, such as berms and ditches • Neutralization/precipitation or other treatment practices prior to discharges • Clean-up of blasting residuals • Provide for post-closure mine water management • Monitor discharges and surface water quality • Site mine water containment units to minimize potential for surface water recharge
Extraction - Waste Rock/ Overburden	• Backfill into dry mine workings with waste rock • Maximize use of overburden in reclamation • Collect and monitor seepage, drainage, and runoff • Segregate and cover reactive waste rock with non-reactive materials where ARD is observed • Use non-reactive waste rock for on-site construction • Provide for adequate dump drainage to minimize potential for slope failure • Conduct baseline surface water monitoring; continue monitoring throughout operation and post-closure • Use run-on controls to minimize potential for infiltration
Beneficiation - Tailings Impoundments	• Design unit to contain maximum reasonable storm event • Consider natural and/or synthetic liners for units located in drainages; consider liners for any seepage/runoff collection sumps/ditches • Maximize the reclaim/reuse of tailings water • Limit mill reagents to least extent necessary • Provide adequate drainage of berms • Include secondary containment of tailings pipelines • Continue ARD testing throughout operations and closure • Collect and treat runoff/seepage from outer slopes of impoundment

Exhibit 16 (cont'd)
Potential Mine Waste Mitigation Measures

Mining Waste Product	Mitigation Measures
Beneficiation - Copper Dump Leach Operations and SX/EW Plants, Gold Heap Leaching	• Design dump leach units to fully drain to collection areas • Ensure that collection, pregnant solution, and raffinate ponds are designed to contain up to the maximum reasonable storm event; line process ponds, heap leach pads, and conveyances • Install leachate detection and collection systems under ponds and heaps; construct seepage ponds downgradient of ponds, heaps, and dumps • Recycle process water • Lime neutralization or wetlands treatment of acid drainage • Provide secondary containment for solution pipes to minimize impacts from pipe failures/spills • Collect and treat drainage that occurs after closure, as necessary • Perform baseline groundwater monitoring and conduct groundwater quality monitoring during operations and post-closure; monitor post-closure discharges and downstream surface water quality • Detoxification of heaps, dumps, and any spent solutions to reduce cyanide, acidity, and metal loadings • Biological treatment for cyanides, nitrates, and heavy metals
Beneficiation - Cyanide Leaching Operations	• Where possible, do not locate leaching operations in or near drainages • Ensure that pregnant and barren ponds and ditches are designed to contain all solution flows and any runoff up to the maximum reasonable storm event • Use double liners and leak detection systems for all heaps, ponds, and drainage ditches • Test detoxified materials prior to disposal or closure to ensure cyanide levels are reduced • Collect and test seepage and runoff from spent ore piles; treat runoff/seepage as necessary; perform downstream water quality monitoring
Beneficiation - *In Situ* Mining	• Ensure proper production well installation/completion to avoid uncontrolled solution releases; provide for adequate well abandonment • Perform a detailed characterization of the site hydrogeology to guide design of recovery systems and determine potential for releases • Carefully monitor pumping pressures of solutions entering and leaving deposits to assure that solutions are not migrating into groundwater • Line surface collection systems and provide for leak detection; design collection systems to contain maximum volumes of leaching solutions and runoff/precipitation/snow melt

Because proposed mining activities may also impact aquatic resources, vegetation, and wildlife, EPA suggests the following potential mitigation measures for use at mine sites:

Exhibit 17
Ecosystem Mitigation Measures

• Employ sediment retention