Environmental Impacts of Metallurgical Engineering

OUTLINE

Complete conversion of one form of energy to another, in other words reversible processes never occur in nature

It is an engineer's goal to completely convert energy to the desired form with the maximum efficiency
At less efficiencies spontaneous processes will result in degradation of energy as dissipated waste heat

Engineering practice worlwide has so far been far away from maximum efficiency, reversibility and sustainability. Although invention of fire, steam engine, electricity have gradually improved the efficiency with which man used energy to satisfy his growing needs, Earth suffered irreversible damage as a result of careless engineering

Mining and smelting of metals upset the environmental balance by

- liberating captured C and S in the ores
- converting metals in inert mineral form to reactive pure form
- moving large masses of rock and dumping most of them in landfills

Dissipative use of metals also degrades the environment through corrosion and leaching

All known metals have applications in industry, technology, and everyday uses, and the number of their commercial uses has been accelerating.
Each industrial process of metal manufacturing generates some kind of waste that is discharged into the environment. Unlike organic chemicals, the metals are nondegradable, very persistent, and their build-up in the environment continues

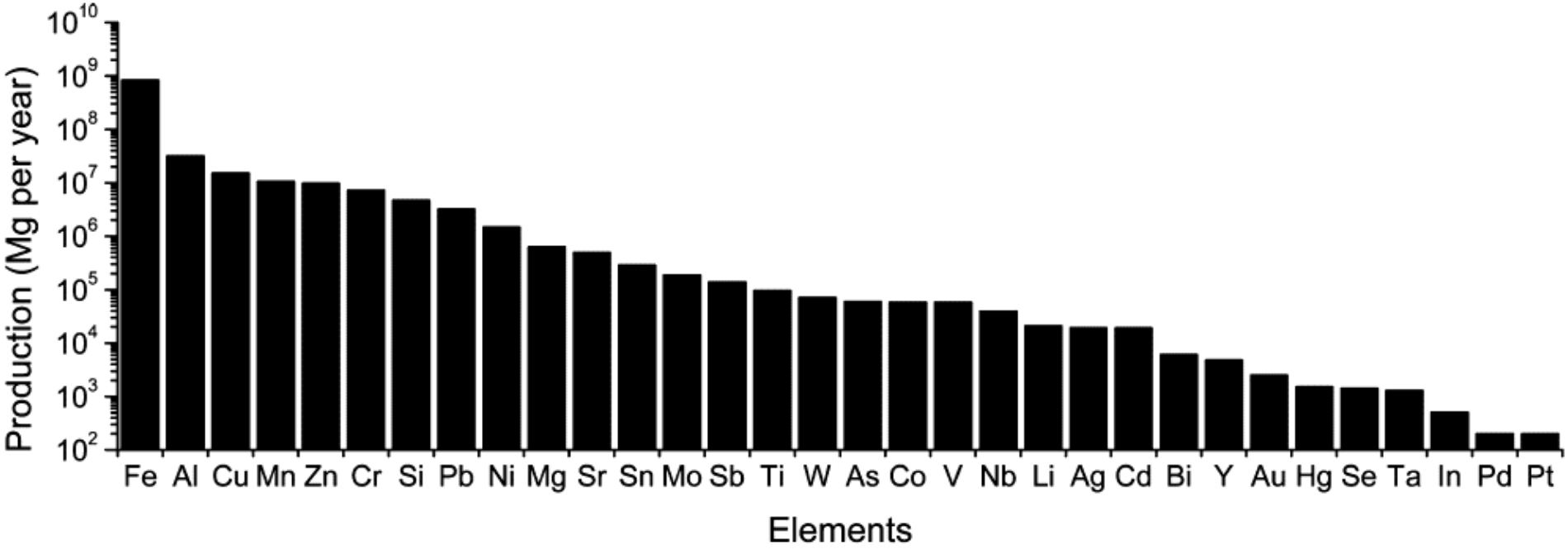
Recycling of metal wastes serves to protect the environment by replacing the mined metal and recovering corroding metal from the environment

The waste management and scrap industries collect discarded metals and then either sort them for sale to the secondary metals industry or store them in landfills for long term containment

Which path a metal takes is determined by

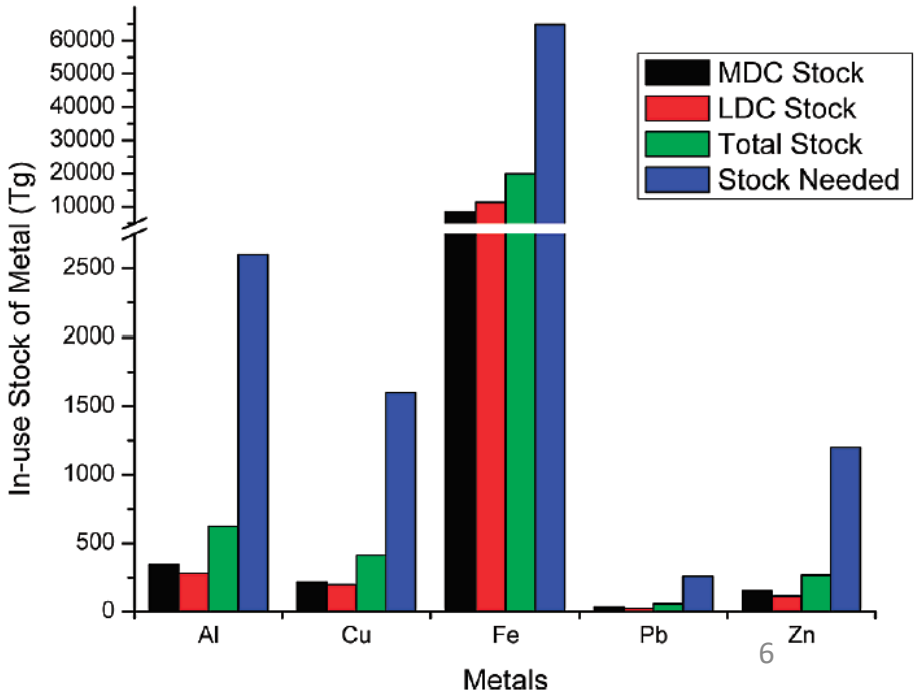
- concentration of metal in discarded products
- ease of separation and concentration
- what manner the metal is discarded (separated or mixed)

Their inputs are usually heterogeneous with a significant amount of uncertainty with regard to material content and timing of discard. Investments on scrap collection and processing systems will increase the ratio of products that are recycled and make these industries more reliable and efficient in the future



Top: Metals extracted worldwide in 2005

Right: Estimates of the in-use stock of five important metals in 2008



metal	global per capita stock	MDC per capita stock[b]	LDC per capita stock[c]
aluminum	80	350–500	35
antimony		1	
cadmium	40	80	
chromium		7–50	
cobalt		1	
copper	35–55	140–300	30–40
gold		35–90	
iron	2200	7000–14000	2000
lead	8	20–150	1–4
magnesium		5	
manganese		100	
mercury		10	
molybdenum		3	
nickel		2–4	
palladium		1–4	
platinum		1–3	
rhodium		0.2	
silver	110	13	
steel		7085	
stainless steel		80v180	15
tin		3	
titanium		13	
tungsten		1	
zinc		80–200	20–40

[a] The years of the determinations vary, but most are for the period 2000–2006. The units of per capita stock are kilograms of metal in most cases, but grams of metal for cadmium, gold, mercury, palladium, platinum, rhodium, and silver. [b] The more-developed countries (MDCs) used in this calculation are Australia, Canada, the European Union EU15, Sweden, Switzerland, Japan, New Zealand, and the United States (altogether about 860 million people in 2005). [c] The less-developed countries (LDCs) used in this calculation consist of all countries except those in the "more-developed" category (altogether about 5620 million people in 2005).

Estimated in-use metal stock per capita in 2008

Metal	Product	Predominant Metal-containing Final Goods	Estimated Residence Time (years)
Al	Building & construction	Siding, window frames	30-50
Al	Infrastructure	Cable used by power utilities	30-40
Al	Transportation	Automotive equipment, railway equipment, aviation	15-40
Al	Packaging	Beverage cans, foil	0.3-0.8
Al	Other		10-15
Sb	Building & construction	Flame retardants	—
Sb	Transportation	Automotive equipment, railway equipment, ship building, aviation	10-30
Sb	Chemicals		—
Sb	Business durables	Ceramics and glass	—
Sb	Other		—
Cd	Consumer and business durables	Batteries	3
Cd	Pigments	Business and consumer applications	—
Cd	Industrial durables	Coatings and platings	—
Cd	Other		—
Cr	Building & infrastructure	Elevators, railways	30-50
Cr	Transportation	Automotive exhaust systems, railway equipment, ship building, aviation	30 for planes, trains, and ships 5-15 for automobiles and parts
Cr	Household appliances & electronics	Appliances, household products	15
Cr	Metal goods & other uses	Cutlery, fasteners	5-15
Cr	Industrial machinery	Heat exchangers, tanks	20
Co	Transportation	Automotive equipment, railway equipment, ship building, aviation	20-40
Co	Chemicals		—
Co	Cutting tools	Blades, disks	1
Co	Industrial durables	Industrial (in-plant) machinery and equipment	20
Cu	Building & construction	Building wire and copper tube	25-40
Cu	Infrastructure	Copper cable used by telecom utilities and power utilities	50
Cu	Transportation	Automotive equipment, railway equipment, ship building, aviation	10-30
Cu	Consumer durables	Appliances and extension cords, consumer electronics, fasteners and closures, household products	10
Cu	Business durables	Business electronics, lighting and wiring	20
Cu	Industrial durables	Industrial (in-plant) machinery and equipment	20

Metal	Product	Predominant Metal-containing Final Goods	Estimated Residence Time (years)
Au	Jewelry		30-50
Au	Dental	Inlays	—
Au	Electrical and electronics	Business electronics, consumer electronics	—
Fe	Building & construction	Building beams, reinforcing bars	30-50
Fe	Transportation	Automotive equipment, railway equipment, ship building, aviation	20-40
Fe	Machinery and appliances	Appliances, industrial (in-plant) machinery and equipment	20
Fe	Other		25
Pb	Building & construction	Lead sheet	40-100
Pb	Machinery and appliances	SLI batteries	1-4
Pb	Machinery and appliances	Stationary batteries	8-12
Pb	Infrastructure	Lead pipe	20-50
Mg	Castings	Transport systems, components	—
Mg	Alloys	Packaging, transport	—
Mg	Iron desulfurization		—
Mg	Other		—
Mn	Iron and steel applications		—
Mn	Building & construction	Structural steel	30-40
Mn	Transportation	High-strength steel	20-40
Mn	Industrial durables	Industrial (in-plant) machinery and equipment	25
Hg	Chlor-alkali production		—
Hg	Manufactured products	Dental amalgams, instruments, lighting	—
Hg	Stock changes		—
Hg	Artisinal gold		—
Mo	Steel alloys	Stainless steel, superalloys	—
Mo	Catalysts		—
Mo	Lubricants	MoS_2	—
Mo	Pigments		—
Mo	Other		—
Ni	Building & construction		30-50
Ni	Infrastructure		30-50
Ni	Transportation	Automotive equipment, railway equipment, ship building, aviation	10-30
Ni	Consumer durables	Appliances, consumer electronics, household products	10-15
Ni	Other		—
Ni	Industrial durables	Industrial (in-plant) machinery and equipment	20
Pd	Transportation	Automotive equipment	20-40
Pd	Consumer durables	Consumer electronics, business electronics	5-10
Pd	Dental		—
Pd	Other		—
Pt	Transportation	Automotive equipment	20-40
Pt	Jewelry		20

Metal	Product	Predominant Metal-containing Final Goods	Estimated Residence Time (years)
Pt	Chemical catalysts	Fuel cells	25
Pt	Electronics	Consumer and business equipment	25
Rh	Transportation	Automotive equipment	20-40
Rh	Glass manufacture		—
Rh	Chemical catalysts	Fuel cells	—
Rh	Other		—
Ag	Industrial applications		1-30
		Electronics	
		Solders	
		Other	
Ag	Jewelry, tableware		20-40
Ag	Photography	Film, plates	20-40
Ag	Coins and medals		10-40
SS	Transportation	Automotive, rail, ship	10-30
SS	Industrial machinery		20
SS	Building & construction		30-50
SS	Electronics		10
SS	Other		15
Sn	Cans and containers		—
Sn	Electrical and electronics		—
Sn	Construction	Corrosion prevention	30-50
Sn	Transport	Corrosion prevention, solder	20-40
Sn	Other		—
Ti	Titanium dioxide pigment		—
Ti	Carbides, chemicals, metal and metal alloys		—
W	Cutting tools		1
W	Lighting		—
W	Other		—
Zn	Building & construction	Galvanised steel (e.g., frames, piping), zinc alloys (e.g., brass appliances), and pure zinc (e.g., roofing)	10-50
Zn	Transportation	Motor vehicles, vehicle tires, and railway transport, sea and air transport	2-20
Zn	Business durables	Machinery	—
Zn	Chemicals		—
Zn	Agriculture		—

Specification of scrap metal sources

Such statistical data is used to generate scenarios of future use intensity, discard, and reuse, with good spatial (city, country, world) and temporal (month, year, ten years) resolution

In order to manage wastes effectively, more investment on scrap collection and processing is needed
This requires a profitable recycling business and to be able to predict the supply and demand of scraps

So we need to evaluate stocks and their rates of growth and decay better and use that information to make informed inferences about the future in our city/country/world

Lets consider the mining and smelting of metal ores as an alternative to recycling industry

Metal ores are extracted by mining, which involves removal of rock from the ground.
About 50% the ore mined in the world is extracted from open pits, the other half coming from underground mines

Open-pit mining produces larger amounts of overburden (the waste rock that overlies the ore) than underground mining does
For example, one of the largest open-pit mines in the world, the Bingham copper mine in Utah, USA, removes >225 000 Mg of rock each day, only 20% of which is ore

Cumulative use of land by mining throughout the world between 1976 and 2000 was about 37 000 km^2 or about 0.2% of Earth's land surface

About 60% of disturbed areas is used for the disposal of overburden, which accounts for about 40% of the solid waste generated yearly

Especially copper mining produces huge amounts of waste:

The ratio of material handled to units of marketable metal is 420:1 with a typical proportion of metal in ore 0.6%

Table 2. Estimated cumulative amounts of mine waste and tailings from 1910 through 1981 in the USA in millions of Mg.†

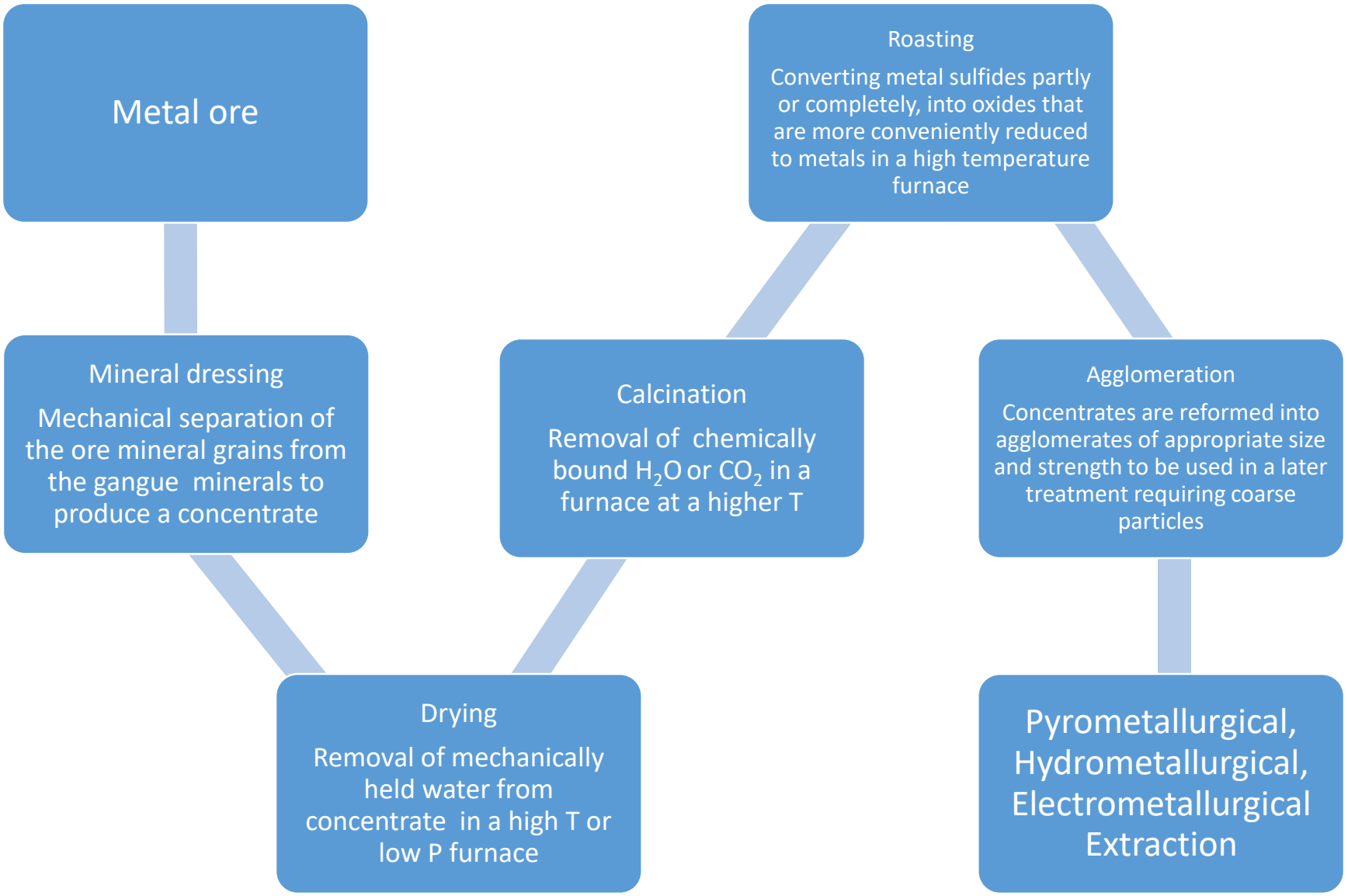
Mining industry	Tailings	Mine waste	Total waste
	Tg		
Cu	6 900	17 000	23 900
Fe	3 000	8 500	11 500
U	180	2 000	2 180
Mo	500	370	870
Zn	730	70	800
Au	350	400	750
Pb	480	50	530
Ag	50	30	80
Total	12 190	28 420	40 610

† USEPA, 1985.

The primary **copper ore** mineral is *chalcopyrite*
Others are secondary minerals formed by the alteration of primary *chalcopyrite* and *chalcocite*
CuS ores are usually associated with *pyrite* (FeS_2) and other base metal sulfides such as ZnS, PbS
Copper minerals are usually associated with siliceous and other gangue minerals so that their grades are as low as 1-2% Cu

Chalcopyrite ($CuFeS_2$)
Bornite (Cu_5FeS_4)
Chalcocite (Cu_2S)
Covellite (CuS)
Enargite ($CuAsS_4$)
Malachite ($CuCO_3.Cu(OH)_2$)
Cuprite (Cu_2O)
Chrysocolla ($CuSiO_3.2H_2O$)

Journey of Metal Oxide from Ore to Ingot



Mineral Dressing

Minerals must be liberated from their intimately associated gangue minerals before they can be collected in separate products

The first part in mineral dressing is comminution which involves crushing and grinding of the ore to a point where each mineral grain is free

The goals of comminution are

1- To obtain the correct degree of liberation of minerals

2- To increase the specific surface area of minerals for hydrometallurgical treatment

Ore particles are continuously screened after crushing in a closed loop process

The second part in mineral dressing is separation of the liberated valuable minerals from gangue minerals or concentration

It is mostly done by physical means because they do not change the characteristics of the raw materials

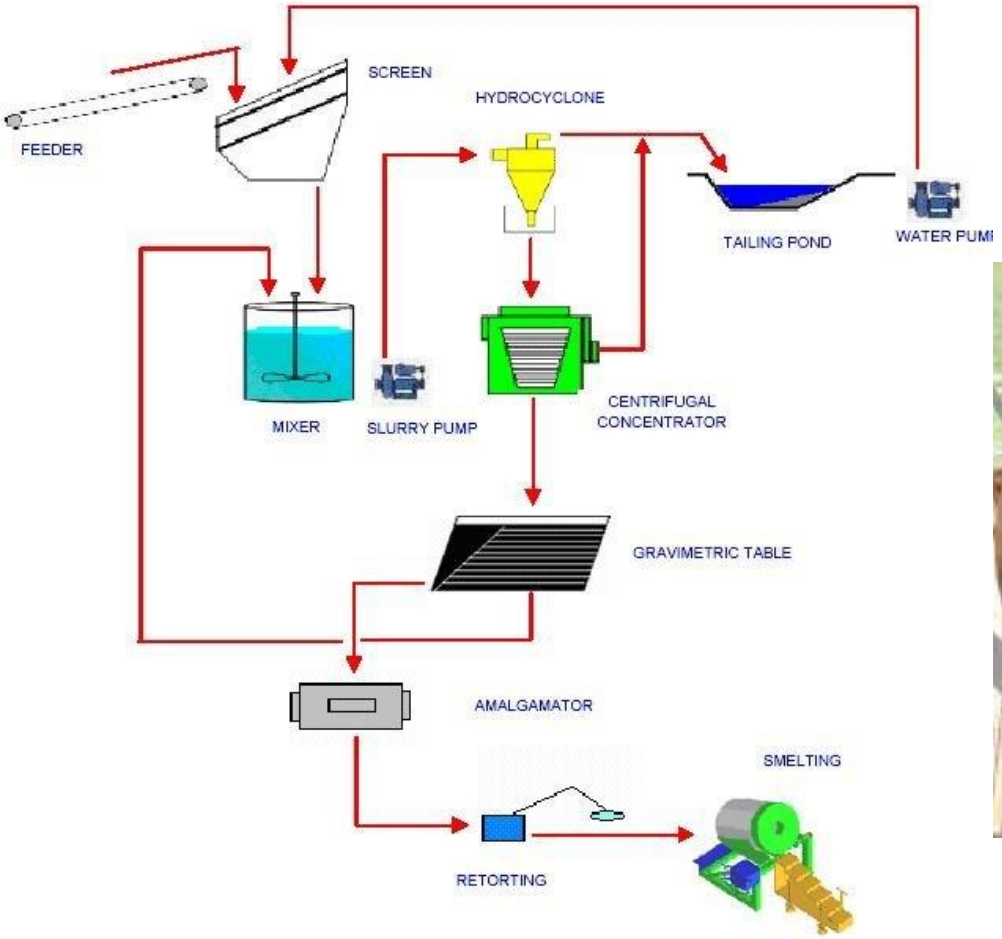
Three end products of concentration are

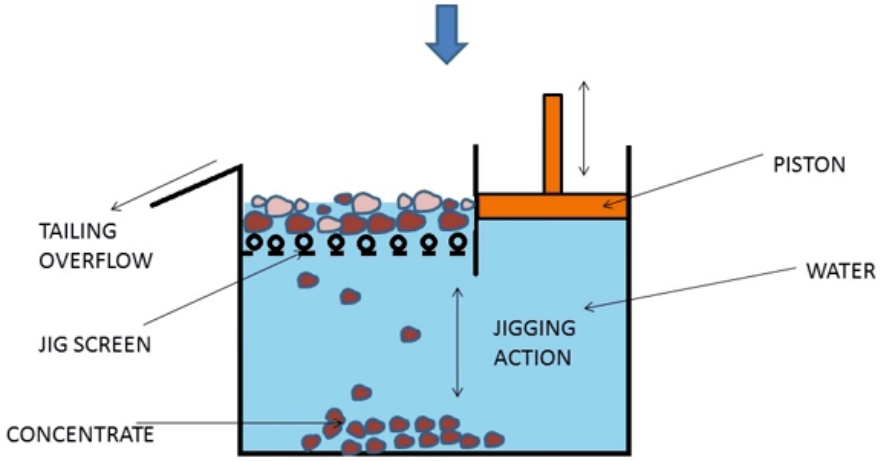
Concentrate – Valuable minerals separated from ore

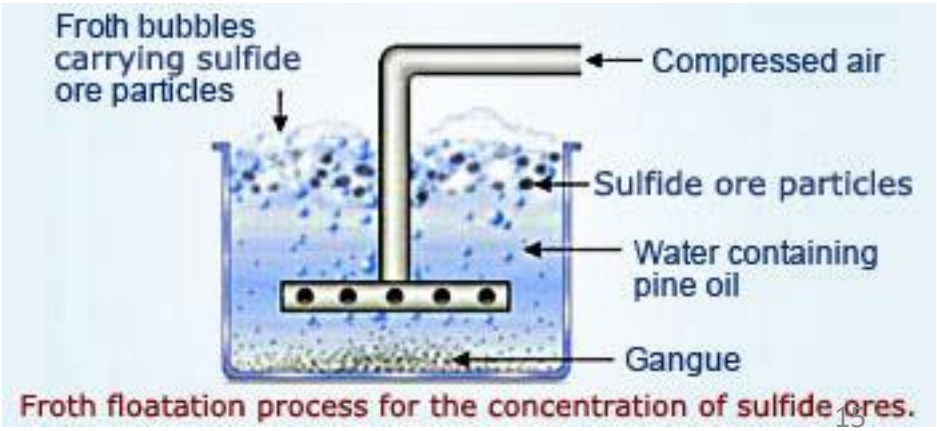
Tailing – Fraction of ore discarded as a valueless part

Middlings – Particles with valuable minerals and gangue locked together. Further liberation needed by comminution

Concentration





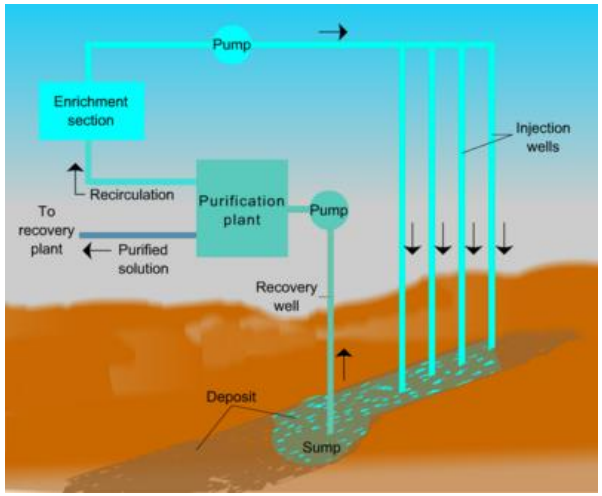


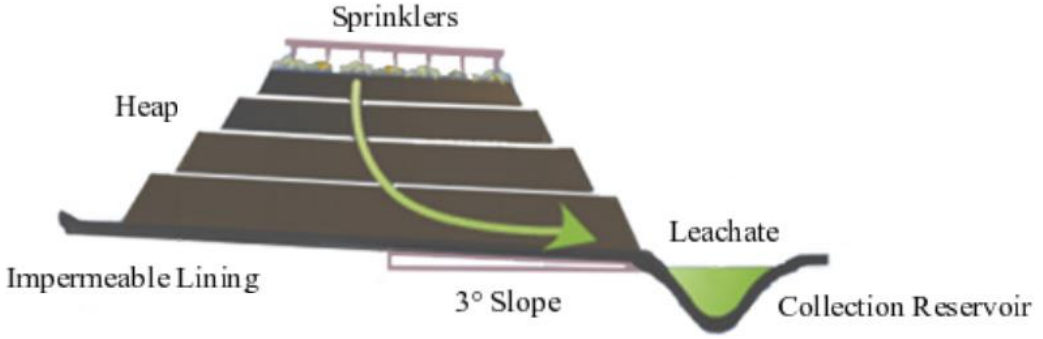
Froth floatation process for the concentration of sulfide ores.

Tailings from Cu-sulfide ore beneficiation amount to as much as 98% of the ore volume and are disposed of in large piles or valley fills

The environmental concern in mining areas is primarily related to mechanical damage of the landscape and acid mine drainage

Although mines are classified on the basis of their predominant product, they may produce large quantities of other elements as coproducts.
For example, Zn mines produce 72% of all Zn; 100% of Cd, Ge, In, and Th; and 3.1, 4.1, and 6.1% of all Au, Ag, and Pb in the USA. As a result, metal ore processing usually leads to the multi-elemental contamination of the environment.





In situ leaching – Mine water for leaching $CuSO_4$

Heap leaching – Ore rocks in dumps

Mining and beneficiation processes generate four categories of large-volume waste:

1. mine waste (overburden, barren rocks),
2. tailings,
3. dump heap leach,
4. mine water

The volume of mine waste as a percentage of the total crude ore ranges from 9 to 27% for underground mines. In surface mining, the amount of waste ranges from 2 to 10 times the total volume of crude ore

Dump leaching, heap leaching, and in situ leaching are the processes used to extract metals from low-grade ore. Sulfuric acid is usually applied in Cu operations. As the liquid percolates through the ore, it leaches out metal. Dump leach piles often cover hundreds of hectares, rise to 60 m, and contain tens of millions of Mg of low-grade ore, which becomes waste after leaching.

The mine water is water that infiltrates a mine and must be removed to facilitate mining

Open-pit Cu mines are rarely filled after mining, because they are so large and the ore bodies are not lying fiat or near to the surface

Modern mines are regraded and revegetated when they are abandoned, as are the waste dumps and tailings piles. This was not true for the older Cu mines, which are a source of metal rich, acid water and sediments.

Revegetation on old gold mining pit in Ghana

Copper mine in Arizona regraded and recontoured with planting for revegetation

Mining, smelting and refining processes produce gaseous and particulate matter emissions, waste waters, and solid wastes (slag). These are emitted into ambient air, discharged into water systems, or disposed on land

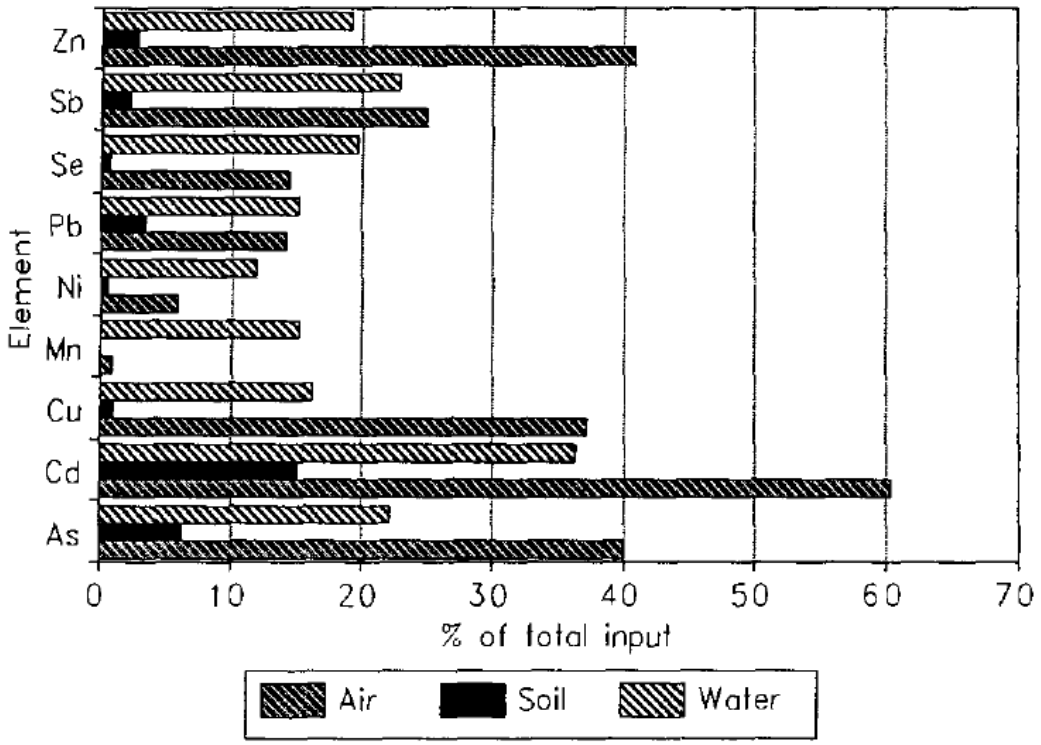


Fig. 4. Proportion of trace element emissions from mining and smelting into air, soil, water (Nriagu and Pacyna, 1988; Nriagu, 1989).

The most noticeable form of contamination from the metal production industry is the discharge of emissions to the atmosphere.

Tall stacks discharge pollutants at such heights that the emissions are sufficiently diluted when dispersed into the lower atmosphere to meet air quality requirements.

The major solid wastes generated by smelting and refining, which may constitute hazardous waste, include: process wastes, residuals from air pollution control, and waste water treatment systems

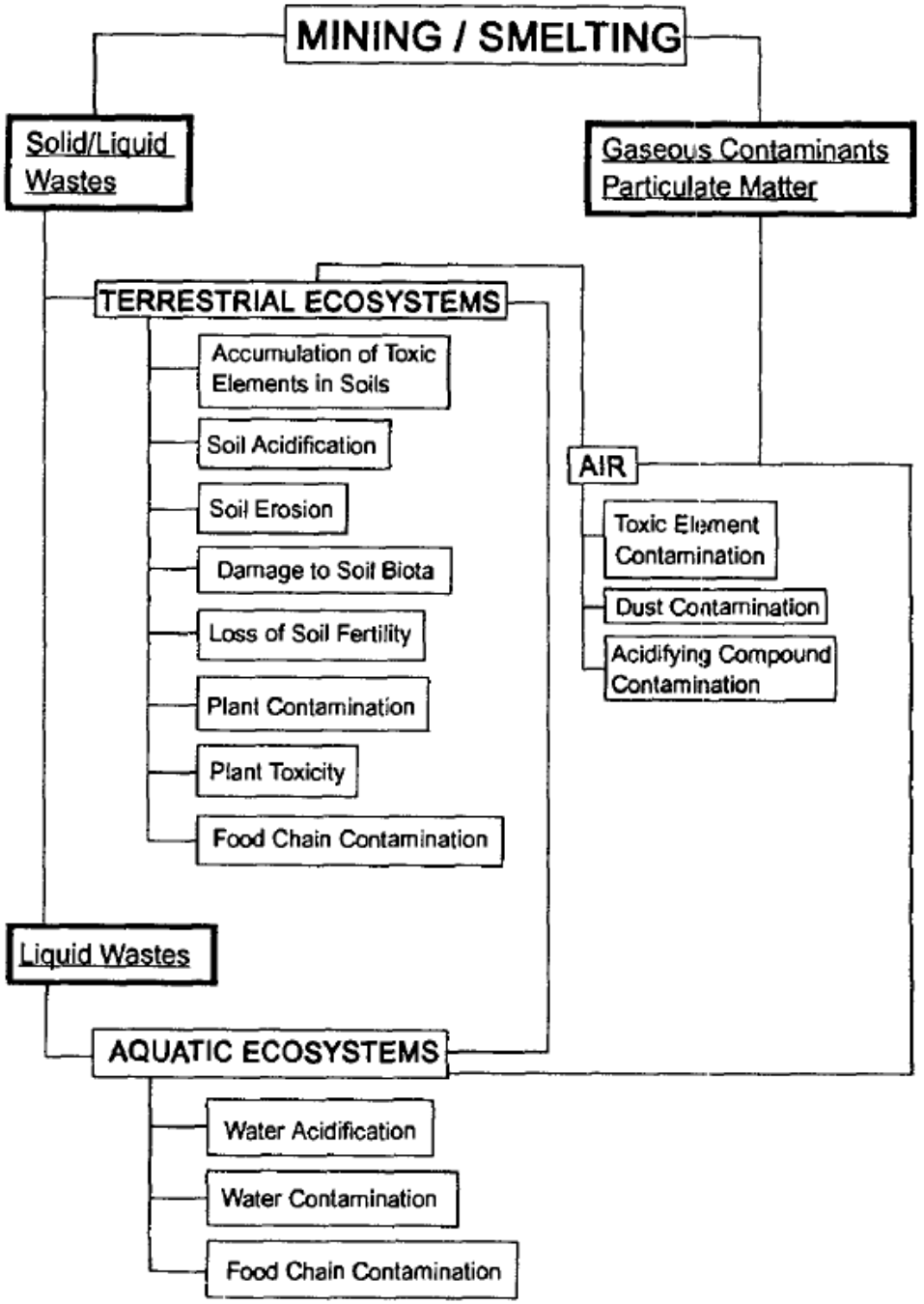


Fig. 5. Schematic diagram of the potential environmental impacts of mining/smelting industries.

Smelting

Simultaneous melting and separation of the charge into two immiscible liquid layers of slag and matte or slag and liquid metal

Smelting for matte – A pyrometallurgical concentration stage in the overall extraction of a metal from its sulphides

Metal sulphides 20-30% Cu —(Matte smelting under neutral or reducing conditions)→ Matte – Cu_2S, FeS (30-55% Cu); Slag – SiO_2, CaO, Al_2O_3

Smelting for metal – Separation and reduction of metal oxides to metals and formation of slag containing gangue minerals, impurities and fluxes

Metal oxides Fe_2O_3, Fe_3O_4 —(Smelting for metal with reducing agent (coal, coke))→ Liquid metal – Pig iron (Fe+4%C+1%Si); Liquid slag – SiO_2, CaO, Al_2O_3

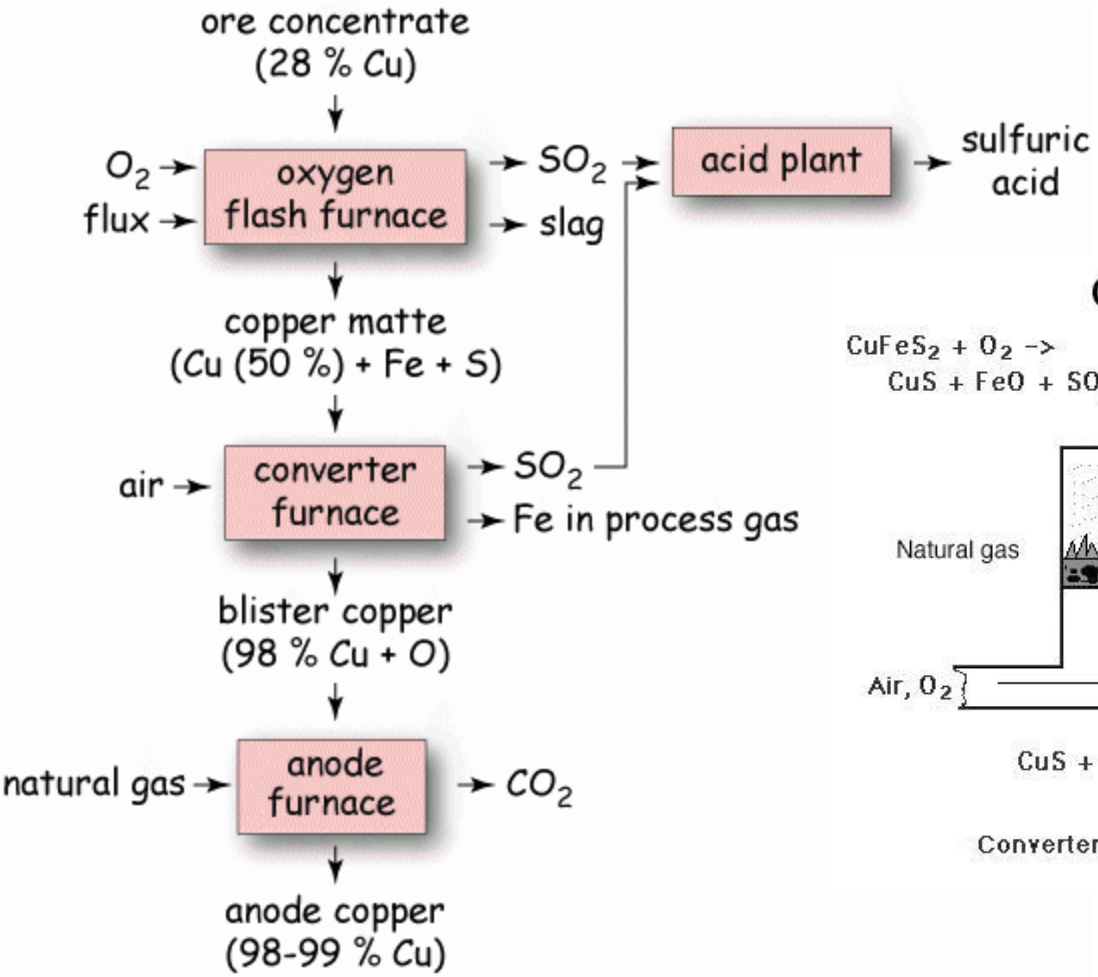
Matte Converting - Preferential oxidation of the more reactive impurity metal sulphides

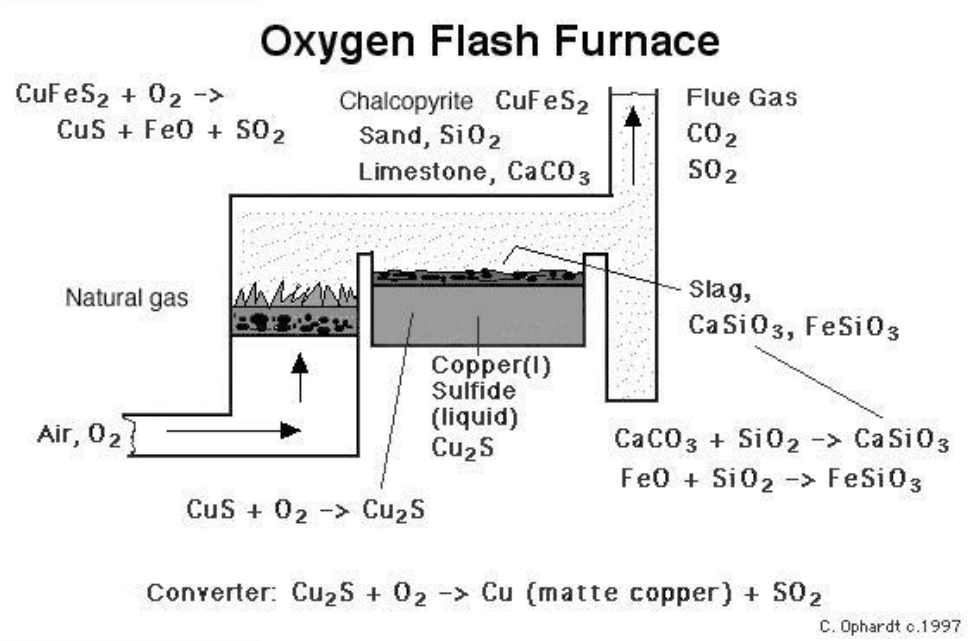
Liquid matte containing metal sulphides Cu_2S, FeS —(air and oxygen blowing)→ Liquid matte containing metal oxides Cu_2O, FeO

Air blowing is controlled to convert the remaining more noble metal sulphide to the required metal

$$2Cu_2S + 3O_2 = 2Cu_2O + 2SO_2$$

Pyrometallurgical Extraction and Refining Processes





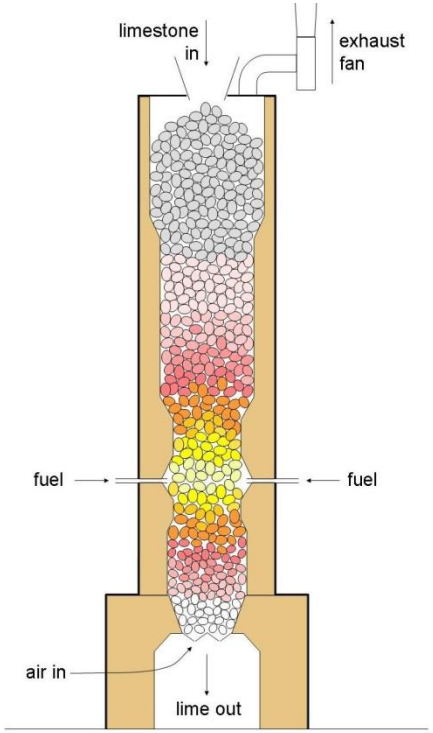
Calcination

The chemically bound water, CO_2 and other gases are removed from metal hydrate or carbonate particles by calcination

The temperature required for complete calcination of a mineral is much higher than drying T

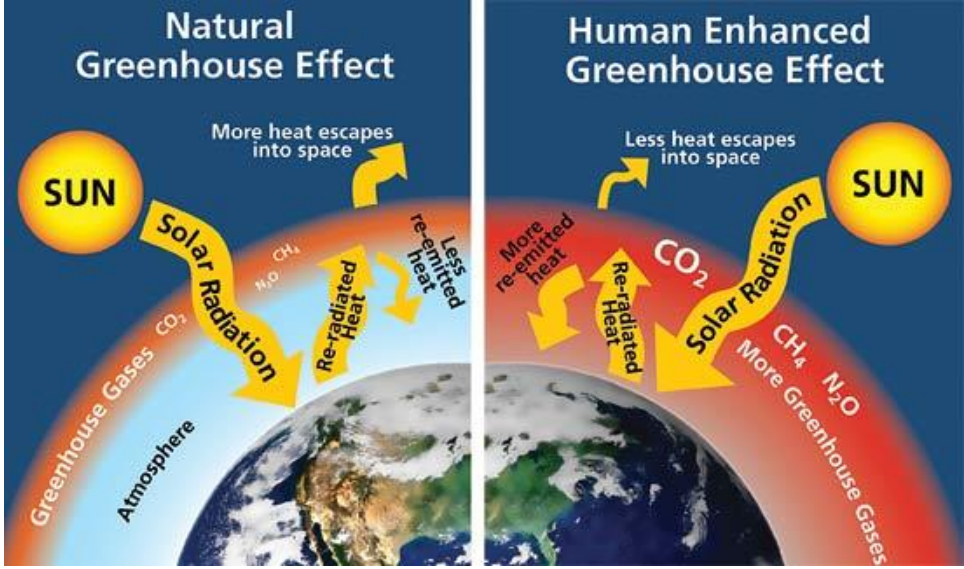
Decomposition temperature (i.e. temperature required for decomposition gas product pressure to reach 1 atm) is different for each mineral

$FeCO_3$	T>200 C
$MnCO_3$	T>400 C
$CaCO_3$	T>900 C
$BaCO_3$	T>1000 C
$Al(OH)_3$	T>1000 C

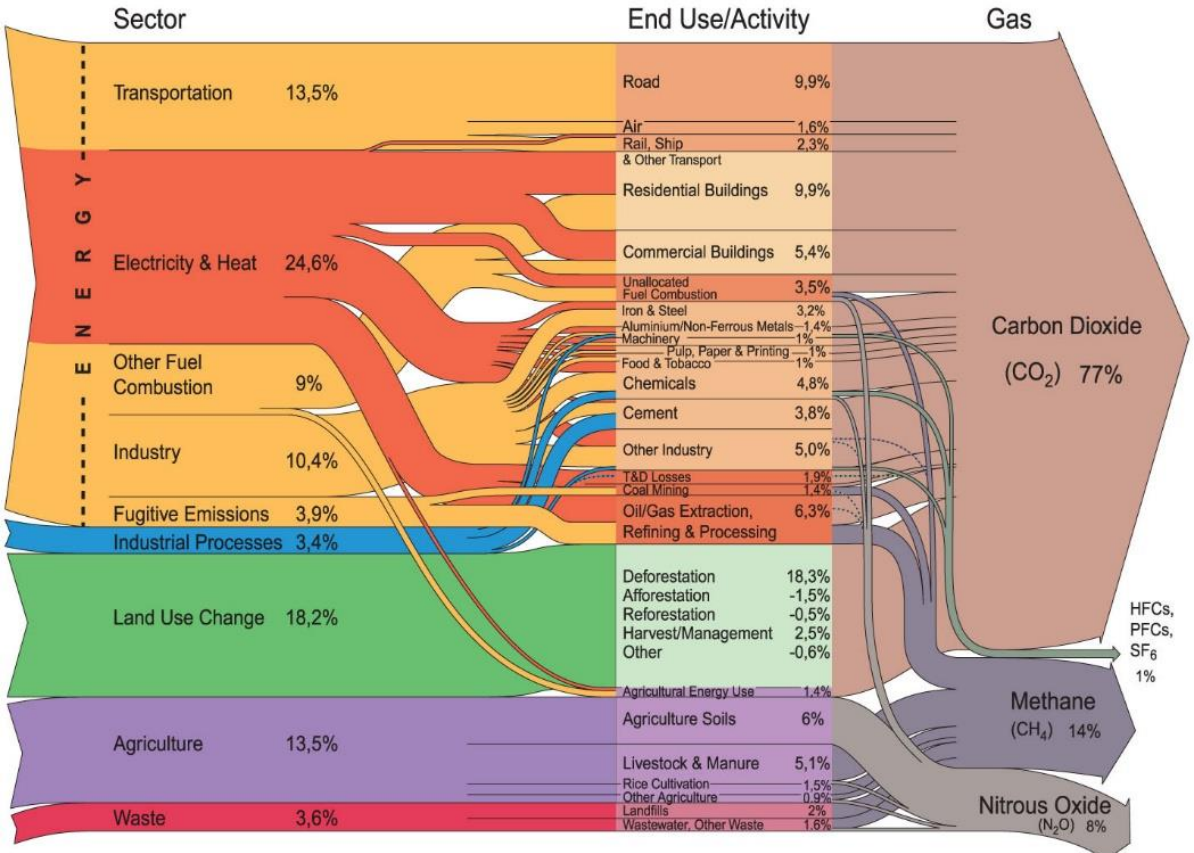


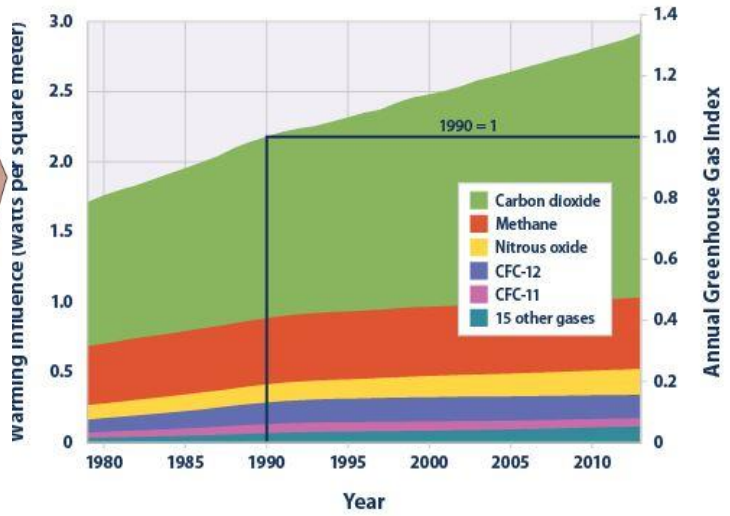
Types of calcination furnaces
Shaft furnace – Calcining coarse particles
Rotary kiln – Particles of mixed coarse and fine size which disintegrate during the process
Fluidized bed furnace – Particles of uniform and fine size

Calcination and iron-making processes are the main industrial contributors to greenhouse gas emissions



World Greenhouse gas emissions by sector





Generally, economically important mineral ores occur as metallic sulfides. Copper smelting is regarded as one of the major man made sources of SO_2, which contributes to acid rain.

Despite the steady reduction of SO_2 emissions since the 1970s and particulate matter emissions since the 1950s, smelting is still a significant source of gaseous and particulate contaminants.

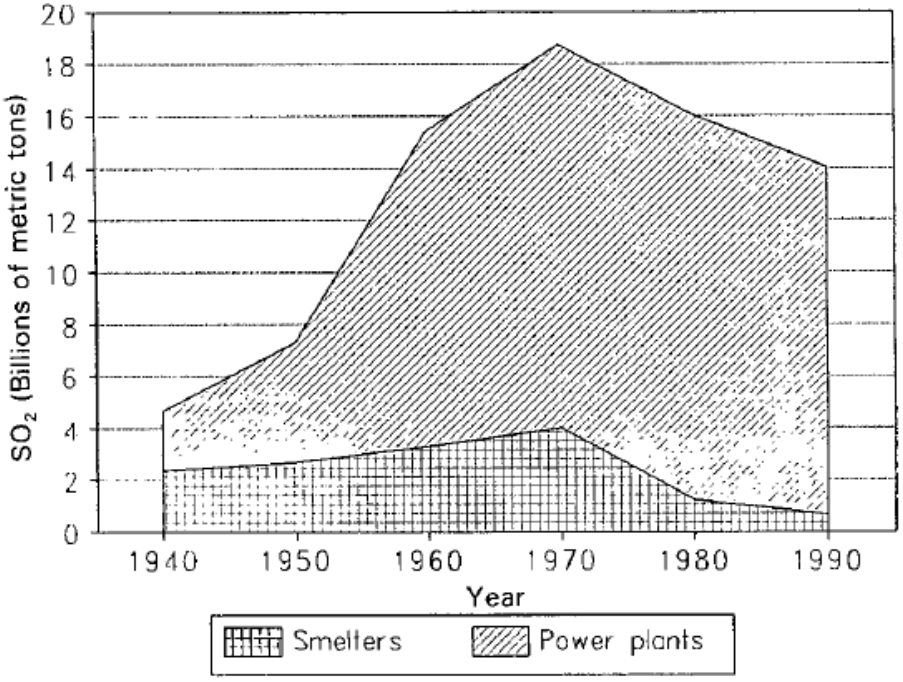


Fig. 1. Estimated global atmospheric emissions of SO_2.

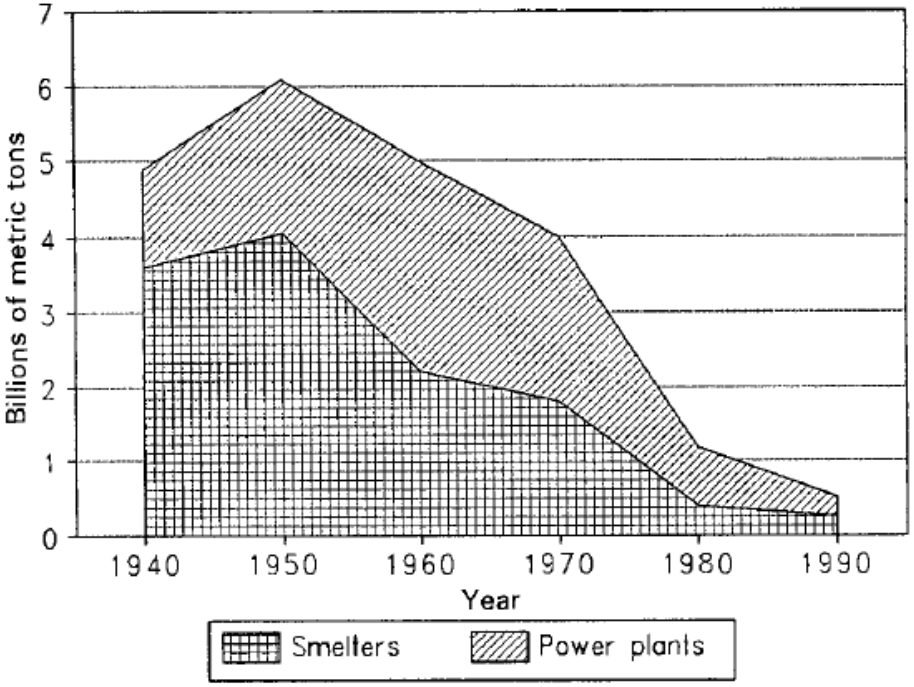


Fig. 2. Estimated global atmospheric emissions of particulate matter.

The Sudbury Ni and Cu smelters in Ontario, Canada produced more SO_2 between 1969 and 1979 than all volcanoes throughout the earth's history Consequently, soil near the three Sudbury smelters had pH values from 3 to 4 and lake water pH from 4 to 5. The water pH has decreased by 1 to 2 units in Sudbury area lakes since preindustrial times as estimated by diatom analysis

Topsoils in the vicinity of smelters contain elevated levels of trace elements The abundance and diversity of soil microorganisms are generally reduced by smelter emissions and acidic soil conditions. This reduction lowers soil fertility by disrupting C and N biogeochemical cycles
Primary metal smelters contribute greatly to the vegetation damages due to SO_2 fumigation, soil acidification, and metal contamination

The trace element uptake from contaminated soils and direct deposition of contaminants from the atmosphere onto plant surfaces can lead to the plant contamination by trace elements. Consequently, plant toxicity and the potential for transfer of contaminating elements along the food chain exist

The gaseous, dust, liquid, and solid wastes discharged from mines and smelters into the environment cause:

- soil and water acidification,
- deterioration of soil biology and fertility,
- soil erosion,
- air, water, soil, and plant contamination by trace elements

Soil degradation

In mining and smelting areas, soils are degraded by disposal of mine tailings, acid mine drainage, and aerial deposition of contaminants from smelters

Soils often undergo strong acidification in areas where metal ores are extracted and processed. This process is caused by acidifying compounds emitted from smoke stacks (pyrite, pyrrotite, chalcopyrite) and draining acidic waters from mines and tailings.

Metal processing does not remove all pyritic minerals so the tailings contain significant sulfide concentrations that oxidize and produce acid:

$$2FeS_2 + \frac{15}{2}O_2 + 7H_2O \rightarrow 2Fe(OH)_3 + 4H_2SO_4$$

The amount acid produced by pyrites is a function of a many variables: temperature, oxygen supply, concentration of sulfides, initial pH of the surroundings, total Fe concentrations, and presence of bacteria

Also emissions of SO_2 from smelters contribute to the soil acidification

Leaching, plant uptake, and runoff of metals from soils increase with soil acidity

For example soils are strongly acidified (pH in range 2.0-7.5) in the Sudbury Cu-Ni mining and smelting basin
Sudbury soils had the concentrations of mobile AI as high as 100 mg/kg, which is one of the factors of plant toxicity of these soils. Also high concentrations of exchangeable Cu and Ni were detected in these soils
There was a linear relationship between the level of the exchangeable metals in the soils and their concentrations in tree leaves

Prolonged soil acidification decreases base saturation
of soils, reduces humus content, and alters mineral composition of soil clay fraction

The abundance and diversity of soil microorganisms (soil fertility) are generally reduced by smelter emissions and acidic conditions

The soil flora of contaminated sites in Sudbury was characterized by a diversity of chlorophytes, and a notable absence of cyanobacteria
Similar results have been reported for soils subject to emissions from various metallurgical plants in Russia: cyanobacteria were absent from soils within a radius of 20 km

The chlorophyte-dominated flora is characteristic of acid soils.
Chlamydomonas acidopholia (green algae isolated from Sudbury soils) were not only acid-tolerant but also metal-tolerant.

Erosion does not change the metal concentrations in the soil material
Its result is translocation of the metal-contaminated material and its dispersion over a bigger area

Wind and water erosion and the associated environmental degradation are widespread problems related to tailing material
Leaching of acidifying compounds from tailings leads to an acidification of adjacent soils

Contamination by trace metals

Mining and smelting are not the main source of global trace metal input into soil. Other sources like discarded manufactured products, coal ashes, agriculture, and transportation are more effective
However, strong soil contamination with trace metals locally in mining/smelting regions has been reported

Table 4. Estimated global inputs of trace elements into soils.†

Element	Discarded manufactured products	Atmospheric fallout‡	Coal ashes	Agriculture§	Other sources¶	Total
	Gg yr^{-1}					
Sb	2.4	2.5 (0.6)	12.0	13.0	3.8	26
As	38.0	13.0 (5.2)	22.0	22.2	2.5	82
Cd	1.2	5.3 (3.3)	7.2	4.8	5.5	22
Cr	458.0	22.0	298.0	116.0	38.0	898
Cu	592.0	25.0 (9.4)	214.0	74.0	71.0	971
Pb	292.0	232.0 (33.1)	144.0	30.2	62.1	959
Mn	300.0	27.0 (0.2)	1076.0	200.0	95.7	1669
Hg	0.7	2.5 (0.05)	2.6	2.5	1.7	8.3
Ni	19.0	24.0 (1.4)	168.0	80.4	35.8	294
Se	0.2	2.0 (0.3)	32.0	10.1	2.1	41
V	1.7	60.0 (0.03)	39.0	6.4	7.1	128
Zn	465.0	92.0 (37.6)	298.0	150.0	149.0	1322

† Nriagu and Pacyna, 1988; Nriagu, 1990.
‡ Number in brackets represent amounts of elements from mining and smelting.
§ Includes agricultural and animal wastes, fertilizers, and peat.
¶ Includes logging and wood wastes, urban refuse, organic wastes, and solid waste from metal fabrication.

Pb and Zn production leads to the most severe soil contamination, not only because of Pb and Zn, but also by Ag, As, Cd, Cu, and Ni

Table 5. Cadmium concentrations in surface soils in the vicinity of mines and smelters.

Range	Mean	Source of contamination	References
mg kg^{-1} dry wt.			
24–440	159	Zn–Pb mining	Matthews and Thornton, 1982
1.0–3.9	1.8	Old mine	Colbourn and Thornton, 1978
0.4–540	6.1	Old mine	Davies and Roberts, 1978
1.2–94	18	Old mine	Davies and White, 1981
0.3–102	2.5	Zn–Pb smelting	Dudka et al., 1995a
0.1–10	4.7	Cu–Ni mining and smelting	Dudka et al., 1995b
0.4–132	3.2	Mining/smelting	Dudka and Sajdak, 1992
1.8–9.2	3.9	Zn–Pb mining and smelting	Asami, 1988a
11–1781	–	Zn smelting	Scokart et al., 1983
3–750	–	Zn smelting	Jordan and Lechevalier, 1975
5–14	–	Cu smelting	Kuo et al., 1983
0.02–10.9	1.1	Cu smelting	Roszyk and Szerszen, 1988a
	12	Zn–Pb smelting	Rauta et al., 1987

Normal Cd soil level: 0.1–1

Table 6. Copper concentrations in surface soils in the vicinity of mines and smelters.

Range	Mean	Source of contamination	Reference
mg kg^{-1} dry wt.			
11–1 890	116.0	Ni–Cu mining and smelting	Dudka et al., 1995b
60–3 700	–	Ni–Cu mining and smelting	Freedman and Hutchinson, 1980
76–9 700	–	Ni–Cu mining and smelting	Hazlett et al., 1983
48–15 000	–	Cu smelting	Rebele et al., 1993
30–3 280	460.5	Cu smelting	Roszyk and Szerszen, 1988a,b
40–1 989	–	Zn smelting	Scokart et al., 1983
24–9 618	–	Cu smelting	Jordan and Lechevalier, 1975

Normal Cu soil level: 2–20

Table 7. Lead concentrations in surface soils in vicinity of mines and smelters.

Range	Mean	Source of contamination	Reference
mg kg^{-1} dry wt.			
6–7 100	160	Zn–Pb smelting	Dudka et al., 1995b
8–710	85	Cu–Pb–Bi smelting	Asami et al., 1990
49–371	150	Ag–Cu–Pb–Zn mining smelting	Asami, 1988a
30–18 400	218.6	Cu smelting	Roszyk and Szerszen, 1988a
28–4 226	–	Cu smelting	Rebele et al., 1993
4–8 200	102	Mining/smelting	Dudka and Sajdak, 1992
475–7 800	3 829	Zn–Pb mining	Matthews and Thornton, 1982
280–448	–	Zn–Pb mining and smelting	Davies and Roberts, 1978
38–14 910	1 759	Pb mining	Davies and White, 1981
190–3 000	–	Old mine	Colbourn and Thornton, 1978
189–14 000	–	Zn smelting	Scokart et al., 1983
92–2 580	862	Zn–Pb smelter	Nwankwo and Elinder, 1979

Normal Pb soil level: 5–30

Table 8. Zinc concentrations in surface soils in vicinity of mines and smelters.

Range	Mean	Source of contamination	References
— mg kg^{-1} dry wt. —			
11–10 500	205	Zn–Pb smelting	Dudka et al., 1995a
49–554	–	Cu smelting	Rebele et al., 1993
238–472	349	Zn–Pb mining and smelting	Thornton et al., 1980
7–910	–	Cu smelting	Drozd et al., 1984
2040–50 000	14 970	Zn–Pb mining	Matthews and Thornton, 1982
10–49 390	728	Zn–Pb mining	Davies and Roberts, 1978
11–641	96	Pb mining	Davies and White, 1981
400–4 245	–	Zn–Pb mining	Letunova and Krivitskiy, 1979
1340–180 000	–	Zn smelting	Scokart et al., 1983
180–3 500	1 050	Zn–Pb smelting	Nwankwo et al., 1979
430–1 370	–	Cu smelting	Kuo et al., 1983
110–60 700	–	Zn smelting	Jordan and Lechevalier, 1975
	554	Ag–Cu–Pb–Zn	Asami, 1988a

Normal Zn soil levels: 15–100

Table 9. Element concentrations in surface soils in vicinity of mines and smelters.

Element	Range	Mean	Normal level	Source of contamination	References
	mg kg^{-1} dry wt.				
As	0.3–145	10.2	1–15	Cu smelting	Roszyk and Szerszen, 1988a
Bi	0.4–122	4.2	0.3	Cu–Pb–Bi smelting	Asami et al., 1992
Cr	30–4560	–	4–80	Cr smelting (smelter slag)	Asami, 1988b
Co	1.3–38.3	5.8	1–10	Cu smelting	Roszyk and Szerszen, 1988b
Hg	0.01–15.1	0.9	0.01–0.5	Cu smelting	Roszyk and Szerszen, 1988b
In	0.02–1.9		0.02–0.08	Zn–Pb mining	Asami et al., 1990
Ni	5–2150	105	2–30	Ni–Cu mining and smelting	Dudka et al., 1995a
	100–3000	–		Ni–Cu mining and smelting	Freedman and Hutchinson, 1980
	160–12300	–		Ni–Cu mining and smelting	Hazlett et al., 1983
	3–450	36		Cu smelting	Roszyk and Szerszen, 1988b
Sb	0.6–37	3.2	0.4	Cu–Pb–Bi smelting	Asami et al., 1990

There is a well-established opinion in the literature that the retention time for trace metals in soils (time span needed to reduce the element concentration by half) is from hundreds to thousands of years

Cd, Ni, and Zn are considered to have the shortest retention time,
Cu medium,
Pb and Cr the longest retention time under similar environmental conditions

The extensive area of Sudbury soils remains barren or semibarren of vegetation as a result of severe environmental conditions. Following environmental improvement in the Sudbury area, several plant species have colonized barren sites; however, recolonization was confined to relatively favorable; sites by species that have evolved metal tolerance

Health effects

Studies done at regions rich with ferrous and nonferrous mining and smelting, hard coal mines, power plants, and industry reveal:

- ambient SO_2 concentrations much greater than the safe level (60 $\mu g/m^3$)
- ambient concentrations of acid aerosols (mainly sulfates) that are high enough to cause a significant deterioration of lung function
- oxygen content of the air decreased by as much as 20%, resulting in a health hazard to heart patients and asthmatics

Such hazardous conditions are believed to be responsible for 15% higher circulatory problems, 30% more cancer cases, and 47% greater respiratory illnesses observed in residents of this region

The case studies performed in the vicinity of the Pb mine and smelter plant revealed that the blood Pb concentrations in exposed children were considerably higher than in a reference group

Primary metal smelters are the main sources of atmospheric emissions of As, Cu, Cd, Sb, and Zn on a global scale and they contribute largely to overall emissions of Cr, Pb, Se, and Ni

Therefore the current levels of metals in the vicinity of many mining and smelting operations are high enough to constitute a hazard to human health

Lets look at the hazardous effects of various metals:
Copper - Environmental concern with Cu production has centered on emissions of SO_2 and easily vaporized trace elements (As, Cd, Hg) from smelters; however Cu emission is also a serious problem.
Lead and Zinc – They are often found together in ore deposits, but the metals have different applications and biological effects. Zinc is a physiologically essential element, whereas Pb has no known positive biological function and creates serious environmental and health hazards

Lead and Zn processing is an important historical source of environmental contamination with Cd, Pb, Zn, and other elements

Lead oxides and sulfates from flue gases are soluble and can be moved to deep levels in the soil by rainwater. They are also dispersed from the source because of their small particle size

Arsenic – It is well-known for its toxicity. Large doses of As (>100 mg per person) induce acute arsenic poisoning resulting in death

Arsenic vaporizes at only 615°C and therefore is released during the roasting of base-metal ores. Older smelters did not capture this vaporized metal at scrubbers and are surrounded by zones rich in As. (e.g. Sudbury)

Cadmium – It is regarded as, potentially, one of the most toxic trace elements in the environment. Cadmium is particularly hazardous because of its easy uptake by plants and its tendency to accumulate in food chain crops.

About 60% of the total input of Cd into air comes from smelting and mining. The metal is recovered from flue dust during the roasting and sintering of sphalerite and in sludge from the electrolytic refining of Zn. With the production of 1 Mg Zn, 3 kg of Cd are produced