Chapter 3

Hydro- & Pyro-Metallurgical Processes

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Spring 2022
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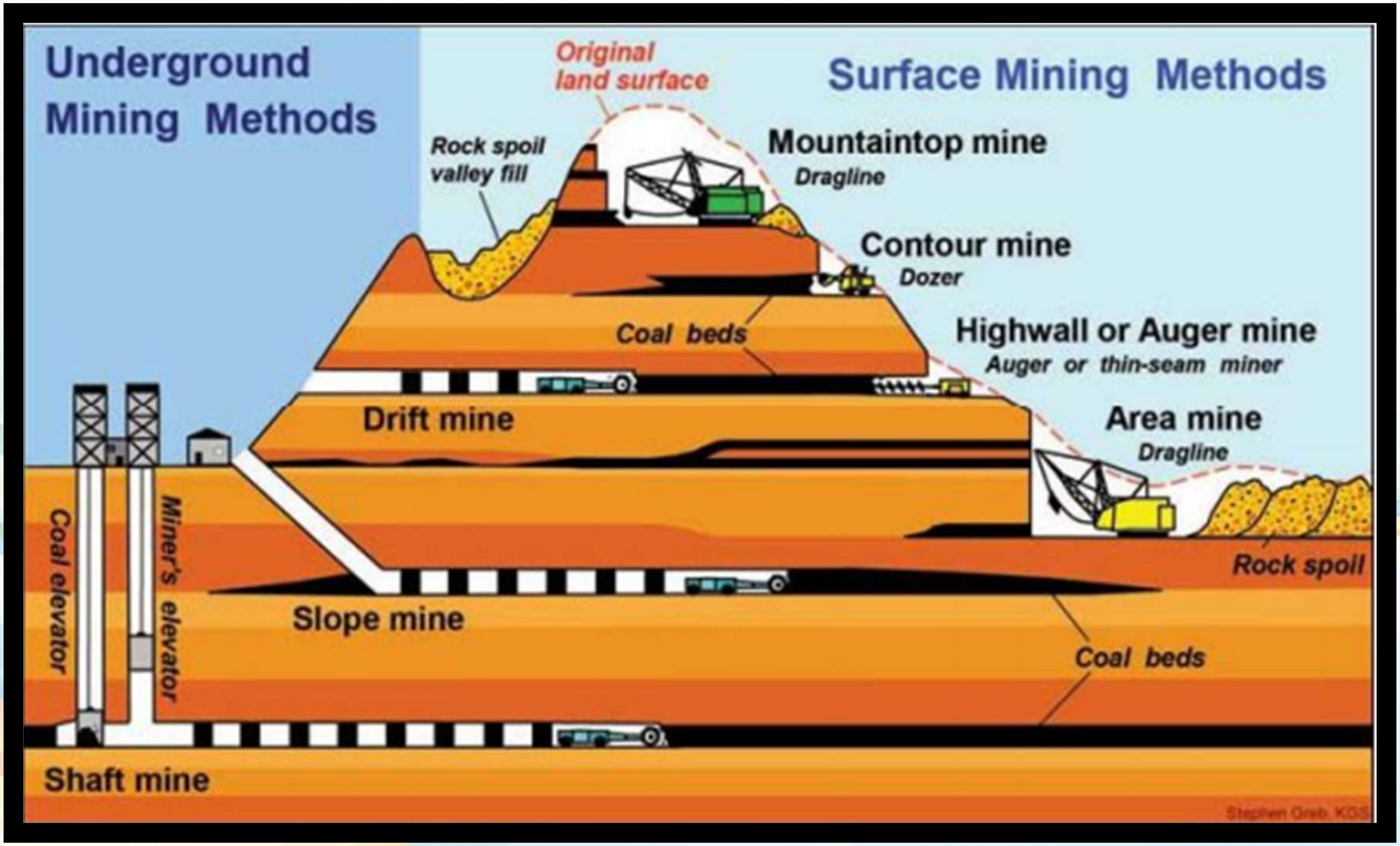
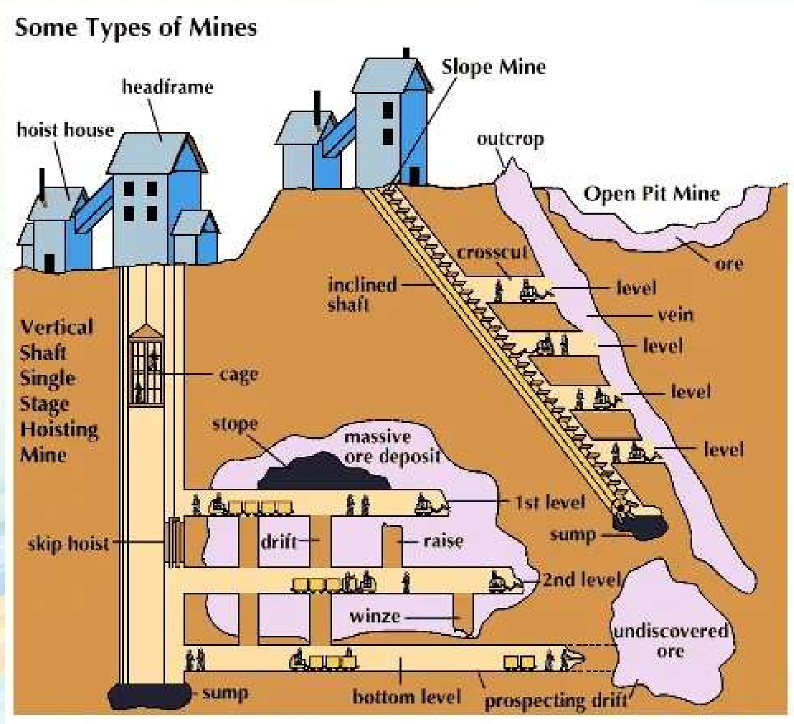
Methods of Mining



Underground Mining

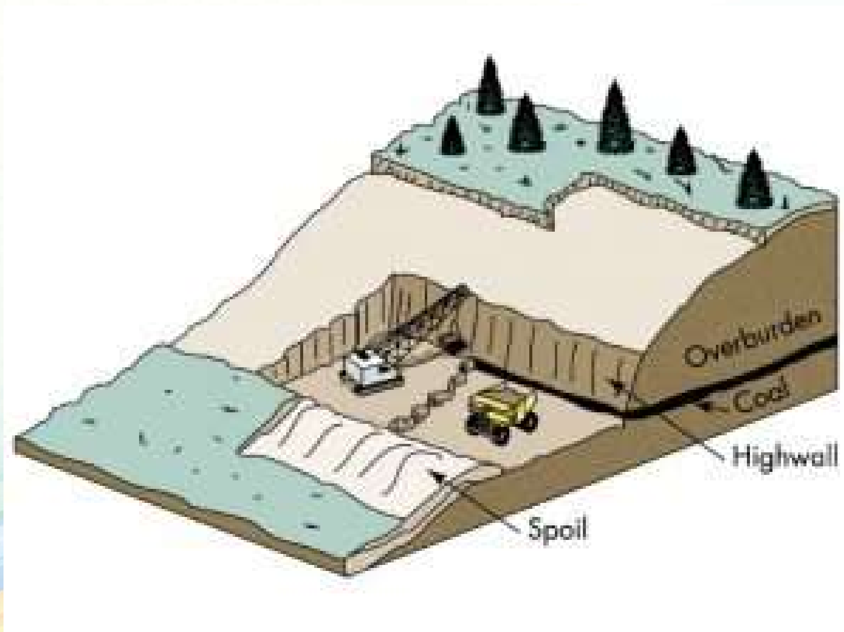
Underground modes of access include drift, slope, and shaft mining.

- Drift mines enter horizontally into the side of a hill and mine the ore within the hill.
- Slope mines usually begin in a valley bottom, and a tunnel slopes down to the ore to be mined.
- Shaft mines are the deepest mines; a vertical shaft with an elevator is made from the surface down to the ore deposit.



Surface Mining

- Surface mining is generally used when the ore is found relatively close to the surface, when multiple seams in close vertical proximity are being mined or when conditions otherwise warrant.
- Surface mining involves the removal of overburden (earth and rock covering the ore) with heavy earth moving equipment and explosives.
- Surface-mining methods include area, contour, mountaintop removal, and auger mining.

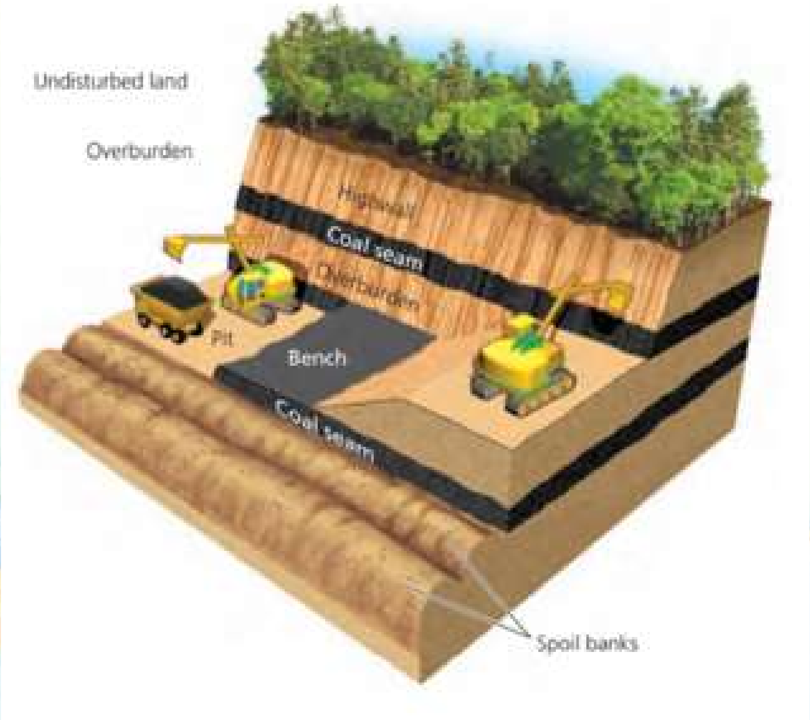


Area and Augur Mining

- Area mines are surface mines that remove shallow ore over a broad area where the land is fairly flat.
- Huge dragline shovels commonly remove rocks overlying the ore.
- After the ore has been removed, the rock is placed back into the pit.
- Augur mines are operated on surface-mine benches; the ore in the side of the hill that can't be reached by contour mining is drilled out.

Contour Mining

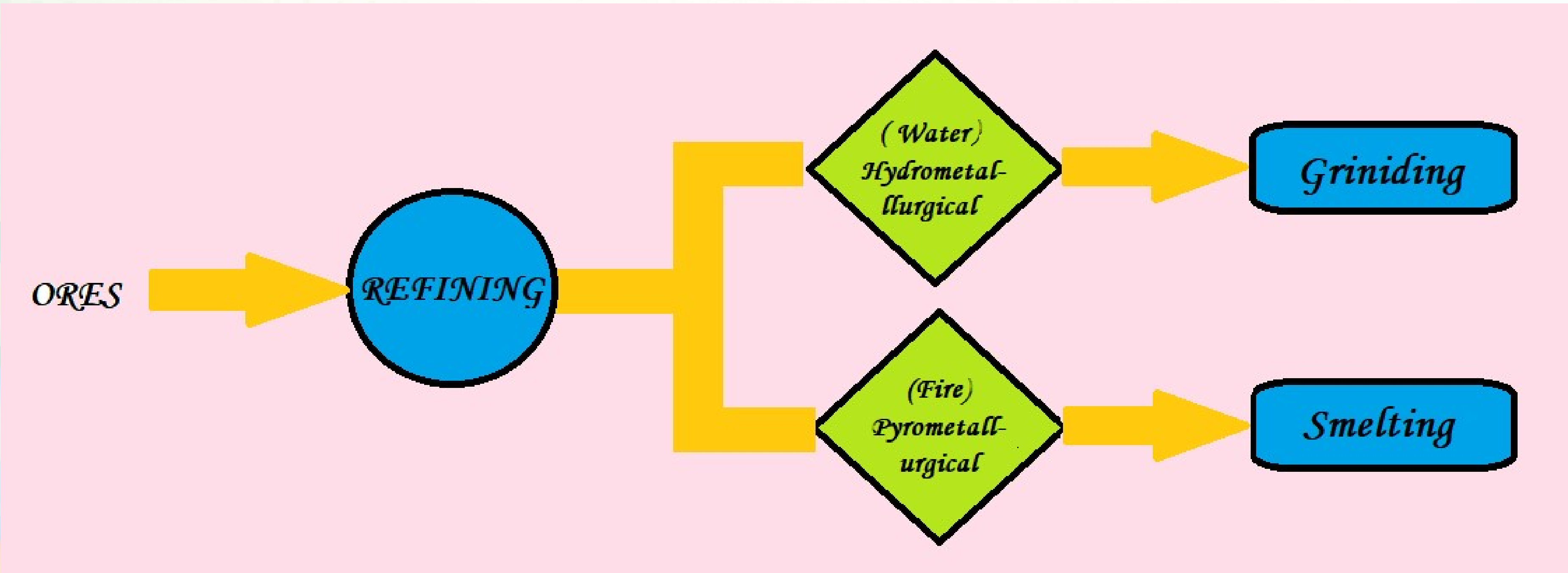
- Contour mines are surface mines that mine ore in steep, hilly, or mountainous terrain.
- A wedge of overburden is removed along the ore outcrop on the side of a hill, forming a bench at the level of the ore.
- After the ore is removed, the overburden is placed back on the bench to return the hill to its natural slope.



Mountaintop Mining

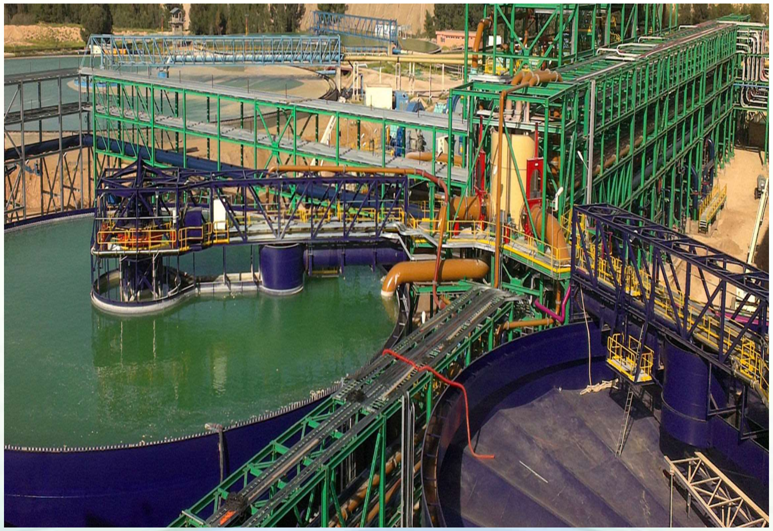
- Mountaintop removal mines are special area mines used where several thick ore seams occur near the top of a mountain.
- Large quantities of overburden are removed from the top of the mountains, and this material is used to fill in valleys next to the mine.

Ores Refining



What is Hydrometallurgy

- Hydrometallurgy is a method for obtaining metals from their ores.
- It is a technique within the field of extractive metallurgy involving the use of aqueous chemistry for the recovery of metals from ores, concentrates, and recycled or residual materials.

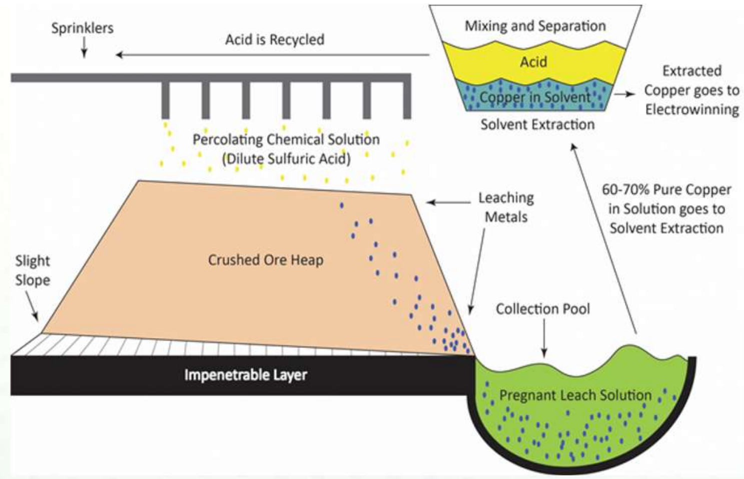


- Hydrometallurgy is typically divided into three general areas:
  a) Leaching
  b) Solution concentration and purification
  c) Metal recovery

a) Leaching

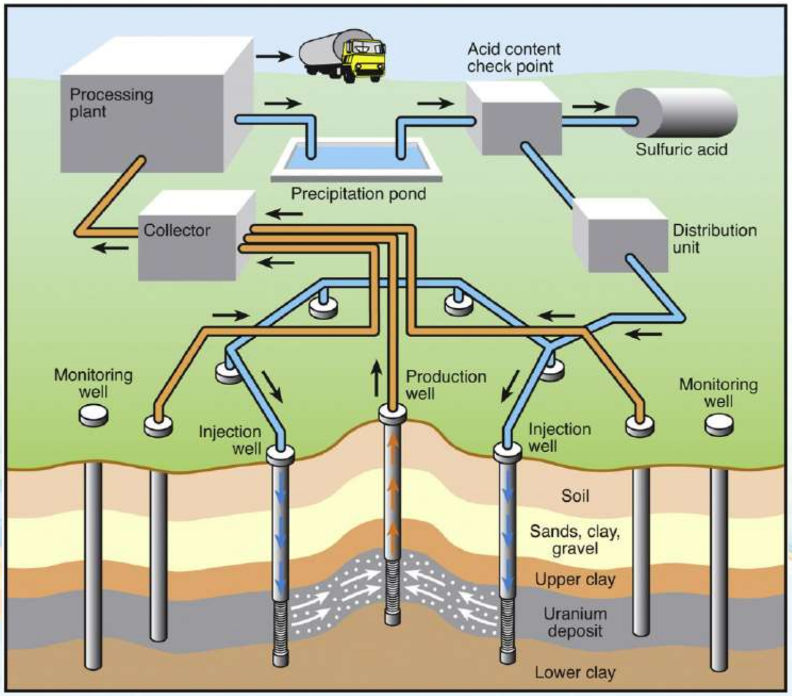
- Leaching involves the use of aqueous solutions containing a lixiviant which is brought into contact with a material containing a valuable metal.
- Lixiviant is a liquid medium used in hydrometallurgy to selectively extract the desired metal from the ore or mineral.
- It assists in rapid and complete leaching. The metal can be recovered from it in a concentrated form after leaching.
- The lixiviant in solution may be acidic or basic in nature.
- The type and concentration of the lixiviant is normally controlled to allow some degree of selectivity for the metal or metals that are to be recovered.

- *In the leaching process, the most important parameters are:*
    1. *Oxidation potential*
    2. *Temperature*
    3. *pH of the solution*
- *These parameters are often manipulated to optimize dissolution of the desired metal component into the aqueous phase.*
- *The four basic leaching techniques are:*
    1. *In-situ leaching*
    2. *Heap leaching*
    3. *Vat leaching*
    4. *Dump leaching*



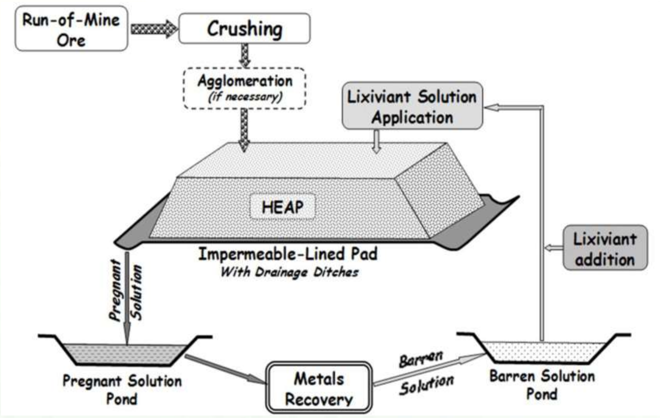
1. In-situ leaching

- *In-situ leaching is also called "solution mining".*
- *The process initially involves drilling of holes into the ore deposit.*
- *Explosives or hydraulic fracturing are used to create open pathways within the deposit for solution to penetrate into.*
- *Leaching solution is pumped into the deposit where it makes contact with the ore.*
- *The solution is then collected and processed.*
- *The Beverley uranium deposit is an example of in- situ leaching.*



2. Heap leaching

- In heap leaching processes, crushed (and sometimes agglomerated) ore is piled in a heap which is lined with an impervious layer.
- Leach solution is sprayed over the top of the heap, and allowed to percolate downward through the heap.
- The heap design usually incorporates collection sumps which allow the "pregnant" leach solution (i.e. solution with dissolved valuable metals) to be pumped for further processing.



3. Vat leaching

- Vat leaching involves contacting material, which has usually undergone size reduction and classification, with leach solution in large tanks or vats.
- Often the vats are equipped with agitators to keep the solids in suspension in the vats and improve the solid to liquid contact.
- After vat leaching, the leached solids and pregnant solution are usually separated prior to further processing.

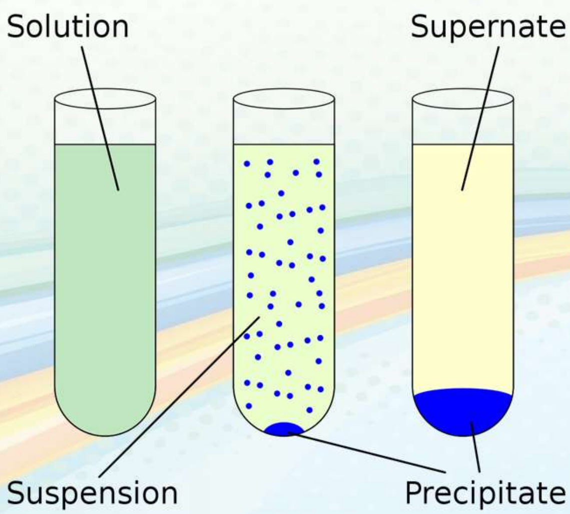
4. Dump leaching

- Dump leaching combines characteristics of heap leaching and in-situ leaching.
- In a dump leach, an impervious layer may or may not be used depending on the dump location.
- Ore is dumped to allow processing similar to heap leaching, but the physical characteristics of the location allow for a valley or pit to act as the sump.

b) Solution Concentration and Purification

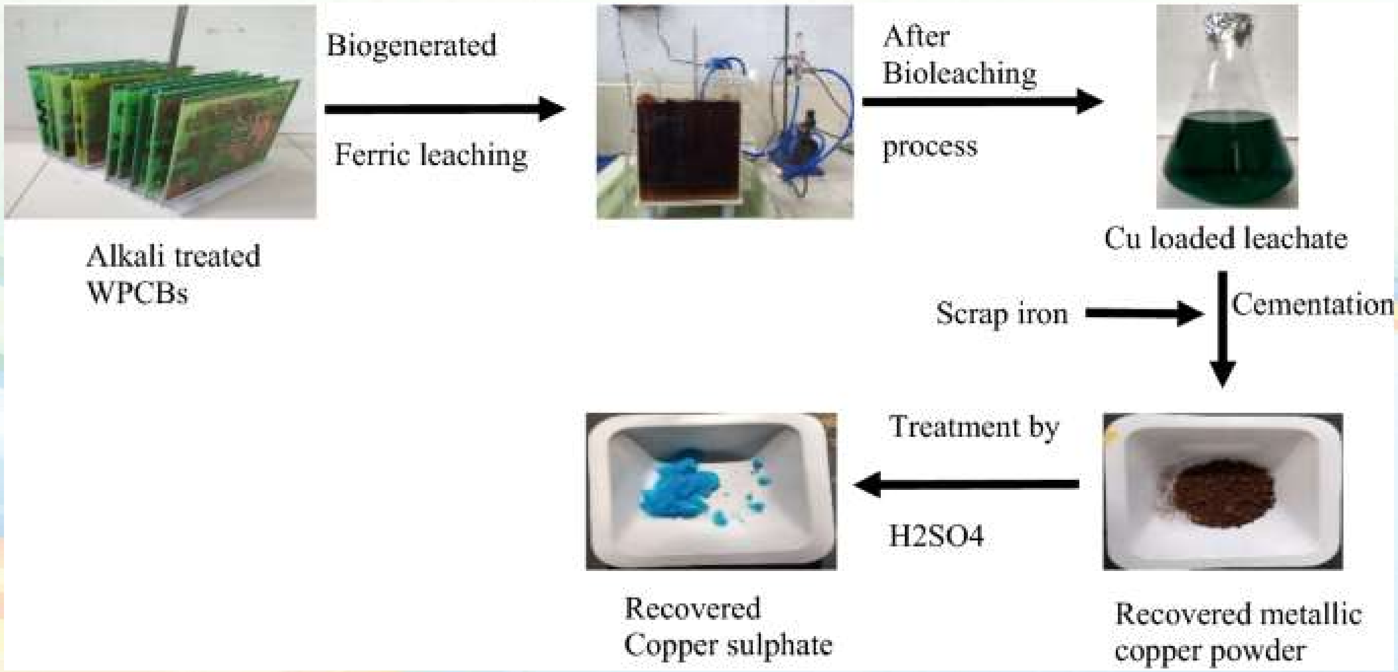
- After leaching, the leached liquor must normally undergo concentration of the metal ions that are to be recovered.
- Additionally, undesirable metal ions sometimes require removal.

1. Precipitation
2. Cementation
3. Solvent Extraction
4. Ion Exchange



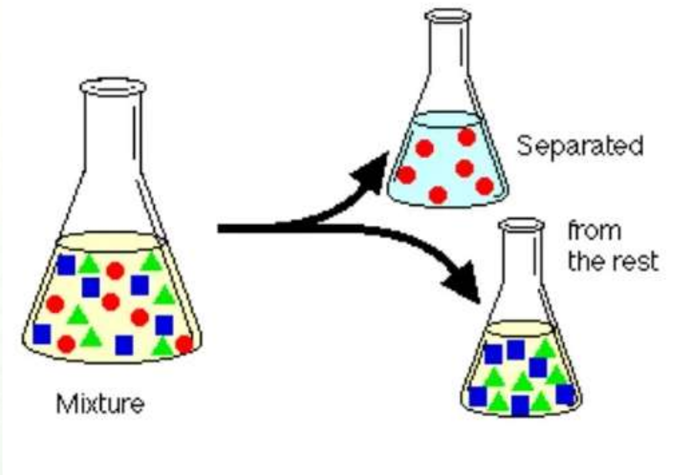
2. Cementation

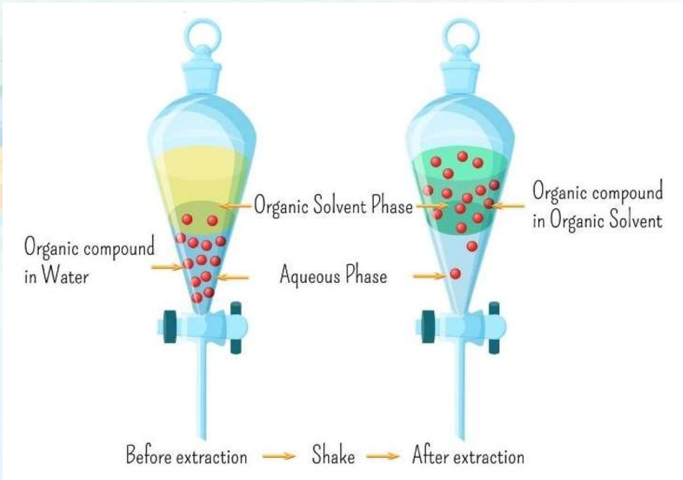
- *Cementation is the process of extracting the metals from a solution based on the electrochemical reaction between the cementing metal and the ion of the precipitated metal.*



3. Solvent extraction

- A mixture of an extractant in a diluent is used to extract a metal from one phase to another.
- In solvent extraction this mixture is often referred to as the "organic" because the main constituent (diluent) is some type of oil.
- The PLS (pregnant leach solution) is mixed to emulsification with the stripped organic and allowed to separate.
- The metal will be exchanged from the PLS to the organic they are modified.

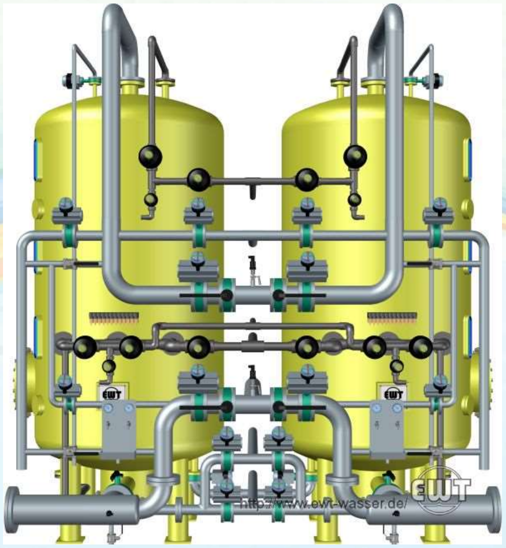




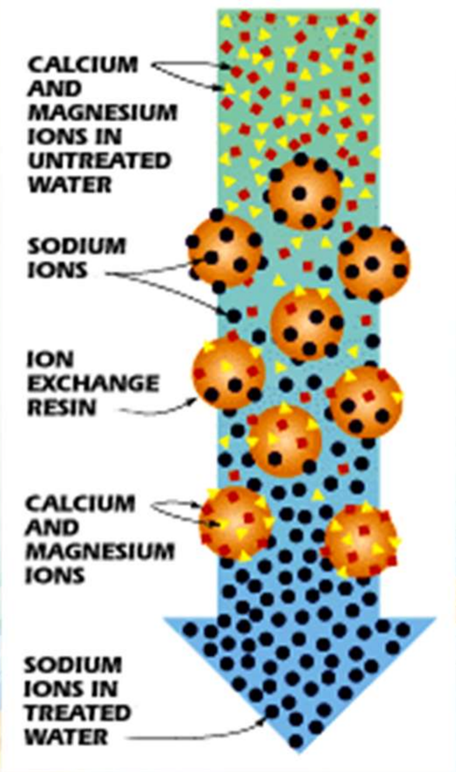
- The resulting streams will be a loaded organic and a raffinate.
- When dealing with electrowinning, the loaded organic is then mixed to emulsification with a lean electrolyte and allowed to separate.
- The metal will be exchanged from the organic to the electrolyte.
- The resulting streams will be a stripped organic and a rich electrolyte.
- The organic stream is recycled through the solvent extraction process while the aqueous streams cycle through leaching and electrowinning processes respectively.

4. Ion Exchange

- Agents that can be used to exchange cations or anions with the solution are:
  1. Chelating agents
  2. Natural zeolite
  3. Activated carbon
  4. Resins
  5. Liquid organics impregnated with chelating.
- Selectivity and recovery are a function of the reagents used and the contaminants present.



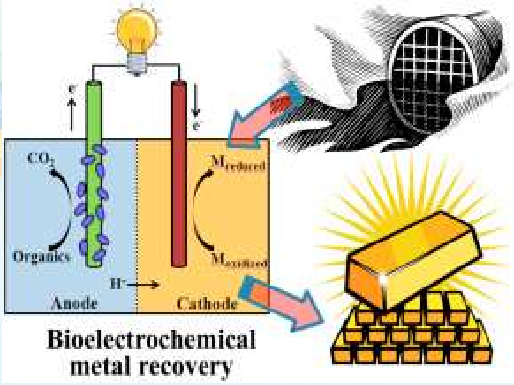
- *Often hydrometallurgy involves the use of chelating agents, which can selectively bind certain metals.*
- *Such chelating agents are typically amines of Schiff bases.*
- *Schiff bases are any of a class of derivatives of the condensation of aldehydes or ketones with primary amines; colorless crystals, weakly basic. Hydrolyzed by water and strong acids to form carbonyl compounds and amines.*



- *Hard water, loaded with Calcium, Magnesium, and many other ions, enters the water softener and contacts millions of special resin beads which hold billions of sodium ions.*
- *The Calcium, Magnesium, and other ions trade places with the Sodium ions, creating softened water.*

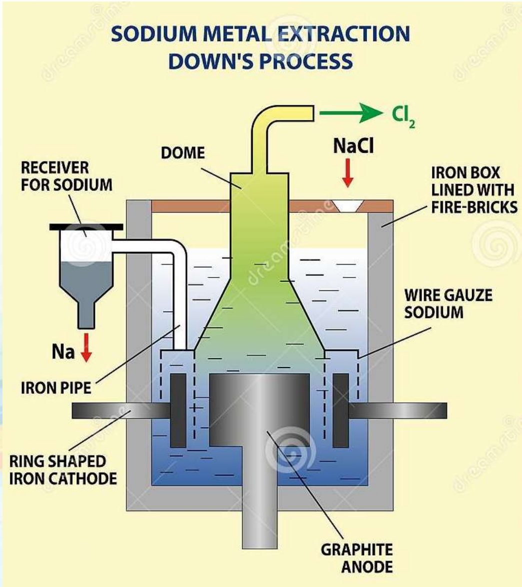
c) Metal Recovery

- Metal recovery is the final step in a hydrometallurgical process.
- Metals suitable for sale as raw materials are often directly produced in the metal recovery step.
- Sometimes, however, further refining is required if ultra-high purity metals are to be produced.
- The primary types of metal recovery processes are:
  1. Electrolysis
  2. Gaseous reduction
  3. Precipitation.



1. Electrolysis

- *Electrowinning and electrorefining respectively involve the recovery and purification of metals using electrodeposition of metals at the cathode, and either metal dissolution or a competing oxidation reaction at the anode.*
- *Electrowinning, also called electroextraction, is the electrodeposition of metals from their ores that have been put in solution or liquefied.*
- *Electrorefining uses a similar process to remove impurities from a metal.*
- *Both processes use electroplating on a large scale and are important techniques for the economical and straightforward purification of non-ferrous metals.*

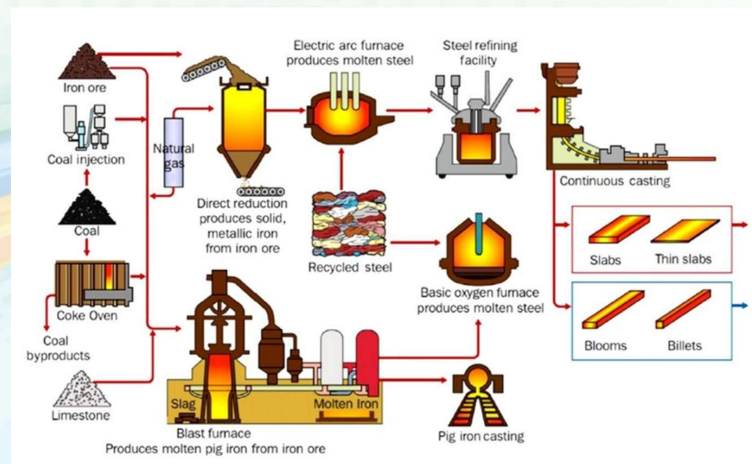


3. Precipitation

- *Precipitation in hydrometallurgy involves the chemical precipitation of either metals and their compounds or of the contaminants from aqueous solutions.*
- *Precipitation will proceed when, through reagent addition, evaporation, pH change or temperature manipulation, any given species exceeds its limit of solubility.*
- *In order to improve efficiency in downstream processes, seeding to initiate crystallization is often used.*

Pyrometallurgical mining

- *Pyrometallurgy is a branch of extractive metallurgy that consists of the thermal treatment of minerals and metallurgical ores and concentrates to bring about physical and chemical transformations in the materials to enable recovery of valuable metals.*
- *Pyrometallurgical treatment may produce saleable products such as pure metals or intermediate compounds or alloys suitable as feed for further processing.*



Categories

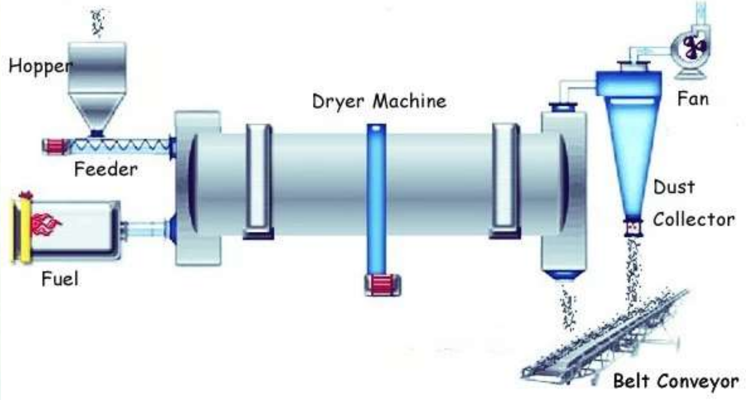
- Pyrometallurgical processes are generally grouped into one or more of the following categories:

1. Drying
2. Calcining
3. Roasting
4. Smelting
5. Refining

- *Most pyrometallurgical processes require energy input to sustain the temperature at which the process takes place.*
- *The energy is usually provided in the form of fossil fuel combustion exothermic reaction of the material or from electrical heat.*
- *When enough material is present in the feed to sustain the process temperature solely by exothermic reaction (without the addition of fuel or electrical heat) the process is said to be autogenous.*

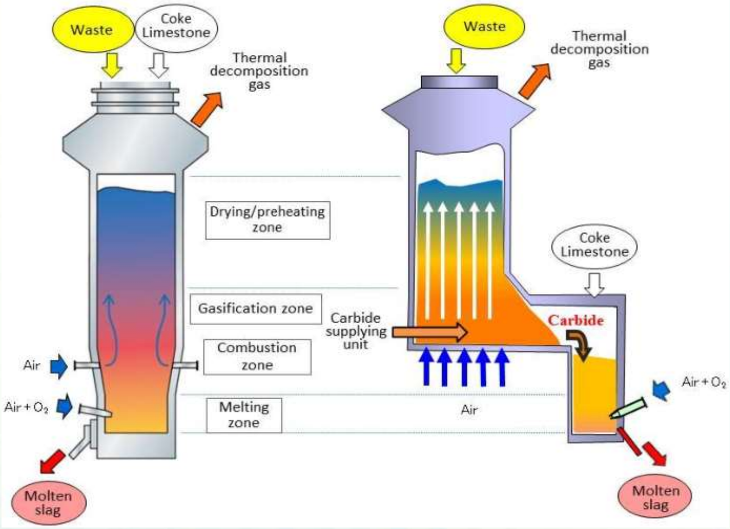
1. Drying

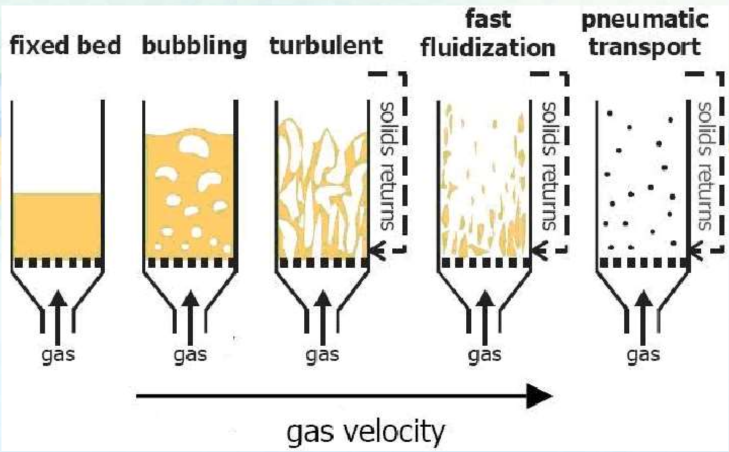
- *Drying is thermal removal of liquid moisture (not chemically bound) from a material.*
- *Drying is usually accomplished by contacting the moist solids with hot combustion gases generated by burning fossil fuels.*
- *In some cases, heat for drying can be provided by hot air or inert gas that has been indirectly heated.*
- *Drying of moist solids is carried out in several types of industrial dryers including rotary dryers, fluidized bed dryers, flash dryers, and spray dryers.*



2. Calcining

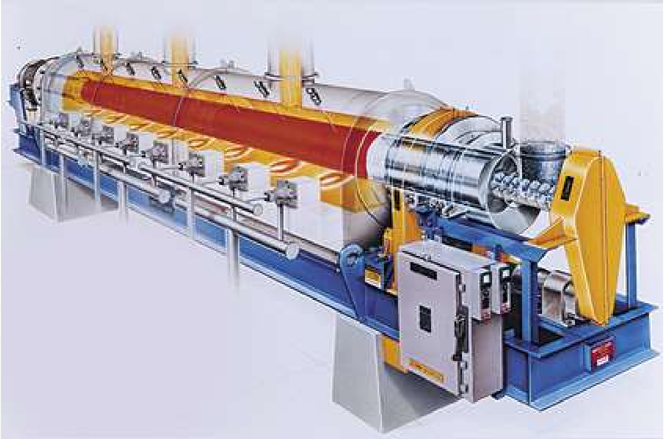
- Calcining is thermal decomposition of a material.
- Examples include decomposition of hydrates such as ferric hydroxide to ferric oxide and water vapor or decomposition of calcium carbonate to calcium oxide and carbon dioxide or iron carbonate to iron oxide.
- Calcination processes are carried out in a variety of furnaces including shaft furnaces rotary kilns and fluidized bed reactors.





3. Roasting

- Roasting consists of thermal gas-solid reactions which can include oxidation reduction chlorination sulfation and pyro hydrolysis.
- The most common example of roasting is the oxidation of metal sulfide ores.
- The metal sulfide is heated in the presence of air to a temperature that allows the oxygen in the air to react with the sulfide to form sulfur dioxide gas and solid metal oxide.
- The solid product from roasting is often called calcine.



4. Smelting

- *Smelting involves thermal reactions in which at least one product is a molten phase.*
- *Metal oxides can then be smelted by heating with coke or charcoal (forms of carbon) a reducing agent that liberates the oxygen as carbon dioxide leaving a refined mineral.*
- *Concern about the production of carbon dioxide is only a recent worry following the identification of the enhanced greenhouse effect.*
- *Carbonate ores are also smelted with charcoal but are sometimes need to be calcined first.*

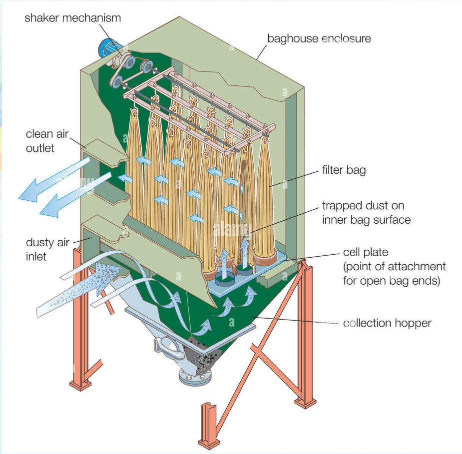
5. Refining

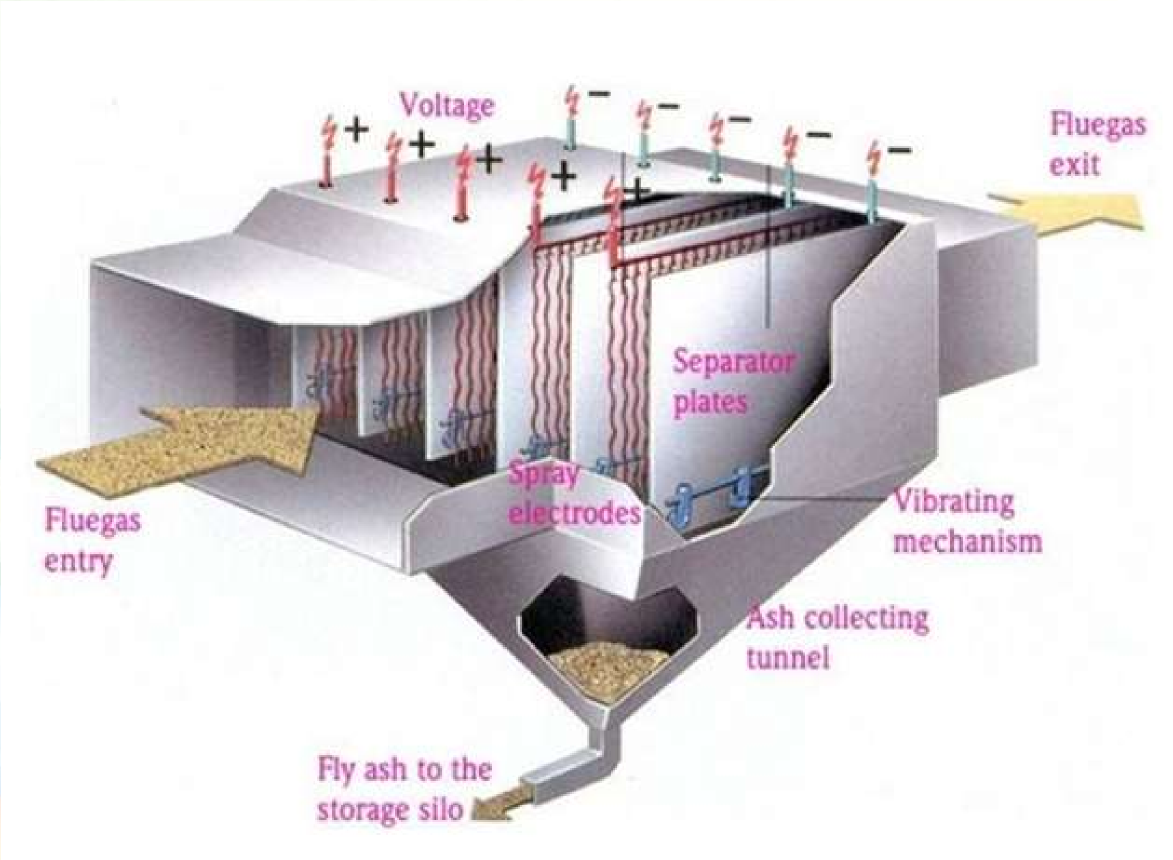
- Refining is the removal of impurities from materials by a thermal process.
- This covers a wide range of processes involving different kinds of furnace or other plant.
- The term refining can also refer to certain electrolytic processes.
- Accordingly some kinds of pyrometallurgical refining are referred to as 'fire refining'.

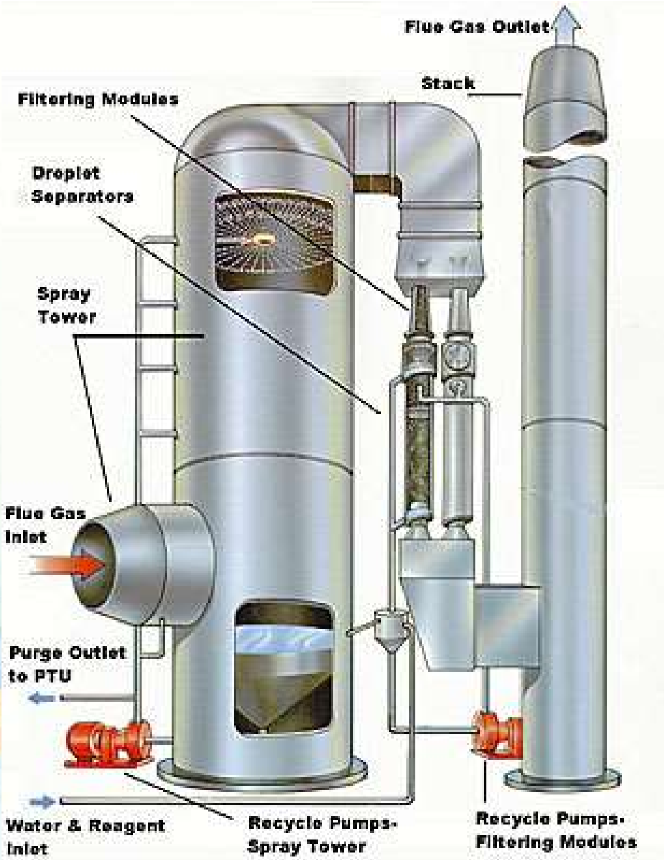
Environmental Aspects

- The gases produced by pyrometallurgical processes often present air pollution problems.
- In the early part of the 20th century gaseous pollution from pyrometallurgical processes was largely uncontrolled.
- For example waste gases from roasting near Queenstown Tasmania over the years killed off all the vegetation which then allowed all the top soil to erode.
- The result was a dramatic and unnatural change to the surrounding terrain.

- Dust or "fume" from pyrometallurgical processes presented serious hazards related to the health and safety for workers in, and residents near pyrometallurgical plants.
- These metallurgical dusts often contained arsenic cadmium, mercury, lead, zinc, and other heavy metals.
- At the same time dust losses from metallurgical plants also represented loss of potentially valuable product.
- Dust capture technologies were developed such as baghouses and electrostatic precipitators.
- Gas treatment techniques were also developed such as wet gas scrubbing.







Electrostatic Precipitators

Wet Gas Scrubbing