NEW PERSPECTIVES IN METALLURGY WITH SPECIAL REFERENCE TO MULTI-REFRACTORY LEVEL ORES

Presented by

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INTRODUCTION

Many new developments in metallurgy are driven by the need to process refractory ores.

In extractive metallurgy, “refractory” is generally used in a relative sense, and means that the ore is not amenable to treatment by a “conventional” process. For example, refractory gold ores are those which are not amenable to “conventional” cyanide leaching.

This presentation focusses on process developments for ores which are refractory on more than one level.

INTRODUCTION

The examples presented cover a variety of challenges in the treatment of base and precious metal ores including:

- Encapsulation in sulphides
- Reduced recovery due to preg-robbing
- Polymetallic ores
- Mixed oxide-sulphide ores
- High leach reagent consumption
- Low recovery by sulphide flotation
- Environmental issues
- Process only applicable to one ore zone
- High capex

In each case, the refractory issues are identified, and possible broader implications of the new technology are presented.

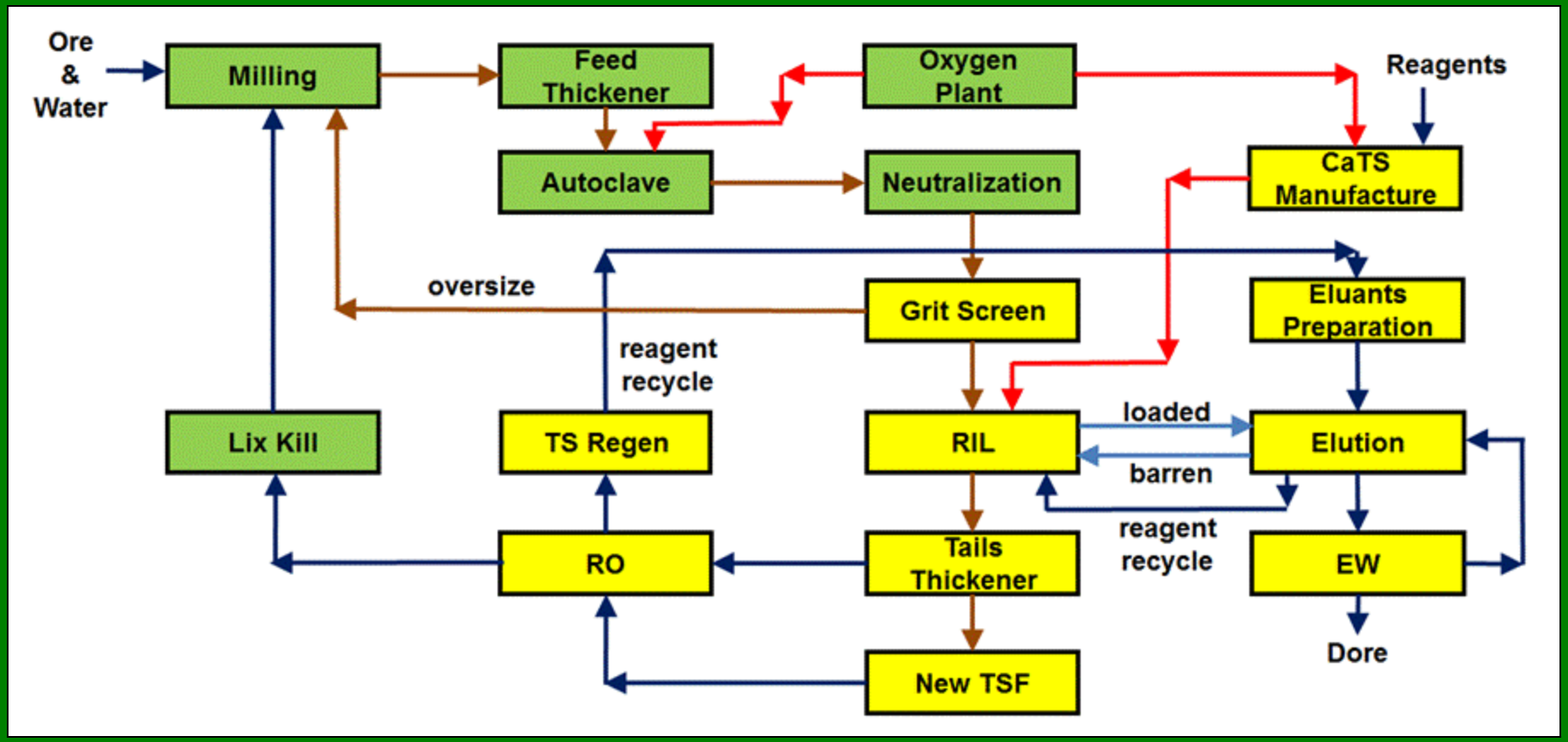
DOUBLE REFRACTORY GOLD ORES

THIOSULPHATE LEACHING PROCESS

- Developed by Barrick Gold, Canada for double refractory ore at Goldstrike, Nevada.
- Processing problems :
  - Colloidal gold locked in arsenian pyrite and marcasite
  - Preg-robbing in CIL due to high carbonaceous material.
- Comprises pressure oxidation to liberate gold then resin-in-leach with calcium thiosulphate which is not affected by preg-robbing.
- Enables Barrick to utilize existing autoclave capacity.
- Demonstration plant operated 2010-2011; commercial plant due on stream Q4 2014.

BARRICK THIOSULPHATE PROCESS FLOWSHEET

Ref: Barrick Presentation, ALTA 2013



IMPLICATIONS

- Alternative to roasting/CIL for preg-robbing/refractory ores which require stringent off-gas cleaning to meet environmental standards.

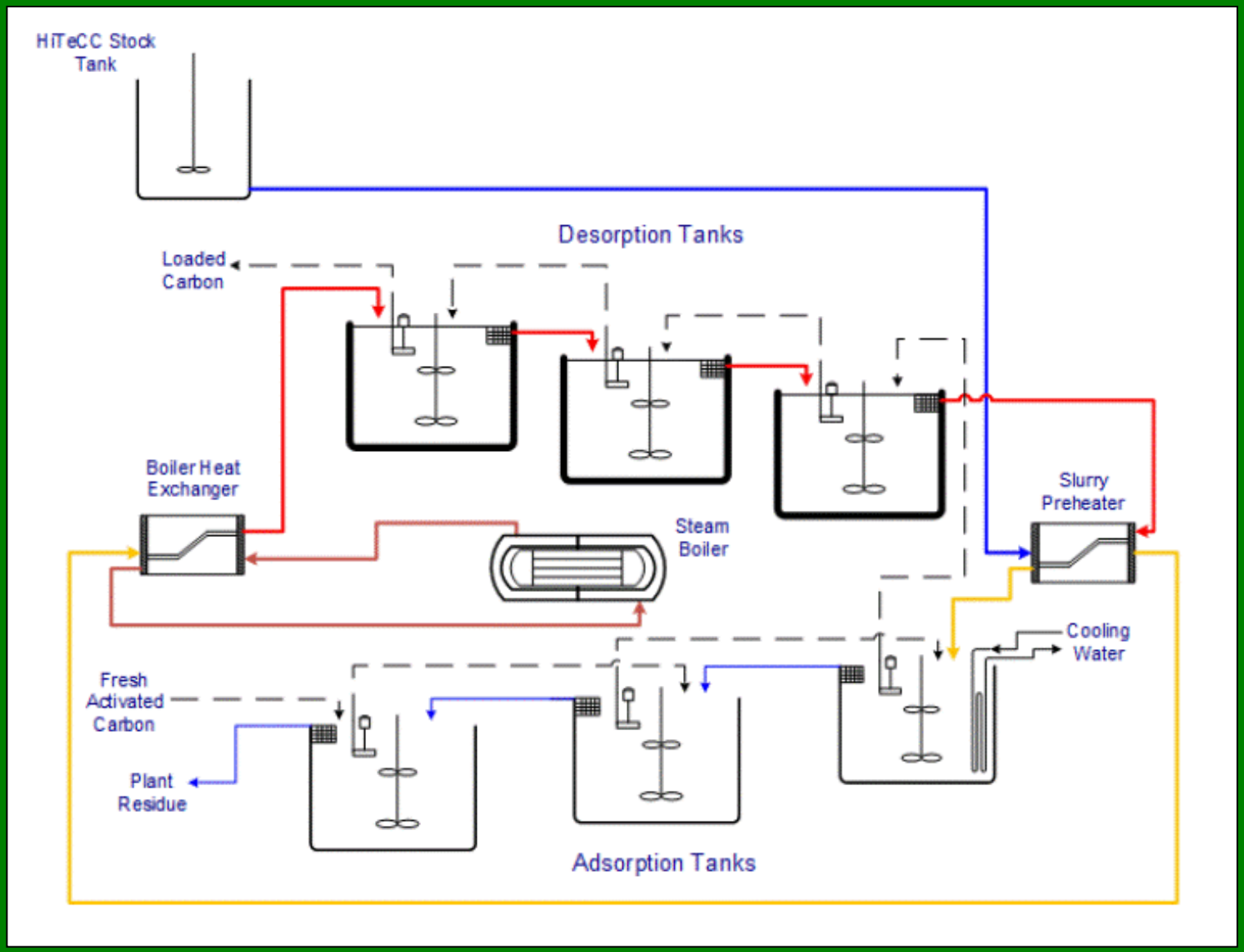
- Provides a non-toxic commercially applied alternative to cyanide for locations where it is difficult to meet environmental regulations or where cyanide is banned.

HiTeCC PROCESS

- Developed and commercially applied at Fosterville Gold Mine, Bendigo, Australia, as Heated Leach Process for the recovery of preg-robbed gold from double refractory ores treated by flotation/bio-oxidation/CIL.
- Rights acquired by BIOMIN, South Africa, in 2013 and further optimized as HiTeCC (High Temperature Caustic Conditioning) Process.
- Following CIL, gold is desorbed from the carbonaceous material at up to 70°C after caustic conditioning, then re-absorbed by activated carbon after cooling in a heat exchanger and water cooling.
- A HiTeCC system has been installed at Nordgold's Suzdal BIOX® plant in Kazakhstan; commissioning is due in Q4 2014.

HiTeCC FLOWSHEET

Ref: BIOMIN Presentation, ALTA 2014



IMPLICATIONS

- Improved performance of bio-oxidation for preg-robbing/refractory ores.

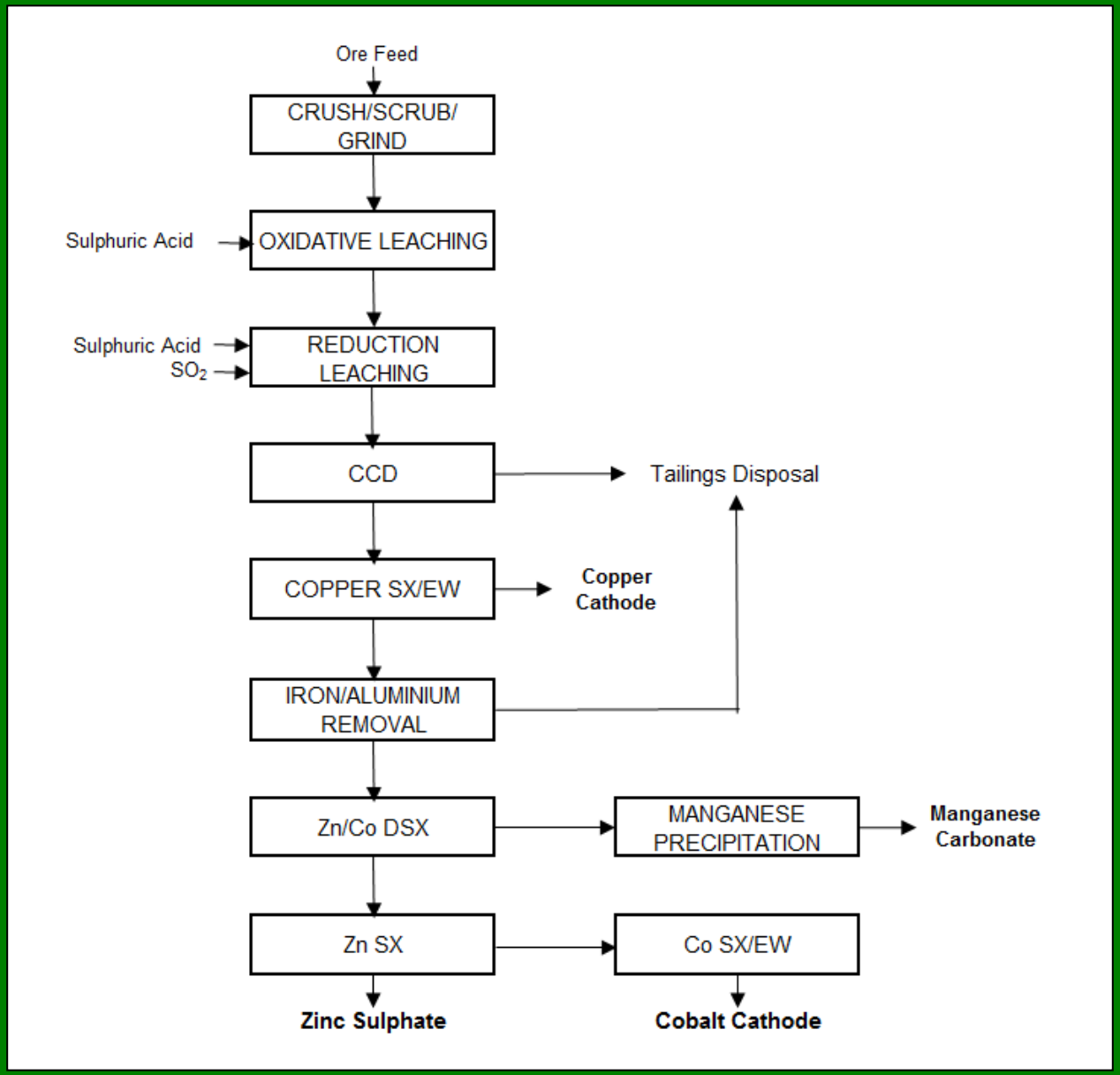
- Could possibly be considered as an alternative to thiosulphate leaching for treating preg-robbing material after pressure oxidation where the use of cyanide is acceptable.

COMPLEX POLYMETALLIC BASE METAL ORES

BOLEO OXIDATIVE/REDUCTION LEACHING PROCESS

- Developed by Baja Mining, Vancouver, for recovery of copper, cobalt, zinc & manganese from Boleo mixed oxide/sulphide ore at Santa Rosalia, Mexico, now owned by KORES consortium, Korea.
- Processing problems:
  - Ore not amenable to flotation as smelter feed.
  - Sulphide minerals require oxidation to render amenable to acid leaching.
  - Conventional separation methods not suitable for Zn, Co, Mn.
- Leaching with sulphuric acid in sea water. Reactive sulphides oxidized by MnO_2 in the ore. SO_2 is used to reduce Mn and Co.
- After conventional copper SX, zinc and cobalt are co-extracted from a bleed stream and separated from manganese by novel DSX (Direct Solvent Extraction) process developed by CSIRO, Perth which uses a synergistic mixture of organic extractants.
- Commencement of copper production is due Q4 2014.

BOLEO PROCESS FLOWSHEET



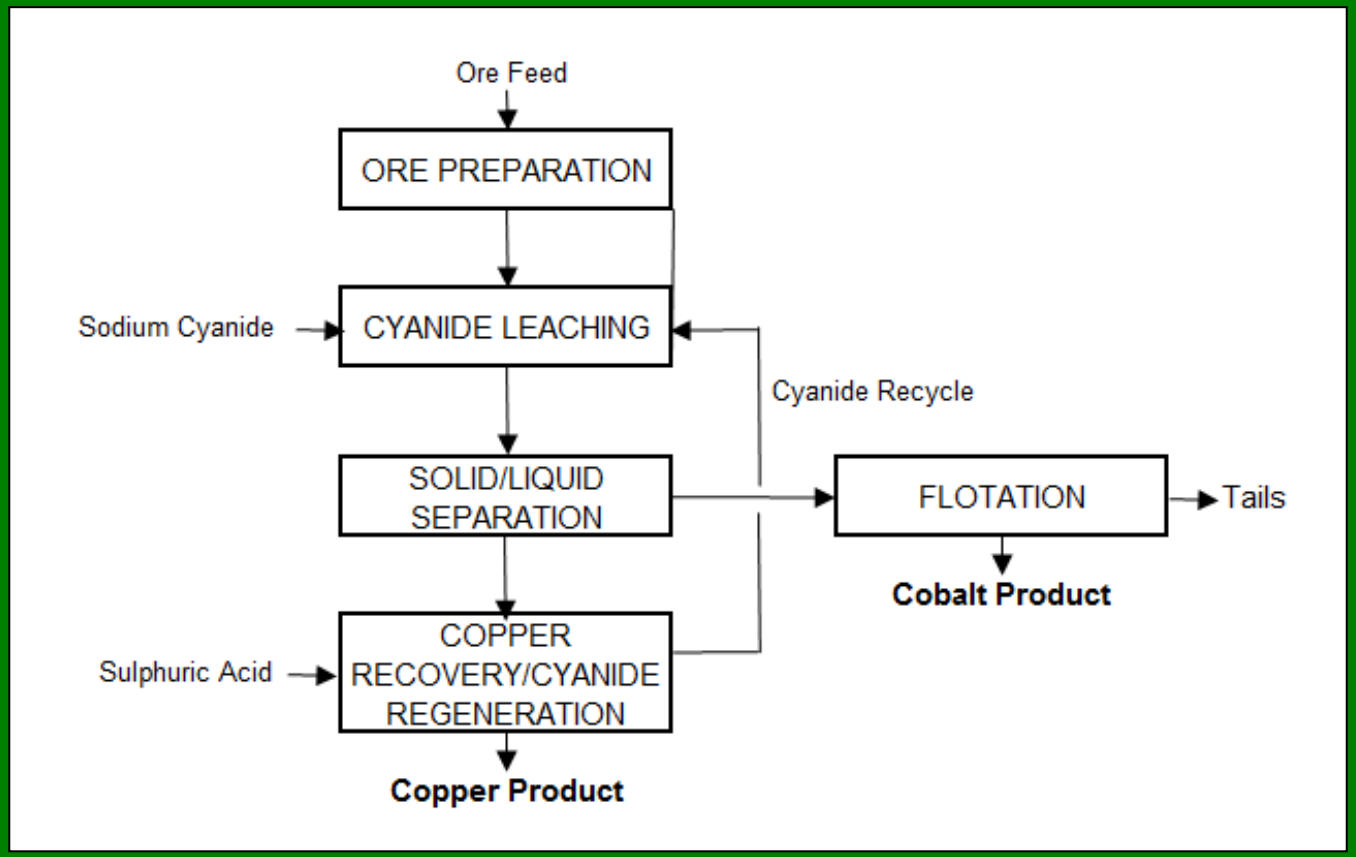
IMPLICATIONS

- Could be considered for other reactive sulphidic ores where MnO_2 is present as a “free” oxidant.
- The novel DSX process can used for other applications involving separation of zinc and cobalt from manganese which cannot be achieved by single organic extractants.
- The principle of using synergistic mixtures of SX extractants can be applied to other difficult separations to make possible or improve hydrometallurgical processes.

COPPER CYANIDE LEACHING PROCESS

- Proposed by Torrens Mining, Perth, for recovery of copper and cobalt products from mixed sulphide ore at Mount Gunson, South Australia.
- Processing problems:
  - Relatively poor copper response to flotation due to fine grained shaley material (good response of cobalt as carrolite).
  - No cobalt credit for copper concentrate, and possible penalty.
  - Sulphuric acid consumption too high for leaching due to carbonaceous gange.
- Initial testwork shows secondary copper sulphides amenable to a cyanide leaching process developed to pilot plant level in 1960s. Cyanide is regenerated and recycled. Cobalt is recovered from the leach residue by flotation.
- A prefeasibility study is currently in progress.

PROPOSED MOUNT GUNSON FLOWSHEET



IMPLICATIONS

- The process could be considered for secondary copper sulphide ores not amenable to flotation or acid leaching.

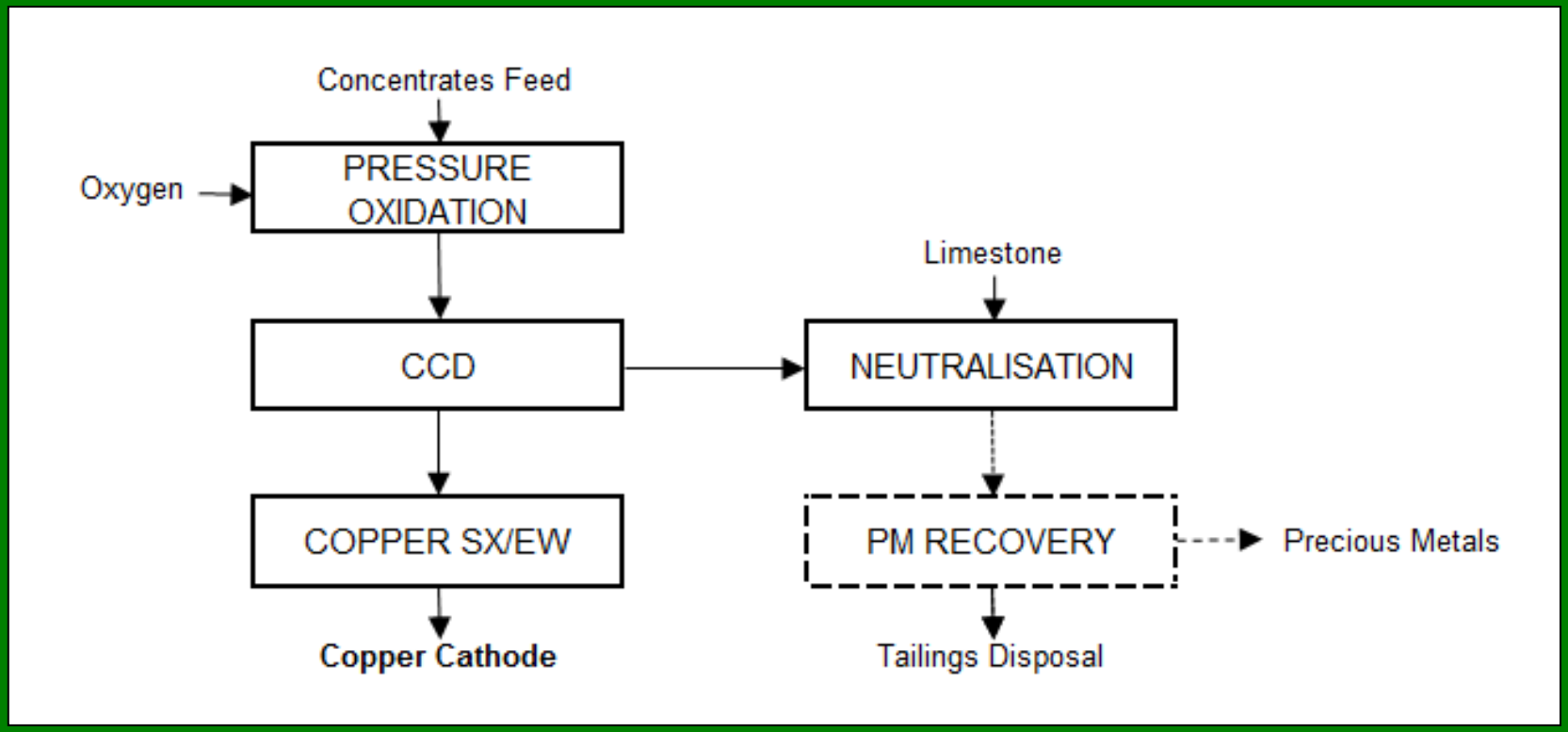
- It offers a means of separating and recovering cobalt from secondary copper sulphide ores.

ARSENIC BEARING BASE METAL SULPHIDE ORES

CESL COPPER-ARSENIC CONCENTRATES LEACHING PROCESS

- The CESL process has been developed to a commercial demonstration scale for copper sulphide (chalcopyrite) concentrates, and a pilot plant scale for copper-arsenic sulphide (enargite) concentrates, by Teck/CESL in Vancouver, Canada.
- Processing problems:
  - Both enargite and chalcopyrite are refractory to conventional atmospheric leaching with sulphuric acid.
  - Poor response to conventional heap leaching of ores
  - Amenable to flotation but many smelters will not accept concentrates due to environmental issue. Also, arsenic grades in concentrates in excess of 0.5% As are difficult to ship.
- Utilizes medium temperature pressure oxidation at about 150C. Copper is recovered by SX/EW. Arsenic is fixed in the tailings as stable scorodite.

CESL COPPER-ARSENIC CONCENTRATES LEACHING FLOWSHEET



IMPLICATIONS

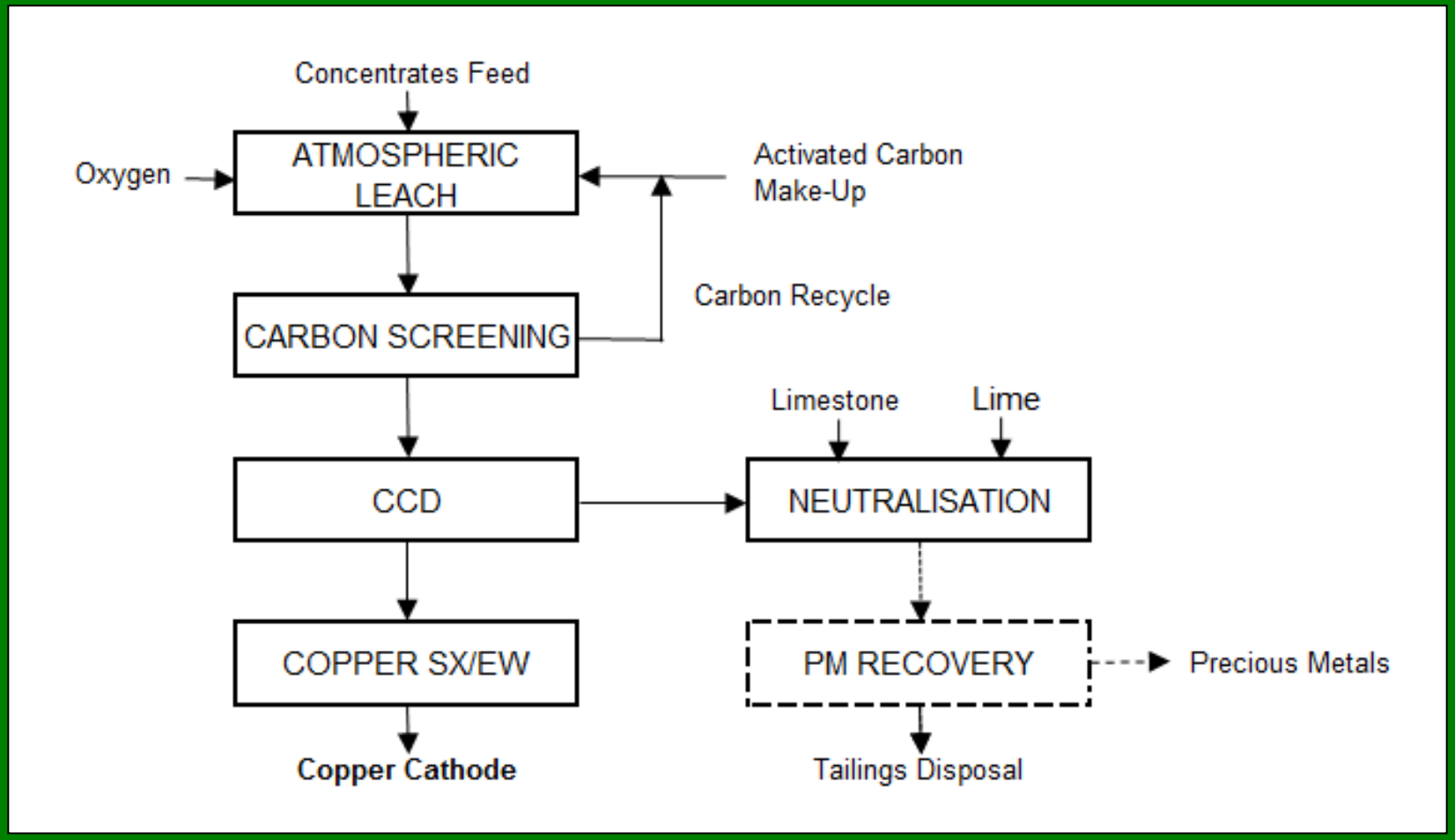
- Could be considered for the many unexploited copper-arsenic deposits or zones within currently mined deposits.

- Provides a hydrometallurgical process alternative avoiding the environmental issues associated with smelting.

GALVANOX COPPER-ARSENIC CONCENTRATES LEACHING PROCESS

- Developed to pilot plant level by Univ. of British Colombia, Canada for recovery of copper from copper-arsenic sulphide (enargite) flotation concentrates, often associated with chalcopyrite.
- Processing problems:
  - Both enargite and chalcopyrite are refractory to conventional atmospheric leaching with sulphuric acid.
  - Poor response to conventional heap leaching of ores Amenable to flotation but many smelters will not accept concentrates due to environmental issue. Also, arsenic grades in concentrates in excess of 0.5% As are difficult to ship.
- Modification of Galvanox copper sulphide concentrates leaching process using activated carbon as a catalyst to enhance leach kinetics for copper arsenic material. Copper is produced by SX/EW. Arsenic is fixed in the tailings as stable scorodite.

GALVANOX COPPER-ARSENIC CONCENTRATES LEACHING FLOWSHEET



IMPLICATIONS

- Could be considered for the many unexploited copper-arsenic deposits or zones within currently mined deposits.

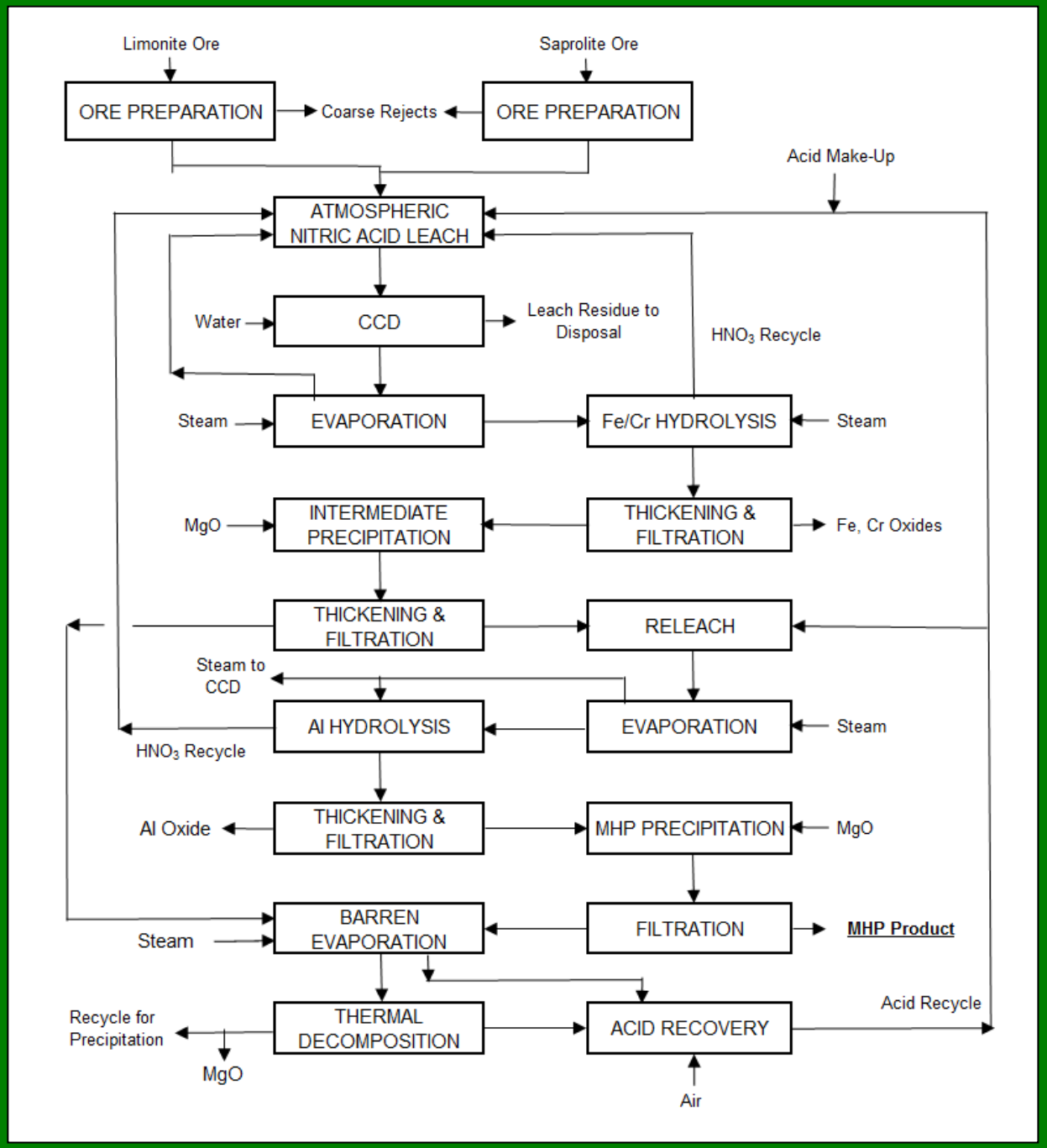
- Provides an atmospheric alternative to pressure oxidation for treating copper-arsenic concentrates.

LOW GRADE NICKEL-COBALT LATERITES ORES

DIRECT (DNi) NICKEL PROCESS

- Developed to pilot plant level by Direct Nickel, Perth, Australia, for treating the full profile of nickel-cobalt laterite ore deposits (i.e. limonite and saprolite).
- Processing problems:
  - Present commercial processes suffer from high capex and/or opex costs
  - They generally are only applicable to one ore zone (EPAL Process, at Ravensthorpe, Western Australia is essentially two processes in parallel - PAL for limonite and AL for saprolite with common downstream processing).
- Nitric acid leach process aimed at treating the full laterite profile in a single process with lower capex and opex, re-use of reagents, and the possibility of saleable by-products.
- Feasibility study is underway for at ANTAM's Buli operation in Halmahera, Indonesia.

DIRECT NICKEL FLOWSHEET



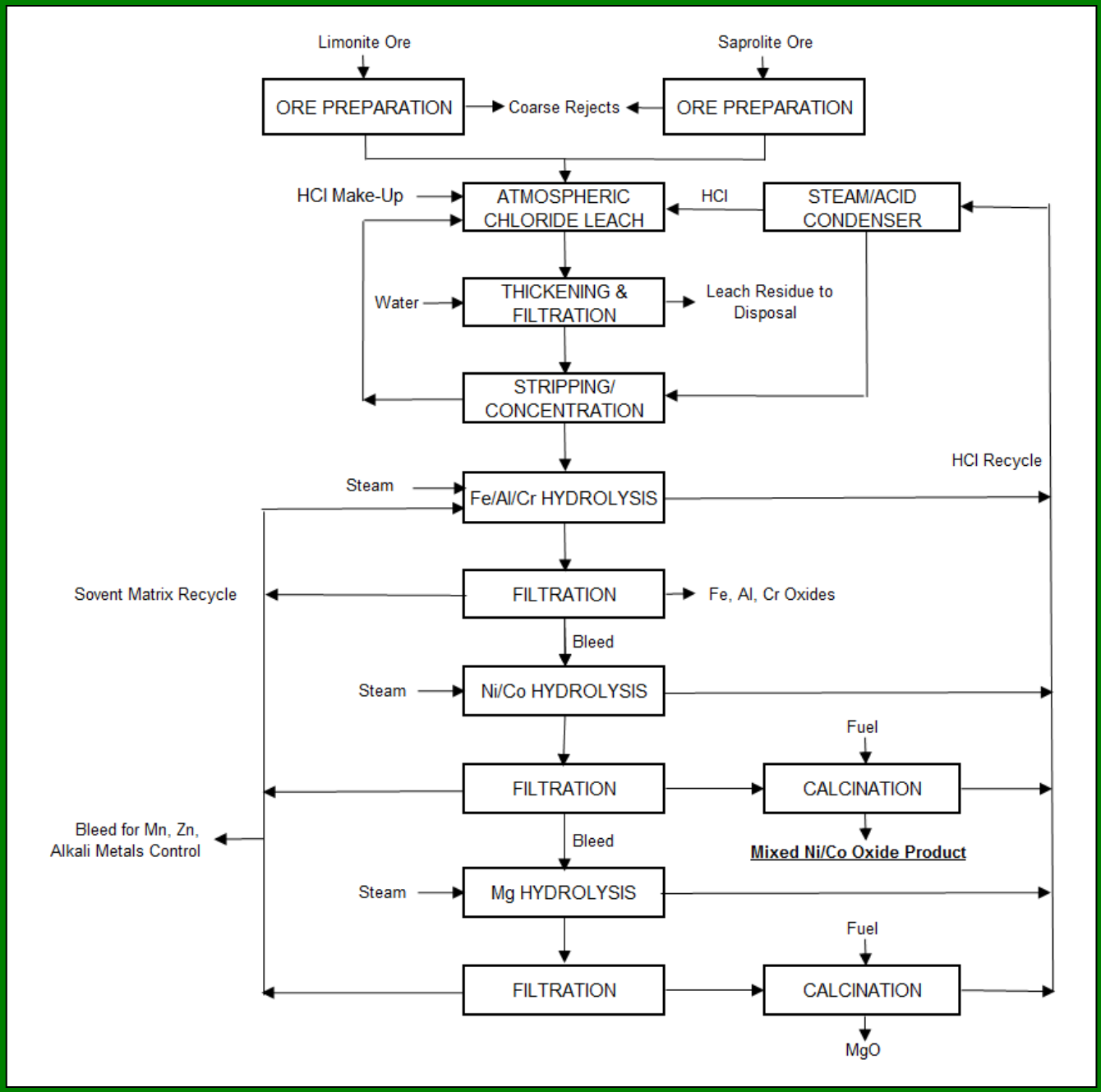
IMPLICATIONS

- Is a potentially lower cost alternative to current processes for low grade nickel-cobalt laterite deposits.
- Has the potential to increase the economic nickel-cobalt output from a low-grade deposit by processing the full ore profile.
- Offers the opportunity to improve the project economics with saleable by-products.

NEOMET PROCESS

- Developed to pilot plant level by Neomet Technologies, Montreal, Canada, for treating the full profile of nickel-cobalt laterite ore deposits (i.e. limonite and saprolite).
- Processing problems:
  - Present commercial processes suffer from high capex and/or opex costs
  - They generally are only applicable to one ore zone (EPAL Process, at Ravensthorpe, Western Australia is essentially two processes in parallel - PAL for limonite and AL for saprolite with common downstream processing).
- Hydrochloric acid leach process aimed at treating the full laterite profile in a single process with lower capex and opex, re-use of reagents, and the possibility of saleable by-products.
- It includes new technology for reducing the energy required for the regeneration and recycle of HCl.

NEOMET FLOWSHEET



IMPLICATIONS

- Is a potentially lower cost alternative to current processes for low grade nickel-cobalt laterite deposits.

- Has the potential to increase the economic nickel-cobalt output from a low-grade deposit by processing the full ore profile.

- Offers the opportunity to improve the project economics with saleable by-products.

- Chloride based alternative to the Direct Nickel Process.

(Chloride processes are also being developed by Anglo Research in South Africa, Nichromet in Canada, Process Research Ortech in Canada and SMS Siemag in Austria.)

ALTA

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