WHAT'S HAPPENING IN COPPER HYDROMET

Presented by

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INTRODUCTION

Copper hydrometallurgical technology is continuing to develop and expand for the treatment of copper oxide and sulphide ores and concentrates.

KEY DRIVERS

- The emergence of SX-EW as a robust, relatively low-tech, process for selectively extracting copper from sulphuric acid leach solutions and producing Grade A cathode product.
- The availability of extensive high grade oxide copper and copper/cobalt ore deposits in the Central African Copperbelt.
- The successful large scale treatment of oxide ores by heap leaching and secondary sulphide ores by heap bio-leaching.
- The need for an economic process for treating low grade and complex primary sulphide ores.
- The desirability of producing a high grade copper product at site, especially for small, medium and remote sulphide ore mines.

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KEY DRIVERS (CONT.)

- The need for an alternative to smelting for concentrates with significant levels of undesirable impurities such as arsenic.

- The successful application of hydrometallurgical processes such as pressure oxidation and bio-oxidation for the treatment of gold and zinc ores and concentrates.

- Increasingly stringent environmental regulations for smelter off-gases.

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CHALLENGES

- High energy consumption of electrowinning from sulphate solutions
- Volatility in the availability and price of elemental sulphur and sulphuric acid.
- High transport cost for reagents to remote sites, especially sulphuric acid.
- Slow leaching kinetics and low recovery from primary sulphides such as chalcopyrite with sulphuric acid solutions at atmospheric temperature due to the formation of a passivation layer.
- Precious metals recovery from leach residues.

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CHALLENGES (CONT.)

- High cost for regenerating and recycling alternative lixiviants such as hydrochloric acid.
- Unfamiliarity of mining industry with alternative lixiviants.
- High risk factor in the application of new technology.
- Lack of skilled labour and support services at remote mine sites.

AREAS OF DEVELOPMENTS

- A resurgence of atmospheric agitated tank sulphuric acid leaching circuits for high grade oxide copper and copper/cobalt ores.

- Application of high temperature atmospheric agitated tank acidic ferric sulphate leaching of secondary sulphide ores.

- Extension of heap bio-leaching to low grade chalcopyrite ores.

- Development of a variety of hydromet treatment processes for copper sulphide concentrates.

- Developments in SX and EW.

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AGITATED TANK SULPHURIC ACID LEACHING OF OXIDE ORES

- Since 1960s, has been largely displaced by lower cost heap leaching.

- However, there has been a recent resurgence for copper and copper/cobalt projects in the Central African Copperbelt due to:
  - Higher grade ores able to support higher capex and opex
  - Higher recovery
  - Short testwork program
  - Relatively fast ramp-up time
  - Reliable scale-up and lower technical risk
  - Need to reduce cobalt minerals.

- Numerous projects in DRC and Zambia.

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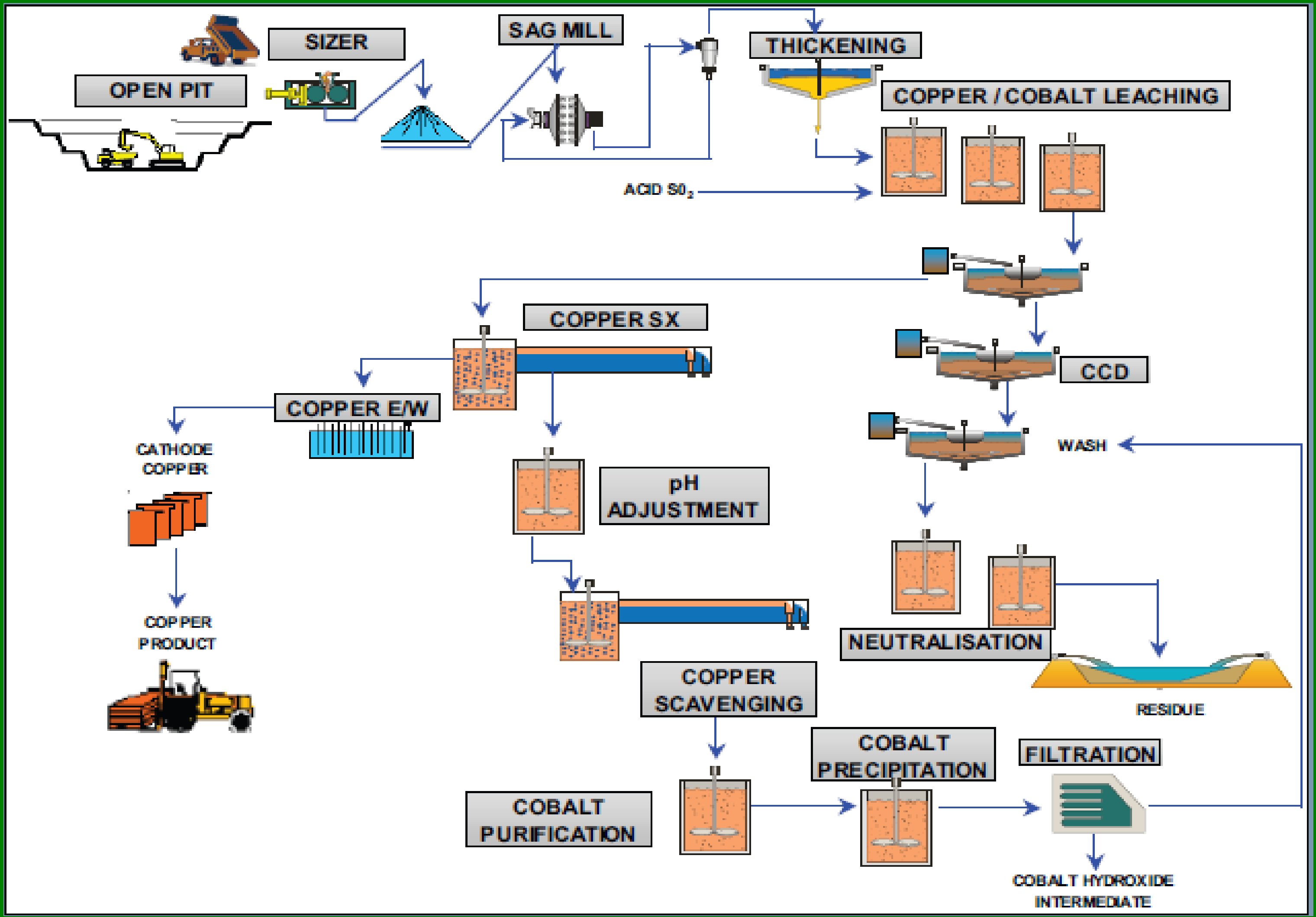
TENKE FUNGURUME FLOWSHEET, FCX, DRC

(Ref: Tenke Mining Corp. presentation March 2006)



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TENKE FUNGURUME OPERATION, FCX, DRC

(Ref: Freeport McMoRan conference presentation, 2009)

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AGITATED TANK ACIDIC FERRIC SULPHATE LEACHING OF SECONDARY SULPHIDE ORES

- Typically applied to high grade secondary sulphide and mixed sulphide/oxide ores. (Heap bio-leaching is commonly used for lower grade ores.)

- Operations:
  - Sepon, MMG, Laos
  - Las Cruces, First Quantum, Spain
  - Mt Gordon, QLD, now closed.

- The ferric iron level is maintained by oxygen injection or pressure oxidation.

- Typically operates at high temperature; cooling ahead of SX.

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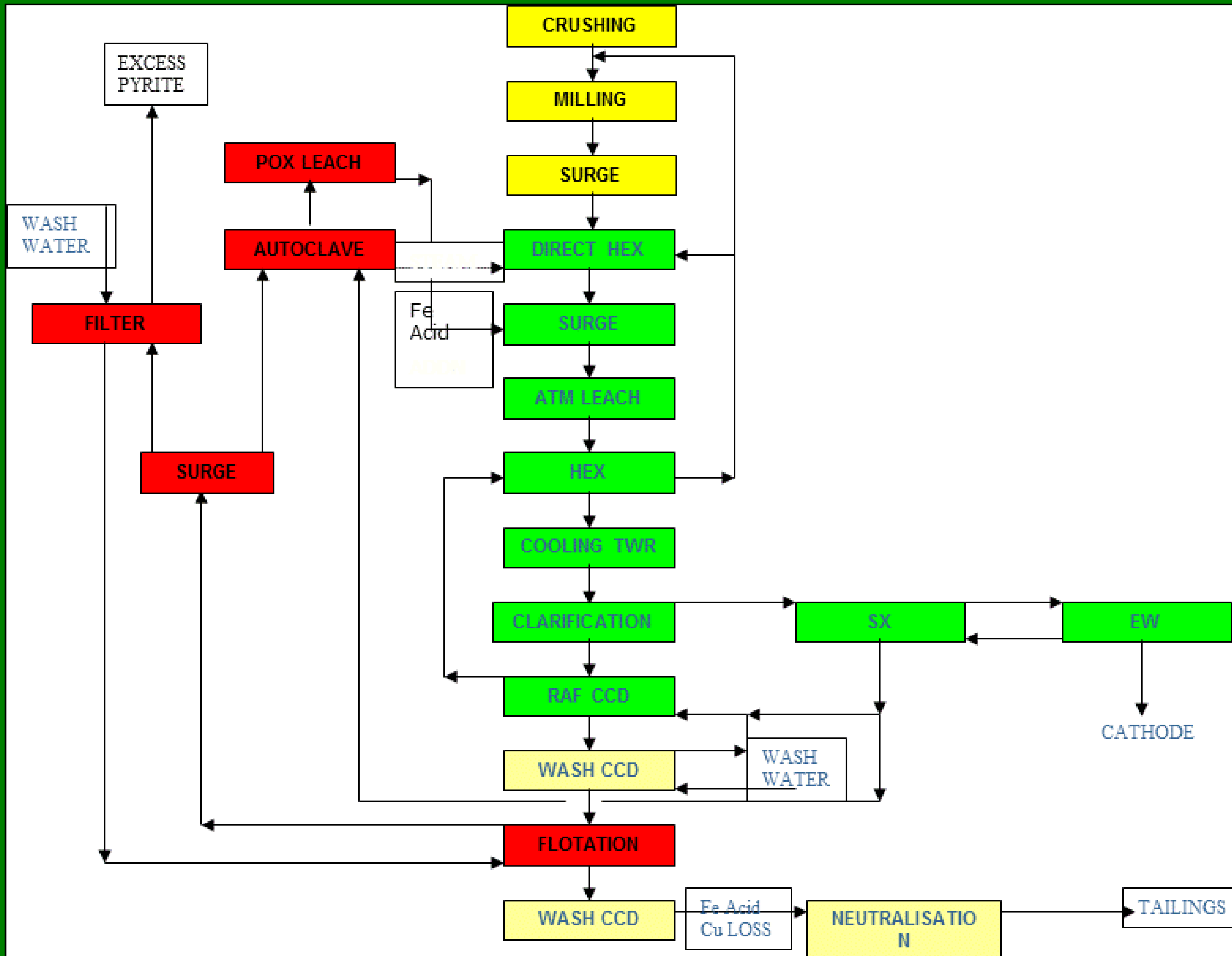
SEPON FLOWSHEET, MMG, DRC

(Ref: David Dreisinger presentation, ALTA 2012)



SEPON OPERATION, MMG, LAOS

HEAP BIO-LEACHING OF LOW GRADE CHALCOPYRITE

- There are many copper primary sulphide deposits which cannot be economically treated by conventional means due to low grade or problem impurities.
- Heap leaching using common iron oxidizing bacteria, ambient temperature and conventional techniques results in very slow leaching rate and low recovery, due to a passivation layer.
- Recovery is typically limited to about 30% in 3-5 years though there are some more reactive orebodies.
- A number of organizations are undertaking development programs including BioHeap/Western Areas, Australia; Mintek, South Africa; BacTech, Canada; GeoBiotics, USA; BHP Billiton, Chile; BioSigma (Codelco/Nippon), Chile; Rio Tinto, USA.
- Strategies include development of special bacteria cultures, maximization of operating temperature, and optimization of irrigation patterns and aeration rates.

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MINTEK TEST HEAP AT DAREHZARE MINE, IRAN

(Ref: Mintek paper, ALTA 2007)

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HYDROMET PROCESSES FOR SULPHIDE CONCENTRATES

- Numerous processes have been tested over many years but only a few have been commercialized, with limited success.

- Current processes under development involve:
  - medium and high temperature pressure oxidation
  - atmospheric tank bio-oxidation
  - atmospheric tank galvanic leaching
  - chloride leaching.

- Of these:
  - high temperature pressure oxidation has been commercialized
  - medium temperature pressure oxidation and tank bio-oxidation have reached small scale commercial or semi-commercial level
  - galvanic leaching has reached pilot plant scale
  - chloride leaching has reached pilot scale (though a commercial operation has been operated in the past).

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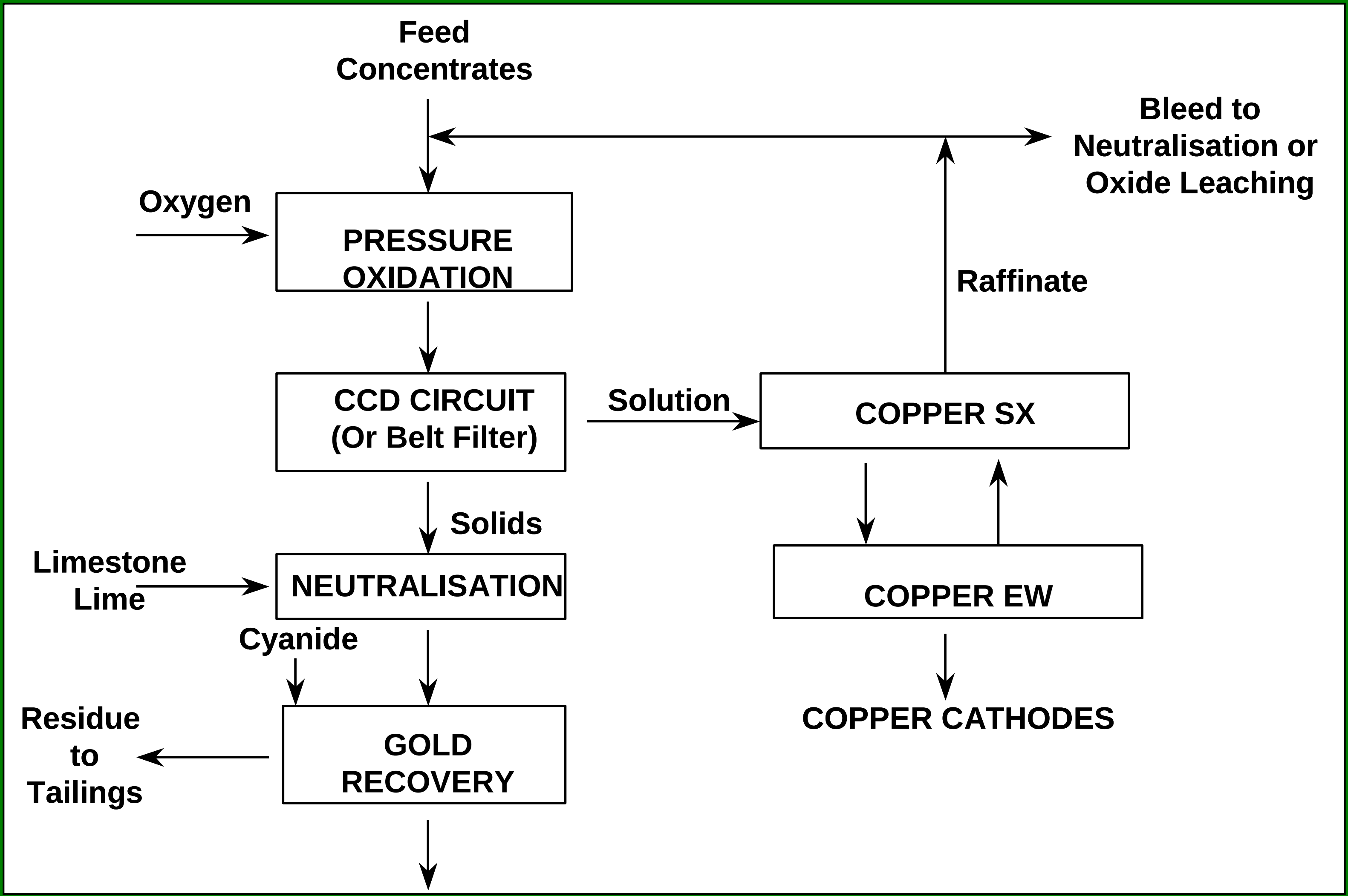
HIGH TEMPERATURE PRESSURE OXIDATION

- Uses pressure oxidation with oxygen in an autoclave at 200-225°C. Copper is solubilized as sulphate, iron precipitates as hematite. Sulphur forms metal sulphates and sulphuric acid.
- Solid-liquid separation is carried out in CCD thickeners and/or filters.
- Copper recovery from the clarified solution is by conventional SX/EW.
- A raffinate bleed is required to control the acid level in solution. The bleed stream is neutralized for disposal or used for leaching associated oxide ore, for example by heap leaching.
- Well proven process for gold and zinc production.

HIGH TEMPERATURE PRESSURE OXIDATION FLOWSHEET



HIGH TEMPERATURE PRESSURE OXIDATION STATUS

- Freeport McMoRan, built a semi-commercial plant at Bagdad Arizona, to treat 15% of Bagdad's flotation concentrate output, which came on stream in 2003. The nominal operating temperature is 225^{o}C with a retention time of 70 minutes. The design copper recovery was 98%. The copper and acid produced are blended into the existing low grade sulphide dump leaching-SX-EW operation.

- First Quantum installed a system at Kansanshi in Zambia to treat some of the flotation concentrate. The acid formed is utilized in oxide ore leaching. Cathode copper is produced by SX-EW.

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FREEPORT MCMORAN PLANT, BAGDAD, ARIZONA

MEDIUM TEMPERATURE PRESSURE OXIDATION

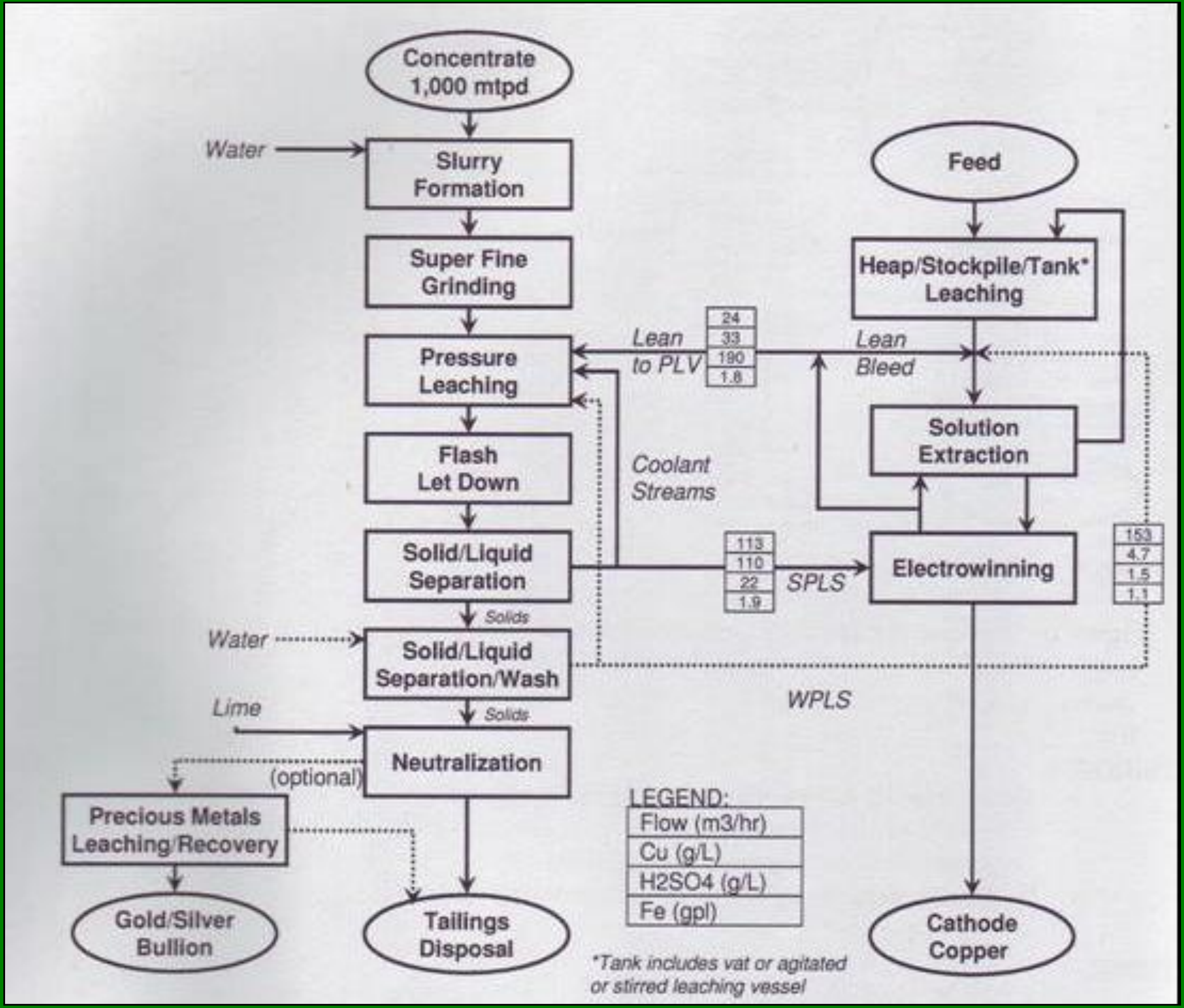
- Uses pressure oxidation with oxygen in an autoclave at around 150°C with a leach time of 1-3 hours.
- Forms elemental sulphur instead of acid which reduces oxygen consumption and limestone needed for neutralization.
- A surfactant is typically used to disperse the sulphur which is in the liquid state
- Being developed by a number of organizations including FCX, USA; Teck/CESL, Canada, Dynatec, Canada; Anglo American, South Africa.
- Variations include ultrafine grinding (FCX, Anglo), chloride addition as a catalyst (Teck/CESL) and residue flotation to maximize recovery (Dynatec).

MEDIUM TEMPERATURE PRESSURE OXIDATION STATUS

- The FCX Process was commercialized at Morenci, in 2007. Overall copper recovery target was 97.5%. 90% of the copper is produced by direct EW. The remaining 10% is sent as a bleed stream for blending with heap leach solution for recovery by SX-EW.

- A semi-commercial CESL Process facility was commissioned at Vale in Brazil in 2008.

FCX MORENCI PROCESS FLOWSHEET



FCX MORENCY AUTOCLAVES

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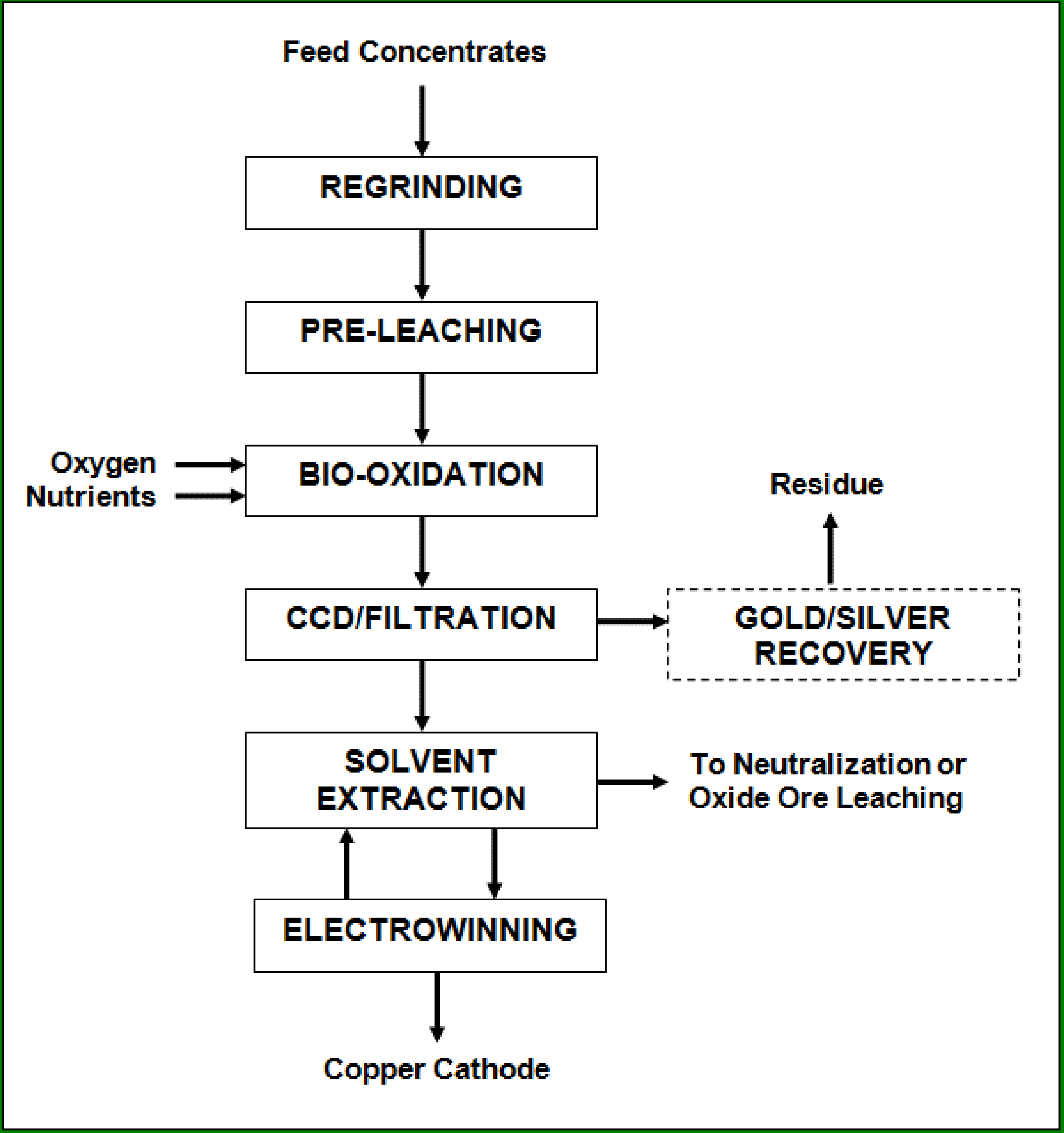
TANK BIO-OXIDATION

- Uses extreme thermophile bio-oxidation in atmospheric agitated tanks at up to 70-80^{o}C.
- Oxygen and nutrients are added. Oxygen efficiency is about 80%.
- Liquid/solids separation/washing of the leach pulp is by CCD/filtration.
- Copper recovery is via conventional SX/EW.
- There is potential for maximizing acid production for leaching of associated oxide ore, if available.
- BioCOP Process is being developed by BHP Billiton.
- A BioCOP semi-commercial plant was built near Chuquicamata, Chile, by BHP Billiton/Codelco to treat chalcopyrite/enargite concentrate in 2003. Plans for a commercial facility did not proceed, reportedly due to high costs and engineering issues.
- Bactech/Mintek have developed a process using moderate thermophiles at 45-50^{o}C with ultrafine grinding up to demo. plant scale.

BHP BILLITON BIOCOP PROCESS



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SEMI-COMMERCIAL BIOCOP PLANT, CHILE

(Ref: D. Dreisinger Key Note presentation, ALTA 2012)

GALVANOX PROCESS

- Being developed by UBC, Canada. Involves atmospheric agitated leaching under "galvanic" conditions at about 80°C
- Takes advantage of the galvanic effect between chalcopyrite and pyrite to break down the passivation layer for chalcopyrite.
- In the leach reactors, chalcopyrite is leached selectively at low potential in the presence of the pyrite catalyst, producing a solid sulphur residue. Ferric iron is generated by oxygen sparging.
- A proportion of the solution is sent through a small oxyhydrolysis autoclave at 220°C to precipitate iron as hematite, and regenerate acid while generating heat for the atmospheric leach step. Copper recovery is by SX-EW.
- Has been operated up to pilot plant scale.
- Recent developments include use of silver as a catalyst to enhance leach kinetics, and activated carbon as a catalyst for treating copper-arsenic ores.

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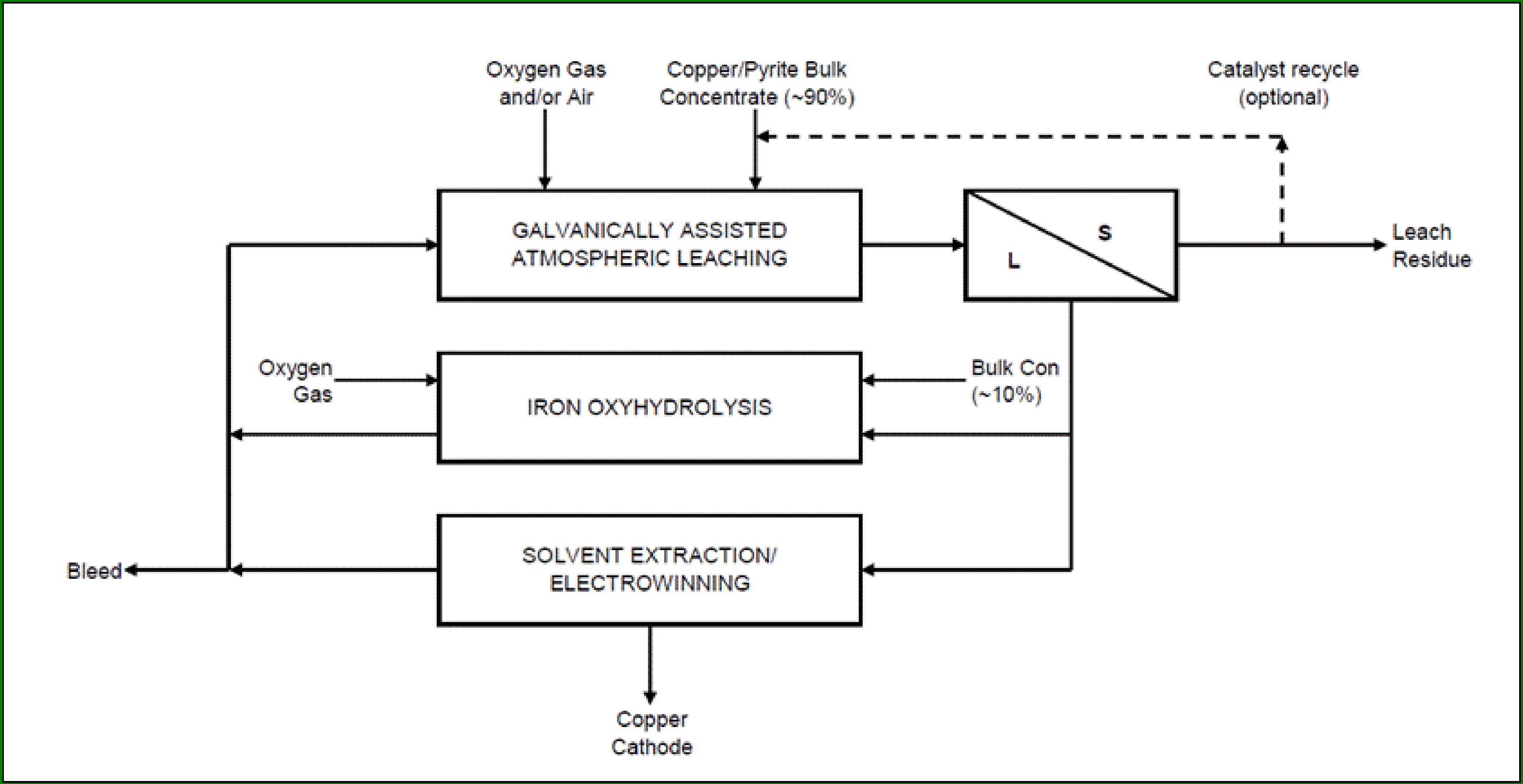
GALVINOX PROCESS FLOWSHEET

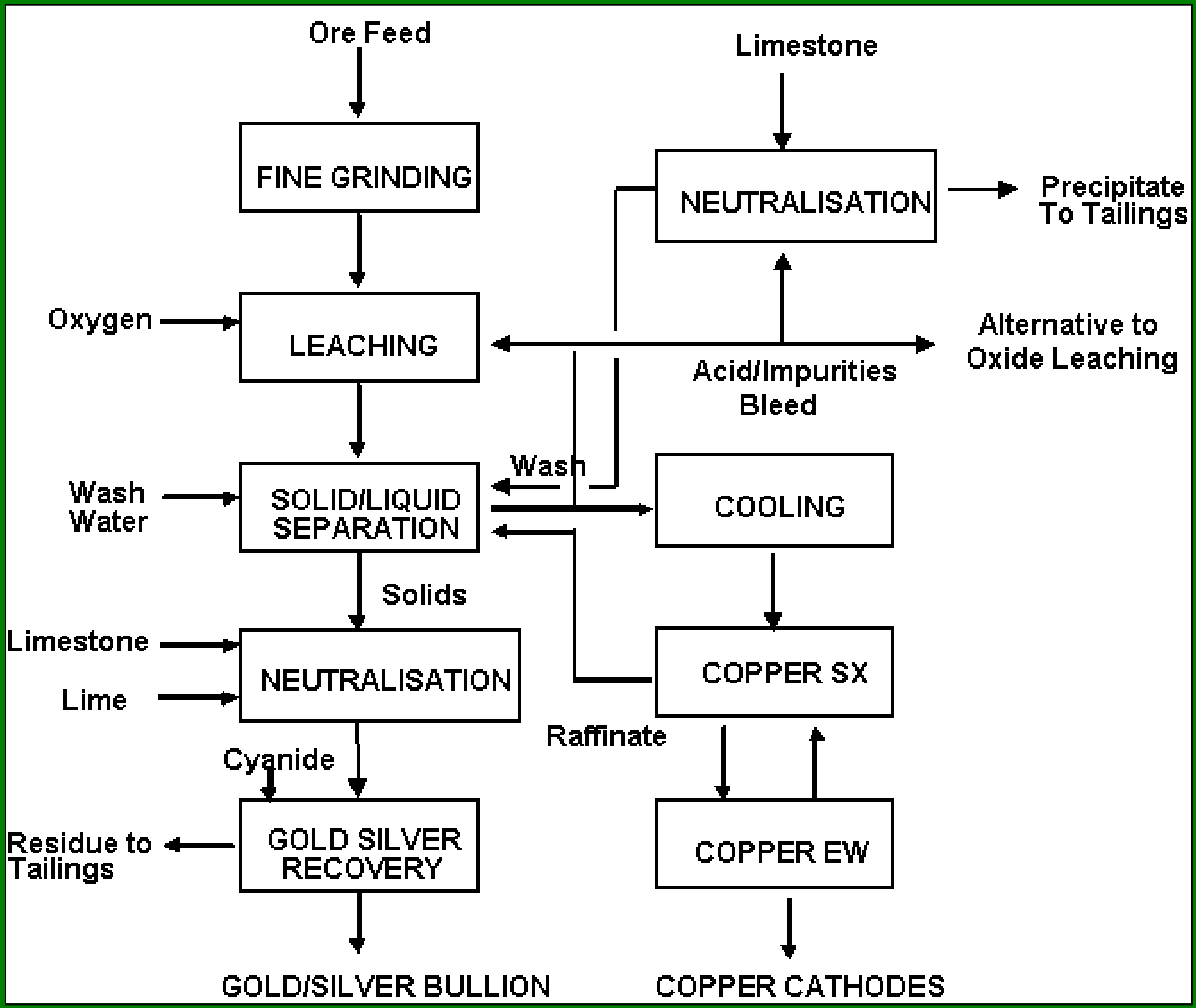


GALVINOX PILOT PLANT

ALBION PROCESS

- Involves atmospheric agitated tank leaching with ferric sulphate at 80°C for about 20 hours, with oxygen sparging to maintain an adequate level of ferric.
- The feed is ultra-finely ground to less than 20 microns,
- Copper recovery is by conventional SX/EW.
- Sulphur is largely oxidized to sulphates. Limestone is required to remove iron and excess acid. Acid generated could be utilized to leach oxide ore.
- Under development by Xstrata and marketed by Core Resources, Australia.
- Has been commercialized for zinc and gold recovery, and has reached pilot plant scale for copper.

ALBION PROCESS FLOWSHEET



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CHLORIDE PROCESSES

- Chloride leach processes are under development by a number of organizations including Neomet, Canada; Process Research Ortech (PRO Process), Canada; SMS Siemag, Austria; Outotec (HydroCopper Process), Finland; Intec, Australia; Nippon (N-CHLO Process), Japan; Sumitomo (SMM Process), Japan.
- They have attained either pilot scale or small demo. scale.
- CSIRO, Perth have developed a synergistic SX extractant mixture applicable enabling conventional sulphate EW to be included in chloride leach processes.

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SOLVENT EXTRACTION & ELECTROWINNING

Improvements in solvent extraction include:

- Blended extractant formulations for particular applications
- Variations in circuit arrangement including:
  - series parallel for low grade solutions and flexibility
  - split circuit for high grade solutions from agitated leaching.
- Further developments in mixer-settler design including:
  - reverse flow
  - Outotec VSF
  - MMS side feed
  - agitator and mix box designs to optimize mixing, mass transfer and droplet size
  - multiple non-jetting picket fences and other settler design features to improve phase disengagement and minimize entrainment.
- Improvements in crud treatment.
- Increased emphasis on fire protection after a spate of fires.

SOLVENT EXTRACTION & ELECTROWINNING (CONT.)

Developments in electrowinning include:

- Higher current density operation by modifying cell design and operating conditions.
- Longer (jumbo) cells to reduce capex and footprint.
- Alternative non-lead anodes (coated titanium).
- Tubular cells, totally enclosed (EMEW, Australia).
- Alleviation of acid mist emission including:
  - EW cell covers
  - new mist suppressant.
- New smoothing additives.
- Systems for enhancement of current efficiency including:
  - modified cell design
  - aeration of cells
  - online wireless based EW management systems.

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REVERSE FLOW SX MIXER-SETTLERS

Ref: Piedras Verdes Operation, Mexico, Tenova Bateman

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OUTOTEC EW CELL COVERS

EMEW CELLS

Ref: Electrometals website

Upcoming Short Courses

Copper Hydromet *November 2013, Melbourne, Australia*

Practically-oriented full-day courses – a valuable introduction for newcomers and a useful refresher for old hands.

A-Z of Copper Ore Leaching	20 November
Copper SX-EW Basic Principles and Detailed Plant Design	21 November
Copper Oxide Ore Heap Leaching Testwork and Scale-up	22 November

Upcoming Conference

ALTA 2014 Nickel-Cobalt-Copper, Uranium-REE and Gold-Precious Metals Conference & Exhibition *May 2014, Perth Australia*

Now in its 18th year, this major event has become an annual gathering of the global Nickel-Cobalt-Copper, Uranium and Gold industries. Uniquely incorporating three international conferences in one week, the event is organised around highly focused technical programs, forums and discussion panels with key international presenters. ALTA 2014 will provide an excellent opportunity for technical interchange and networking with senior industry professionals from around the globe.

Conference Sessions
Nickel-Cobalt-Copper 26-28 May including Hydroprocessing of Sulphides Forum
Uranium-REE 29-30 May including Uranium SX Forum *Parallel with Gold-PM sessions*
Gold-Precious Metals 29-30 May including Refractory Gold Ores Forum *Parallel with Uranium-REE sessions*
Short Courses
SX and its Application to Copper, Uranium and Nickel-Cobalt **24 May**
Uranium Ore Processing 31 May
Exhibition 26-30 May

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