Innovations in Copper Mineral Processing Technology

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Company Overview

Highlights

- Specialist Metallurgical services:
  - **hrl**testing (metallurgical laboratory – operating over 30 years).
  - Marketing of licensed processing technology (Albion Process and Toowong Process).
  - Process engineering, design and flowsheet development
  - Scoping and Feasibility Studies
  - Technology Development Partner

- Strong Technical Team (~50 Staff):
  - Grinding, flotation and hydrometallurgical expertise
  - Flowsheet development with an economic focus and outcomes that can be engineered and operated
  - Project development, commissioning and operational experience

Mineral Processing Technologies

Update on Copper Applications using;

- **Ore Sorting** — Rejecting Low Grade Material from Copper Ores
- **Heavy Medium Separation** — Rejecting Low Grade Material from Copper Ores
- **Toowong Process** — Removing Impurities from Copper Concentrates
- **Albion Process** — Treating Low grade/dirty Copper Concentrates

Definition of a Metallurgist

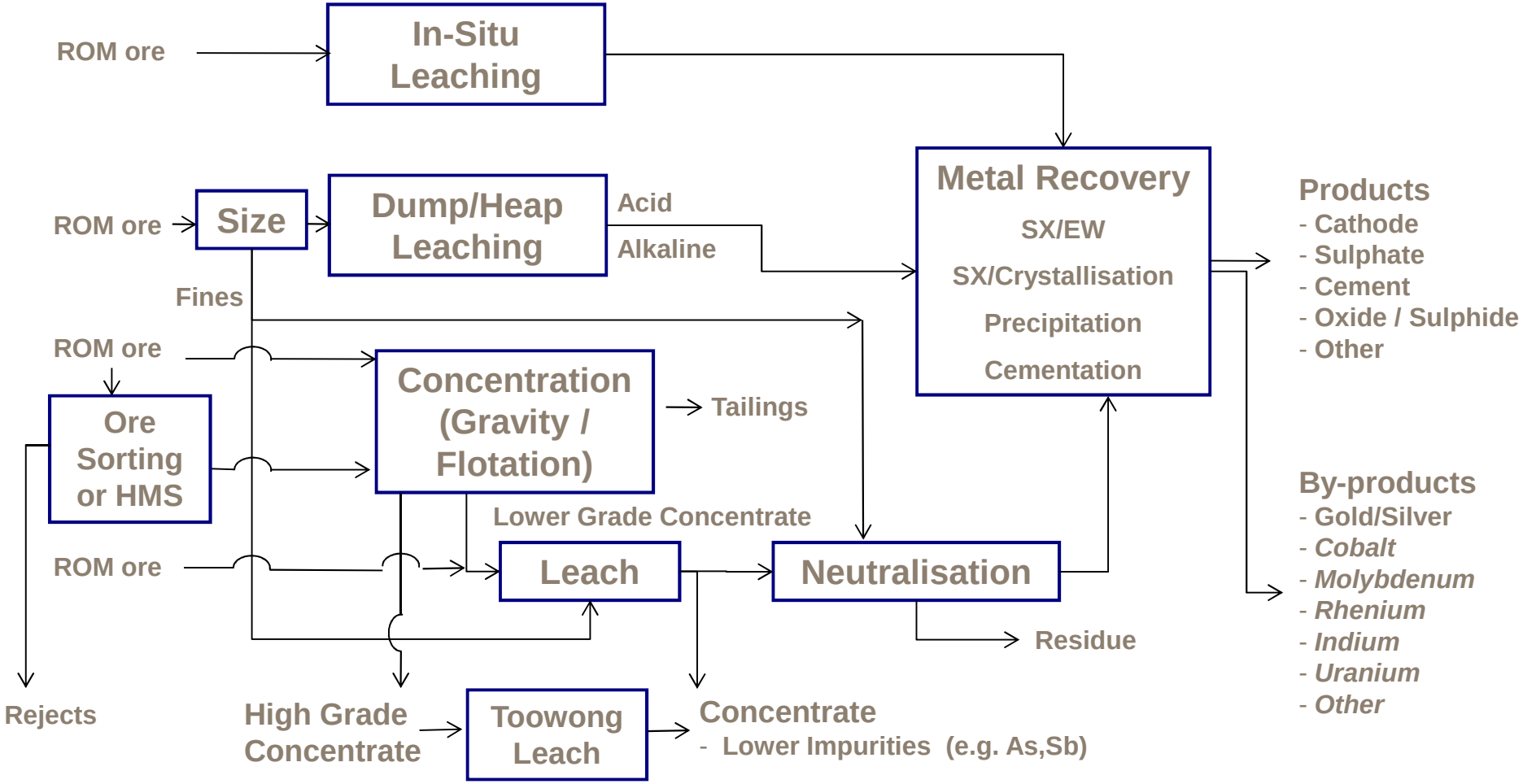
met·al·lur·gist (mtl-ûrjst)

> A pseudo scientist, who uses undetermined suppositions, inexpressible hypotheses; which are based on unreliable information, uncertain quantities, and incomplete data;

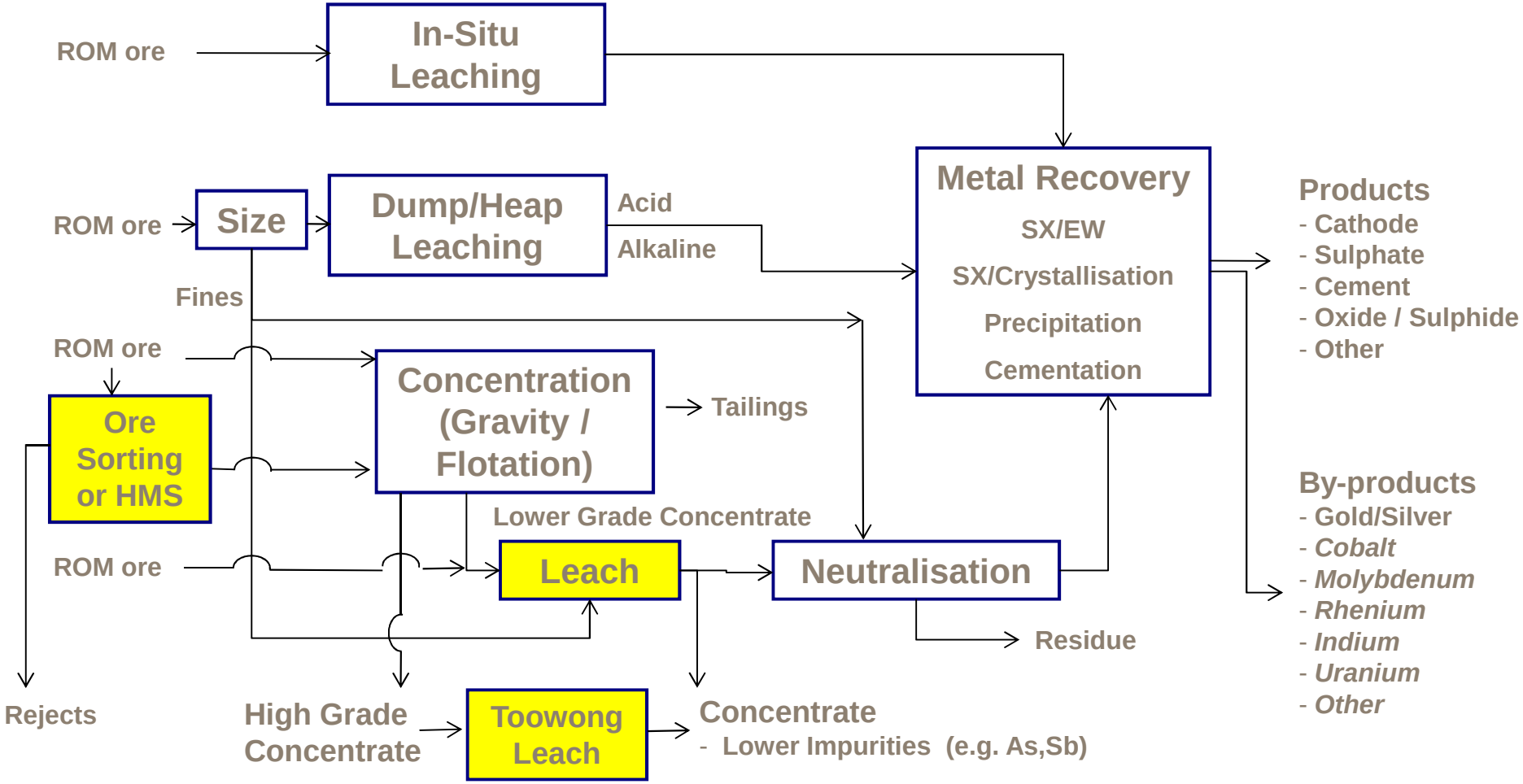
derived from non-reproducible experiments and incomplete investigations; using equipment and instruments of questionable accuracy, insufficient resolution, and inadequate sensitivity, to arrive at timid, tentative, cloudy, abstruse, and non-committed conclusions prefaced by the phrase

"IT DEPENDS……"

Copper Processing Flowsheets



Copper Processing Flowsheets



Reasons for Copper Ore Sorting

- Pre-concentrate ore at mine:
  - Removes low-grade fraction that is uneconomic to process.
  - Reduces haulage costs.
  - Reduces grinding energy and flotation reagent costs.
  - Improves metal recoveries.
- Monitor the mill feed which provides real time data to operators for process optimization.

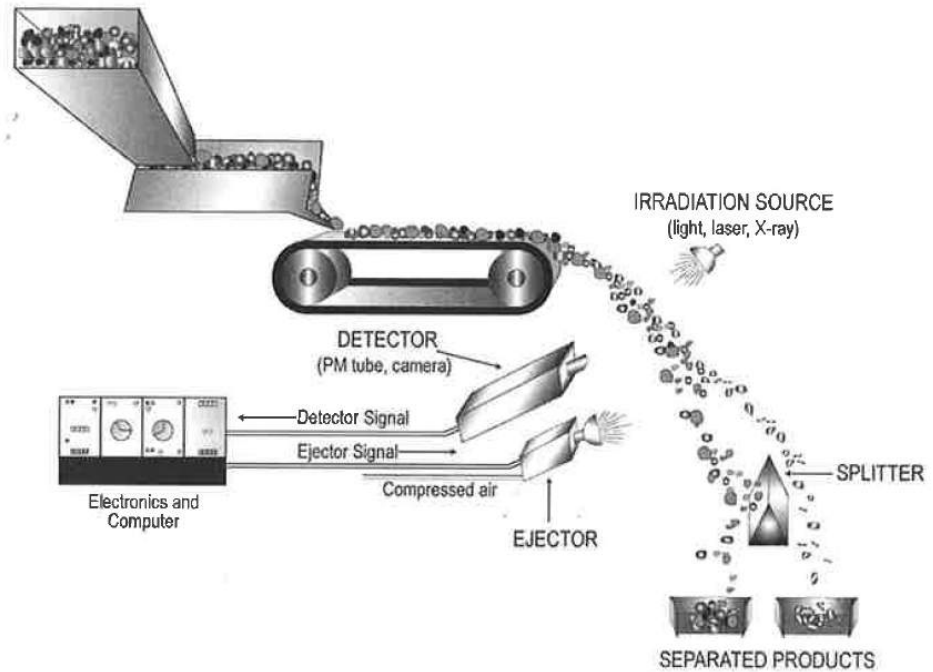
Some of these apply to Heavy Medium Separation also

Reasons for Copper Ore Sorting cont.

- Pre-concentrate feed into high-grade and low-grade stockpiles:
  - Optimize multiple process streams i.e. send ore to either mill, heap leach or smelter.
  - Allows smaller mills to be built or increase capacity of an existing mill.
  - Manage ore blending programs more effectively.
- For copper heap leach applications, removes gangue acid-consuming (GAC) rocks which reduces acid costs.

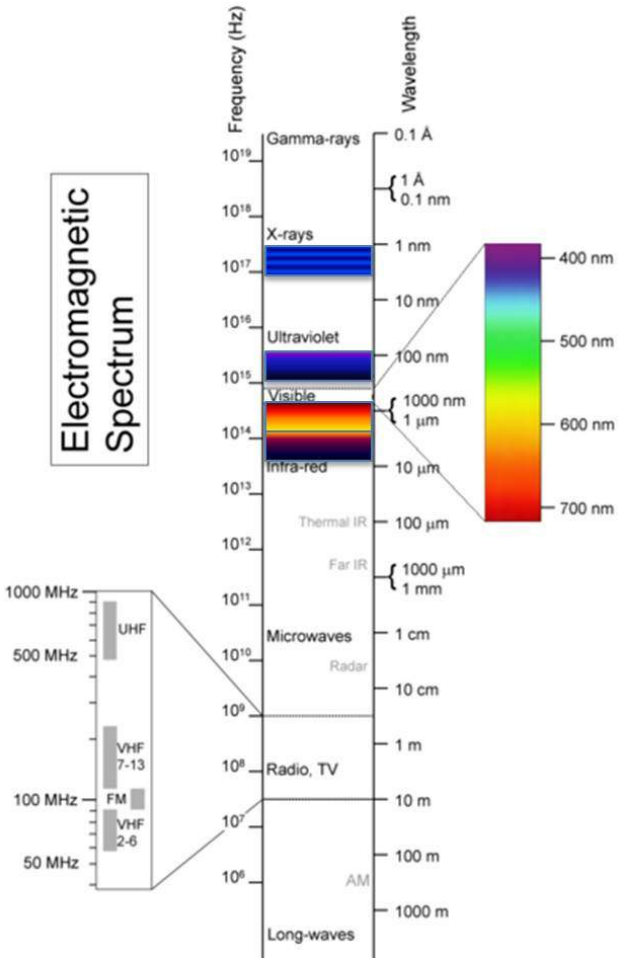
Sorter General Operation

- The processer, using pre-determined criteria, decides what ore is accepted and which ore is rejected.
- Processer drives either valves/flop gates or pneumatic pulses to send the products and rejects to their appropriate bin or conveyor.



Ore Sorting Techniques

- Optical
- Specific wavelength:
  - X-Ray Transmission (XRT)
  - X-Ray Fluorescence/ Ultraviolet
  - Near infrared
  - Radiometry (Gamma Rays)
- X-Ray Luminescence
- High Frequency Electromagnetic
- Colour



XRT examples

- **Industrial Examples:**
  - Metallurgical testwork has been completed on copper ores using XRT technology.

Sample	Mass Distribution (%)	Copper Distribution (%)	Copper Grade (%)			Copper Upgrade
	Product	Product	Head	Product	Rejects	
A	67%	93%	1.0	1.4	0.1	1.4
A	60%	87%	1.0	1.5	0.1	1.5
B	60%	85%	1.0	1.4	0.2	1.4
C	24%	65%	1.0	2.7	0.3	2.7
D	56%	88%	1.0	1.6	0.1	1.6
E	74%	86%	1.0	1.2	0.1	1.2
F	89%	95%	1.0	1.1	0.1	1.1

Colour examples

- **Industrial Examples:**
  - Scats from a Ball Mill

Pink - Carbonates (low Cu)

Grey - Bedded Siltstones (high Cu)

Colour examples

- **Industrial Examples:**
  - Scats from a Ball Mill

Red/Pink - Native Copper

Examples of GAC Rock Removal

- Testwork on projects have successfully tested ores with the objective of removing gangue acid consuming (GAC) minerals. These include:
  - Removal of calcites/carbonates in a finished quartz stream.
  - Rejection of GAC minerals from manganese and iron ores.
  - Removal of carbonates from uranium ore to achieve an upgraded concentrate before downstream processing.
  - and with this we believe similar applications could be used on copper ores.

Heavy Medium Separation (HMS)

- Heavy medium separation is the process of separating copper ores by a specific medium (ferro-silicon) density.
- Testwork on copper ores at a size range of -76 mm + 6 mm and a medium density of 2.8 demonstrated that 49% of the mass can be rejected whilst only losing 14% of copper – an upgrade of 169%.

Stream	Feed (-76 mm +6 mm)	+2.8 SG (Product)	-2.8 SG (Rejects)
Mass Distribution (%)	100%	51%	49%
Copper Grade (%)	1.5	2.5	0.4
Copper Distribution (%)	100%	86%	14%
Copper Upgrade (%)		169%	

Heavy Medium Separation (HMS) cont.

- **Industrial Examples:**
  - Jaguar lead, copper, zinc and silver project in Western Australia, installed a HMS plant in 2011.

    (30 to 35% mass rejected, with 40% upgrade in Feed Grade)

"Mill performance was improved after completion of the Heavy Media Separation plant (HMS) which removes waste rock from diluted ore and stringer sulphides and increases the mill head grade, reducing processing costs"

Independence Group 2011/12 Annual Report

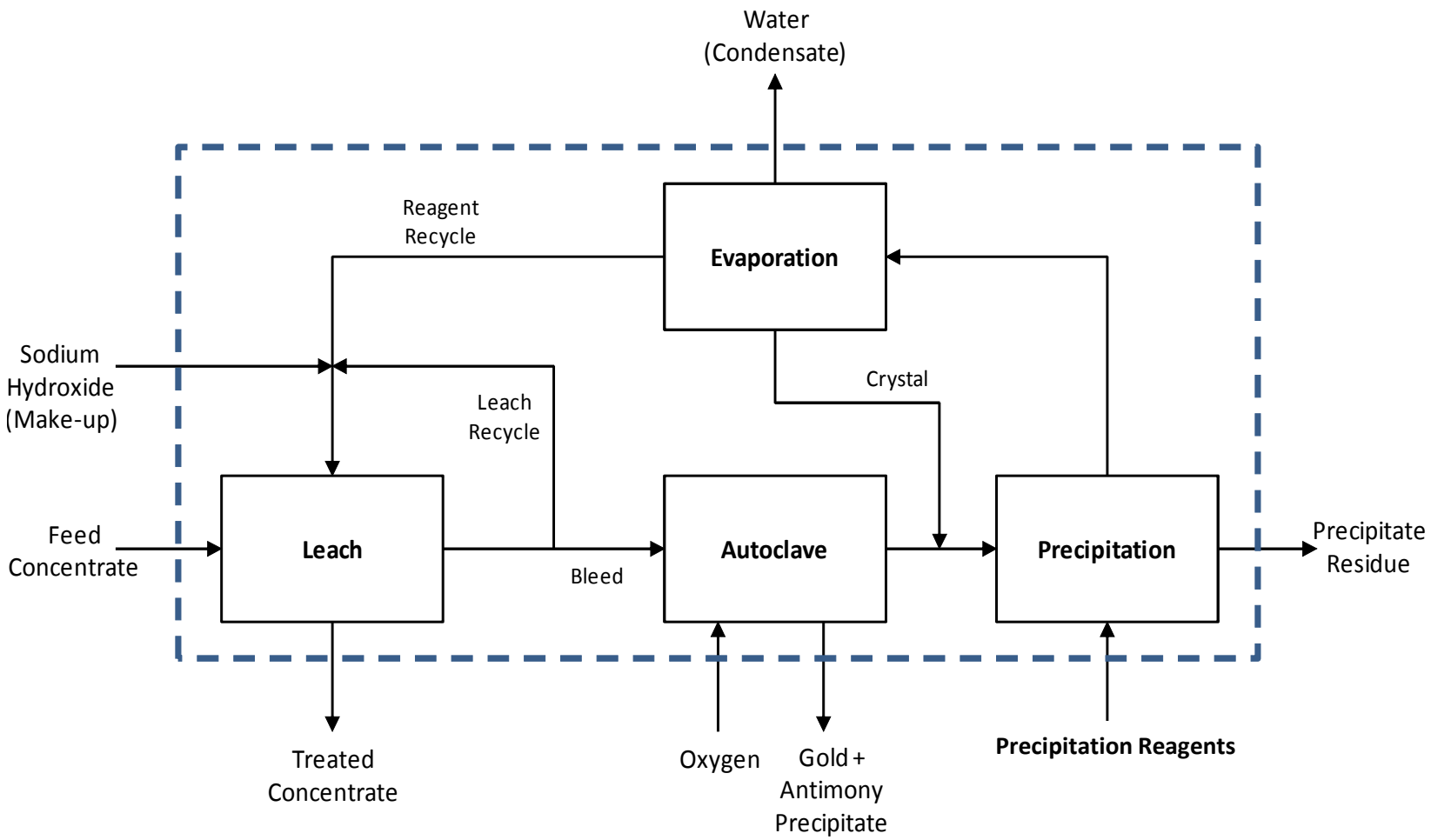
Toowong Process

- Determined a clear need with increasing levels of Arsenic in Copper Concentrates
- Started development work in 2009
- Extensive batch and continuous locked cycle testing
- Tested a range of copper (1.1% to 3.3% As) and nickel concentrates (0.8% As)
- Leaches Enargite, Tennantite, Tetrahedrite, Gersdorffite
- Mini Pilot in November 2011
- Maxi Pilot in November 2012

Maxi Pilot Plant - Overview

- Ran from 19th Nov - 21st Dec 2012
- Major $4.5M integrated pilot campaign employing over 60 personnel
- ~53 kg/day Copper Concentrate treated
  - 11 days, Toowong Blend
  - 23 days, Tampakan Composite

Maxi Pilot Plant - Flowsheet



Maxi Pilot Plant - Operation

November 2012

Leach Circuit

Concentrate Repulp Circuit

Maxi Pilot Plant - Operation

November 2012

Leach Residue Filtration

PLS Oxidation Autoclave

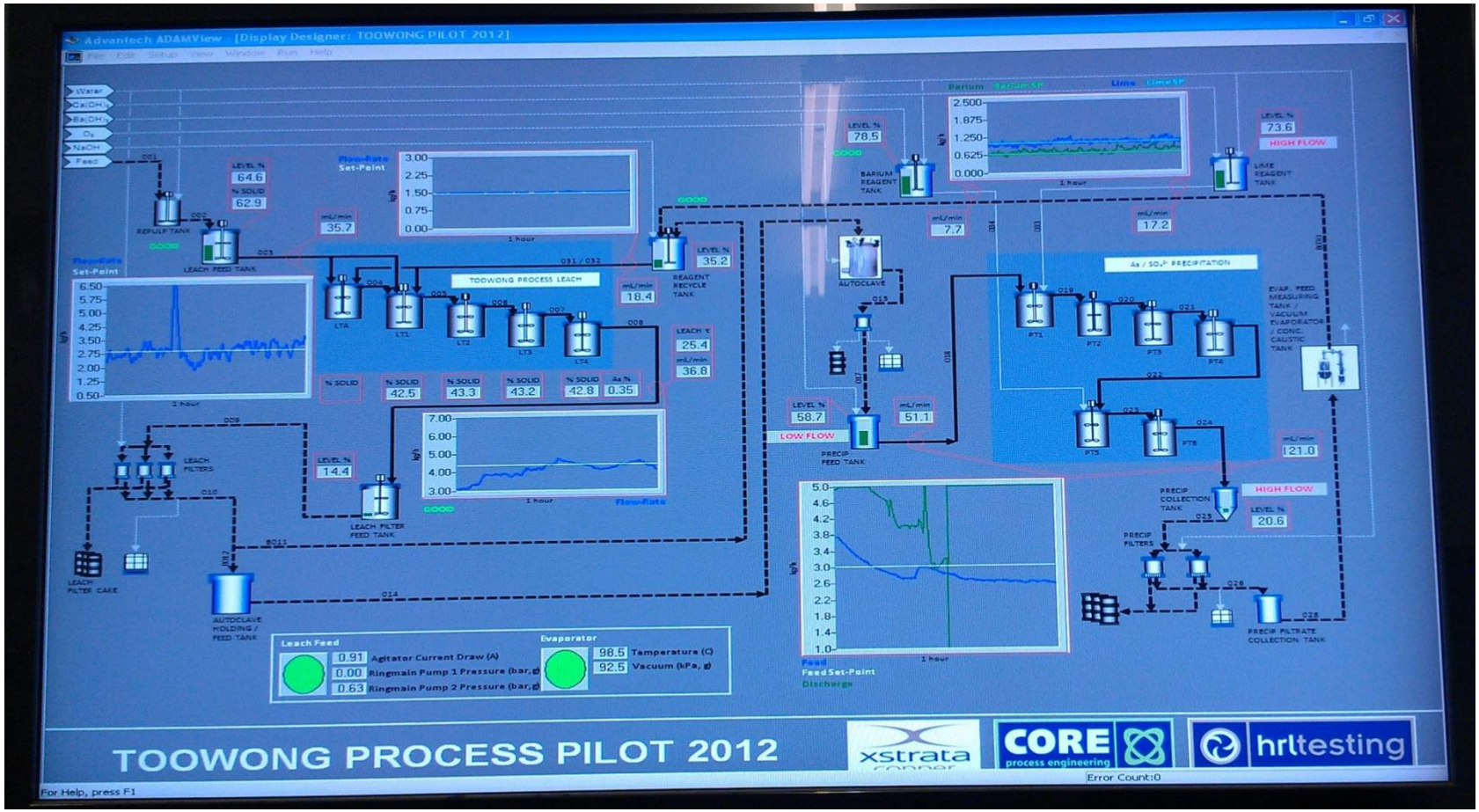
Maxi Pilot Plant - Operation

November 2012

Arsenic and Sulphate Precipitation and Filtration

Caustic Evaporator

Maxi Pilot Plant - Operation



Live Process Monitoring
(Temperature, Pressure, Mass Flow, Tank Level, Current Draw)

Maxi Pilot Plant - Operation

- Key results:

		Toowong Blend			Tampakan Concentrate		
	Units	Feed	Product	Extracted	Feed	Product	Extracted
As	%	1.11	0.11	90%	1.12	0.09	92%
Sb	%	0.06	0.01	78%	0.08	0.01	85%

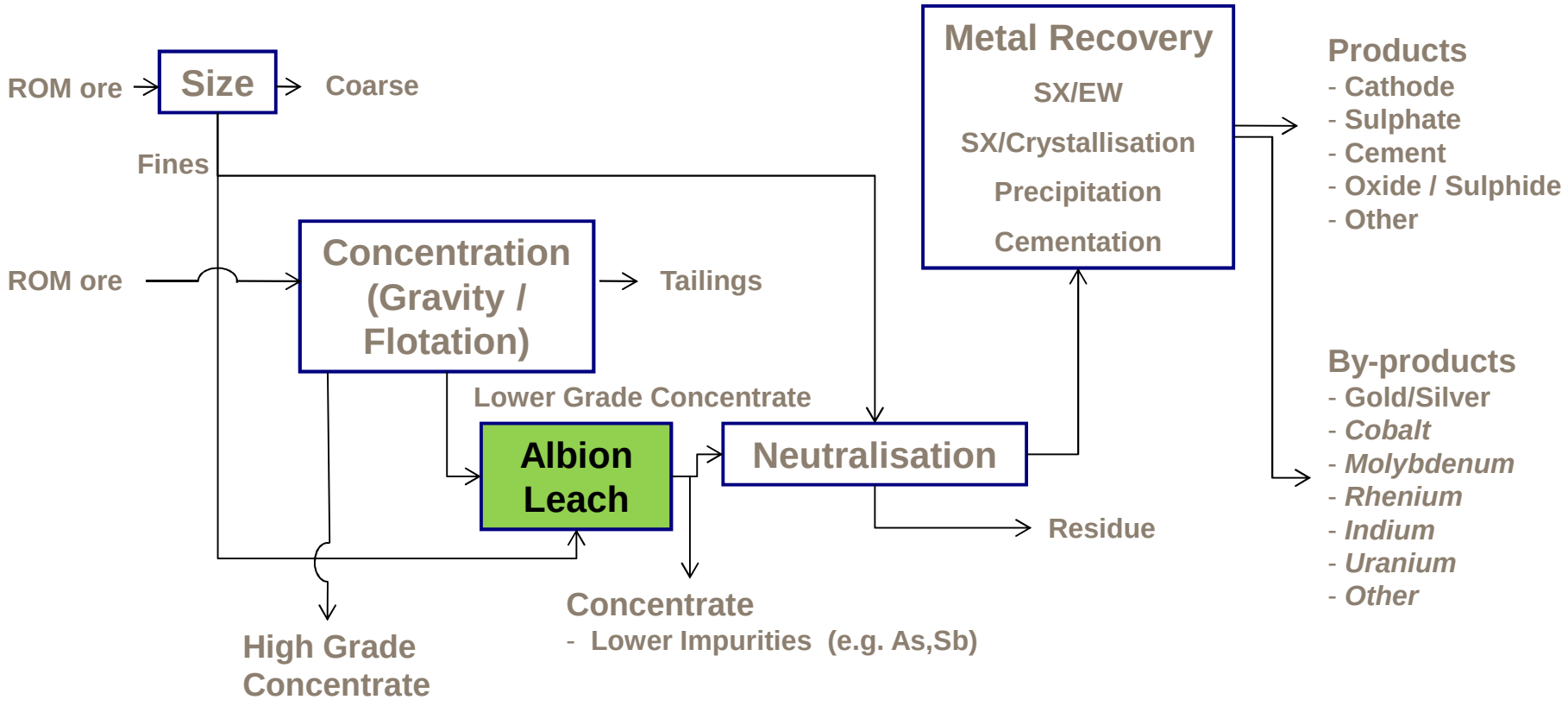
  - 0.09% arsenic in treated concentrate over the final 10 days of testing Tampakan concentrate (average)
  - >90% arsenic extraction over the final 10 days of testing (average)

  - Also significant removable of antimony, mercury and tin

Toowong Funding and IP

- Core Resources and Xstrata (Now Glencore) Funded Development
- Provisional Patent lodged in Oct 2011
- Glencore currently owns IP, (since has reverted to Core)
- Core Resources has rights to use and licence to third parties any patents granted

Albion Process Leach Flowsheets



Albion Process Leach Flowsheets

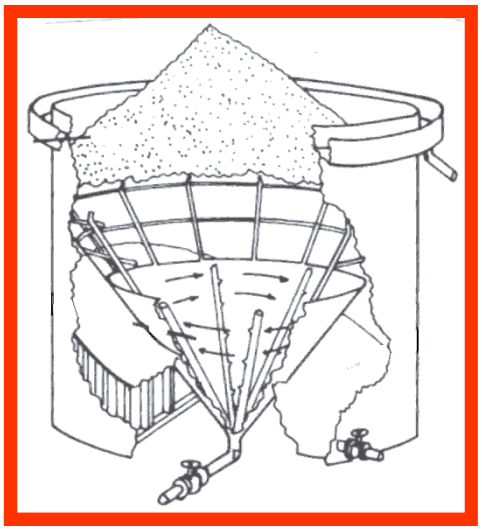
Opportunities to Add Value

- Alternative products
- By-products
- In-situ acid production – reduce acid cost
- Use of alternative neutralising materials – reduce neutralising cost
- Impurity removal
- Integrated flowsheets
- Additional metal recovery
- Key drivers

Albion Process Leach Product Options

Copper Cathode

- Larger scale projects
- Low/moderate power costs
- Remote / high transport costs



$$Cu^{2+} + Fe = Fe^{2+} + Cu$$

Copper Sulphate

- Premium over metal
- Smaller scale projects
- Power costs higher
- Local demand – zinc flotation, fertilizer plant, feedlot

Other (Cement, Copper Sulphide, Copper Oxide)

- Copper cement – concentrates or low cost scrap iron available
- Intermediate product – market nearby or integrated flowsheet

Impurity Removal

Many large undeveloped copper deposits have significant impurity issues.

• Salobo, Brazil	High Fluorine
• La Granja, Peru	High Arsenic
• Tampakan, Philippines	High Arsenic
• Nena, PNG	High Arsenic
• Many other South American Copper Projects	High Arsenic

Concentrate and Leaching Synergies

Case Study

Normal grade concentrate for sale

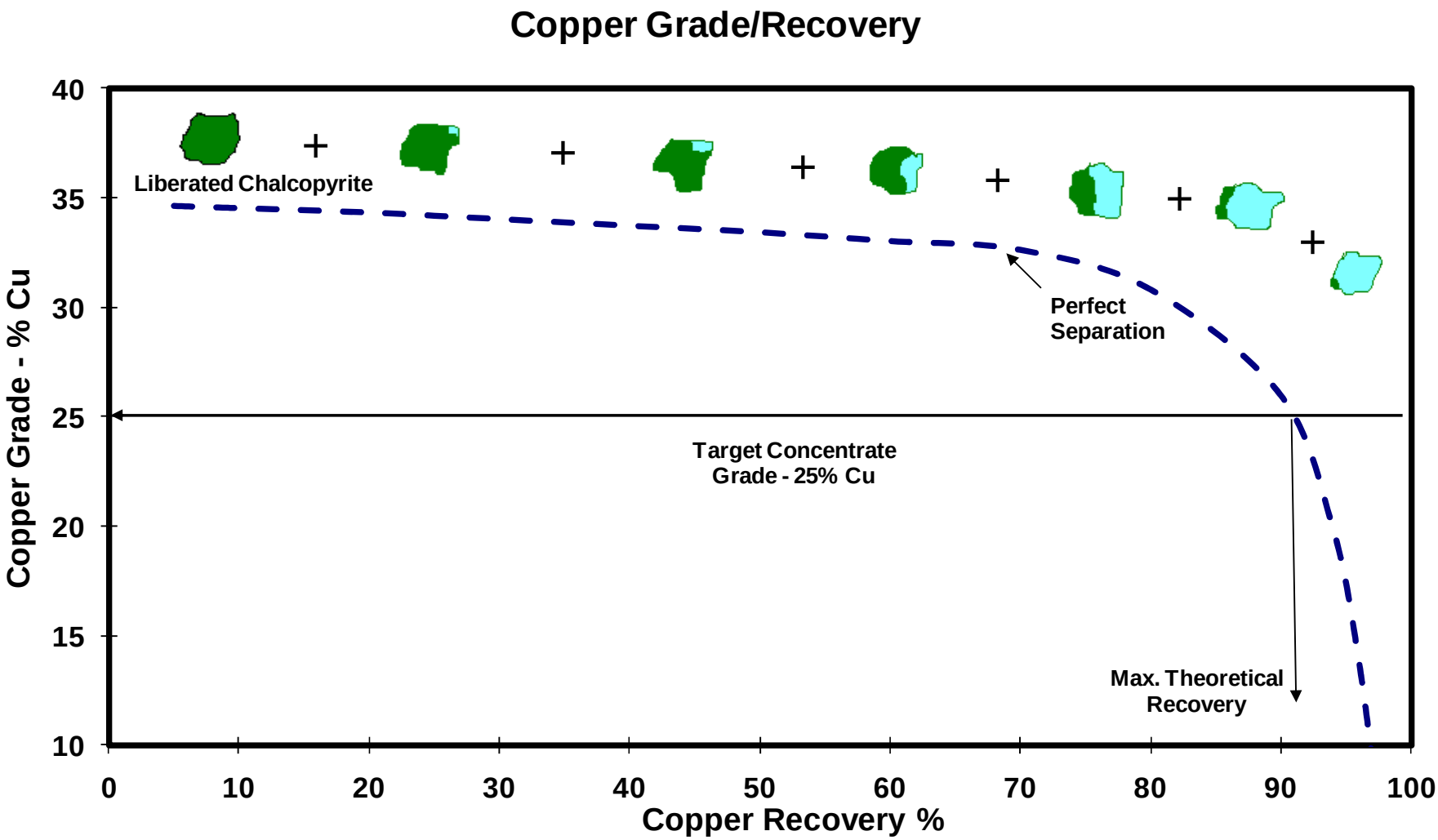
vs.

High grade concentrate for sale

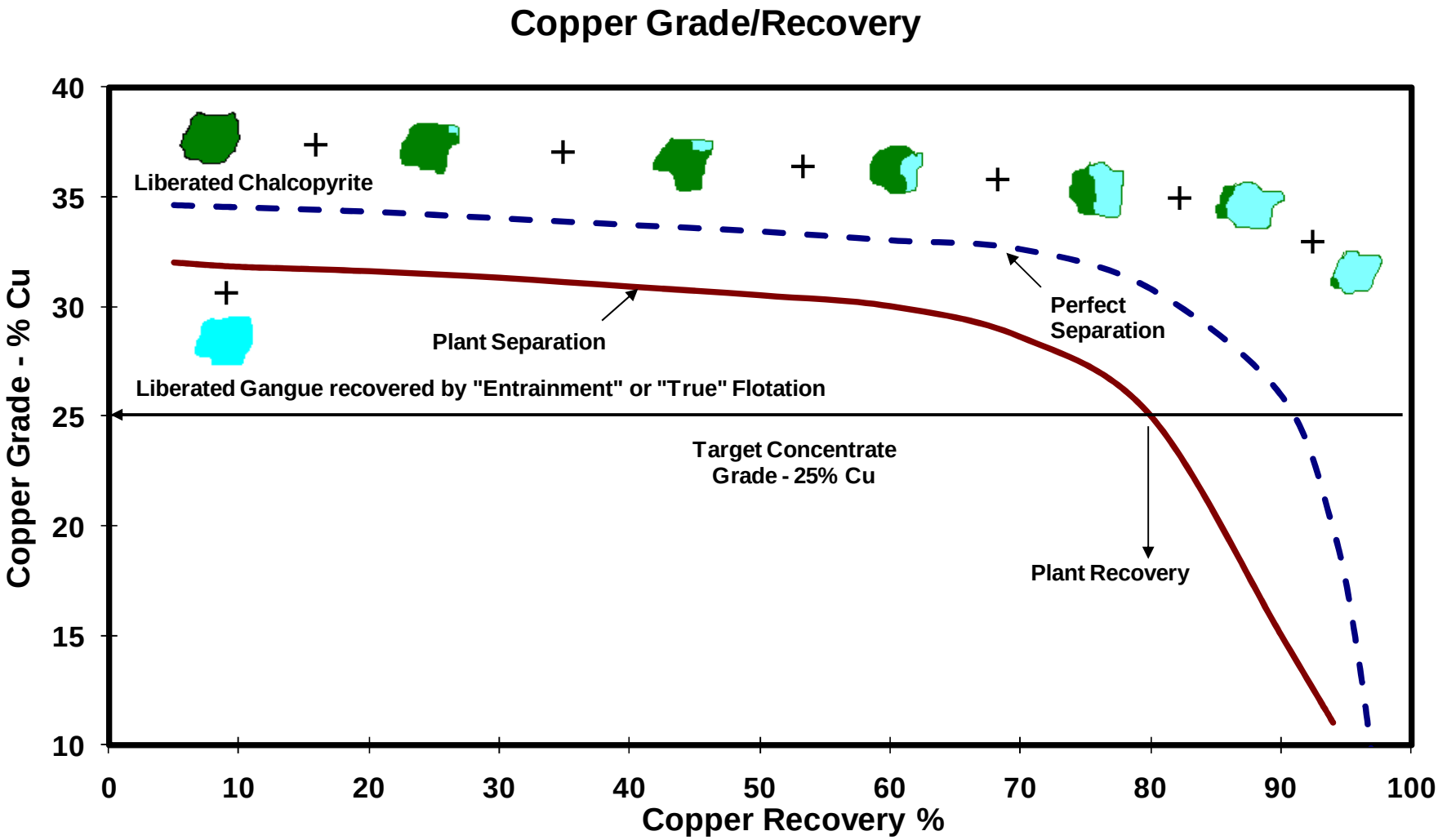
plus

Low grade concentrate to leaching

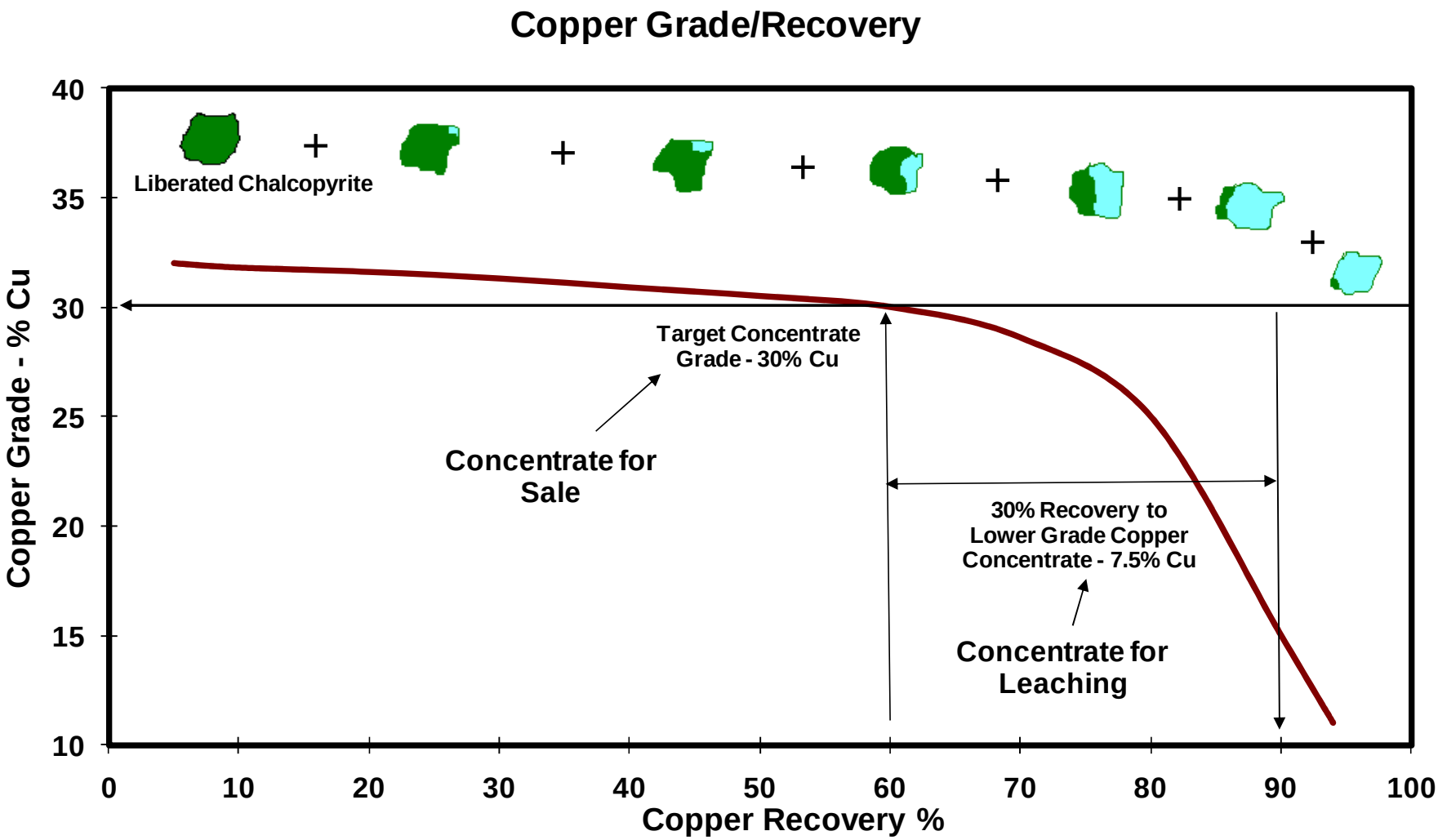
Copper Recovery



Copper Recovery



Copper Recovery – Case Study



Case Study - Project A

- Copper/Cobalt concentrate recovered from tailings of existing copper operation
- Grade of concentrate - 2.2% Cu and 0.28% Co
- Prefeasibility testing followed by Albion Process Pilot Plant run
- Pilot Results on ~600 kg of concentrate over 24 day run
  - 94% Copper extraction
  - 81% Cobalt extraction
- Downstream cobalt recovery testwork now being conducted
- Project Capex in the order of $80M

Case Study - Project B

- Copper/Gold concentrate recovered from tailings of existing copper operation (additional 17% Cu and 25% Au recovery)
- Grade of concentrate - 2.4% Cu and 1.5 g/t Au
- Tonnes of concentrate – 640,000 tpa , containing ~15,000 tpa Cu and ~30,000 oz Au/y
- Scoping Study results
  - 93% Copper recovery
  - 85% Gold recovery
- Project Capex in the order of US$200M

Summary

- Ore sorting can be used in copper processing for:
  - Upgrading ore to reduce haulage, reduce processing costs and improve the overall capital cost position along with;
  - Removing GAC minerals in heap leach applications.
- Heavy Medium Separation can be used on some copper ores to improve project economics.
- Toowong Process has demonstrated that it is an option for removing impurities from “dirty” copper concentrates.
- Albion Process has a role in improving overall project economics, by improving recovery of copper from certain more difficult projects, along with dealing with impurities.

Independent Company

Eberhard Krause - HydroMet Solutions Inc.

"Initially, HS was somewhat concerned that Barrick had chosen Core, rather than an independent engineering firm, to carry out this pre-feasibility study (PFS), because one might have expected a positive bias towards the Albion Process option .... **As was demonstrated by the outcome of the pre-feasibility study, which looked at three potential process options (Albion, Roaster and a hybrid roaster/Albion Process), such worries were unfounded"**

Questions ?