NIKKELVERK

A GLENCORE COMPANY

Hydromet-seminar at Glencore
Lecture 4: **Developing a Hydromet Flowsheet**

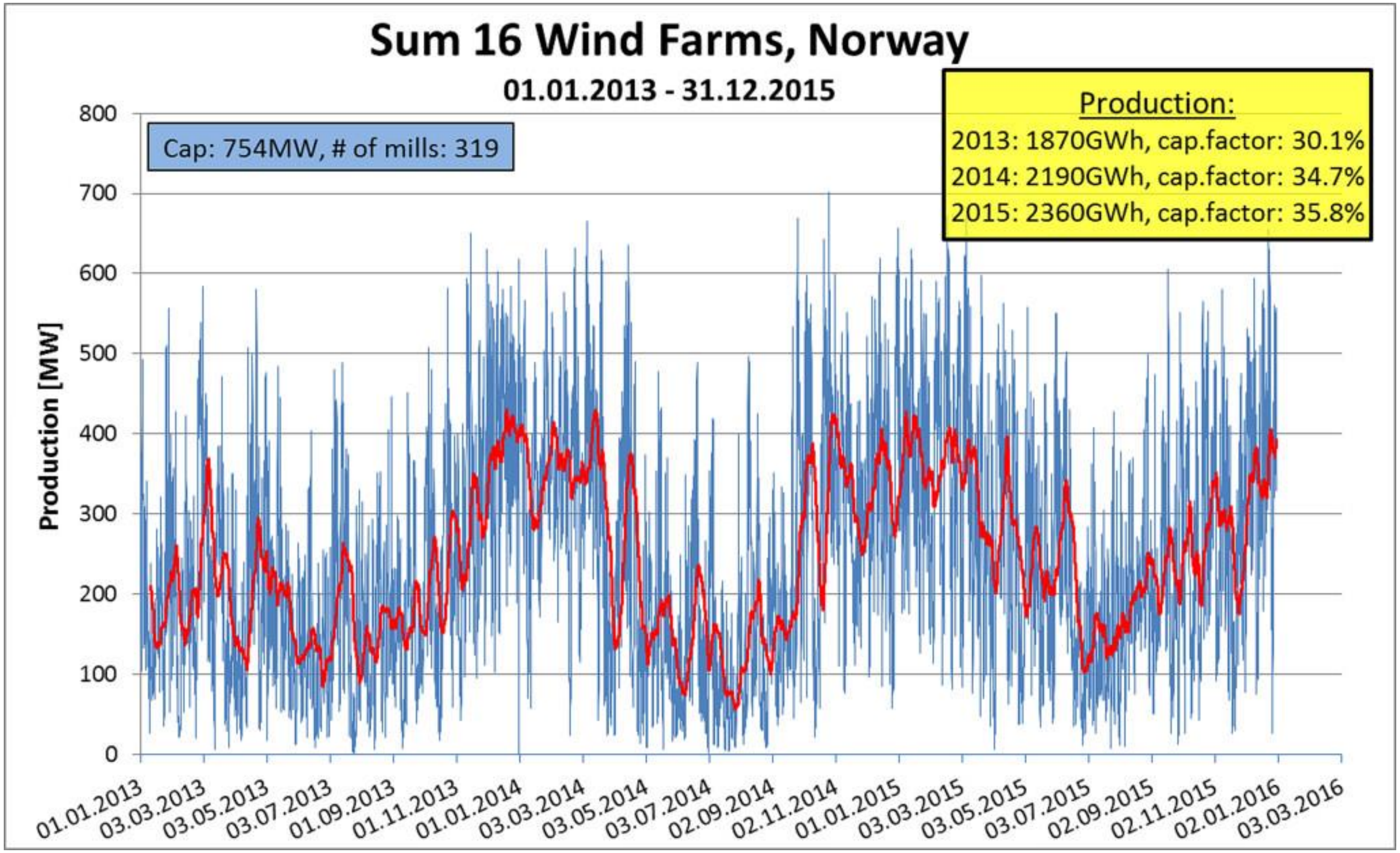
Developing a Hydrometallurgical Flowsheet
Basis for a project: The resource

- Basis for all mineral projects are the resource.
  - A resource in the ground that contains one or more minerals with economic value in the market place
  - The resource usually sets some limitations on what You can do, and where
  - But once You have defined the resource to a certain degree(size and grade) by drilling and sampling, it is time to start looking at different scopes
  - And in this work, development of process flowsheets is a main task.

Developing a Hydrometallurgical Flowsheet
Things to consider for a greenfield project

- Country hosting the resource
  - Politics (restrictions of ownership, jobs, participation in development etc.)
  - EH&S regulations (most companies adhere to European rules as minimum)
    - Wastes and emissions, process plant located seaside or inland?
  - Skills of labor
  - Energy, available from grid or build power plant?
    - Fossil or renewables, what to do with CO_2-emissions?
  - Logistics
    - How to get chemicals and production materials,
    - Get products to market
  - Finances and economy (Capex & Opex, taxes & royalties)

Developing a Hydrometallurgical Flowsheet
Energy, renewables not "so simple"...



Developing a Hydrometallurgical Flowsheet
Defining a flowsheet is usually a compromise

- Not only technology (state-of-the-art) defines a flowsheet, how to treat mineral resources
  – All the above may have signifivant influence on the technology choices
  – It is the overall goals for the projects that may determine which technologies that are chosen
    - Of which economy and finance are first priority
    - But governance and social responsibility comes high
    - As does environmental concerns

Developing a Hydrometallurgical Flowsheet

Pretreatment to fit the concentrate to a HM flowsheet

- What pretreatment will the resource need to fit a hydromet flowsheet?
  - Mining, some separation & concentration possible?
  - Concentrating, is it possible?
    - crush, grind, screen, classify, flotation...
    - Any pyroprocessing needed? Calcination, smelting, reduction...
  - The project needs mineral and pyromet engineers...
  - Ready for the hydromet flowsheet?

Developing a Hydrometallurgical Flowsheet
The "toolbox" of a hydrometallurgist...

Conventional processes available to develop flowsheets:

- Comminution (crushing, grinding, size reduction etc.)
- Dissolution methods (chemical leaching, electrochemical dissolution, etching, tank leaching, static bed, heap leach etc.)
- Chemical precipitation (oxides, hydroxides, carbonates, sulphides etc.)
- Crystallisation (metal salts)
- Electrochemical precipitation (cementation, H2-reduction)
- Electrodeposition
- Liquid-liquid Extraction (organic solvents)
- Ion Exchange (resins)
- Ultra Filtration/RO etc.

Developing a Hydrometallurgical Flowsheet
Hydroxide precipitations, what is possible?

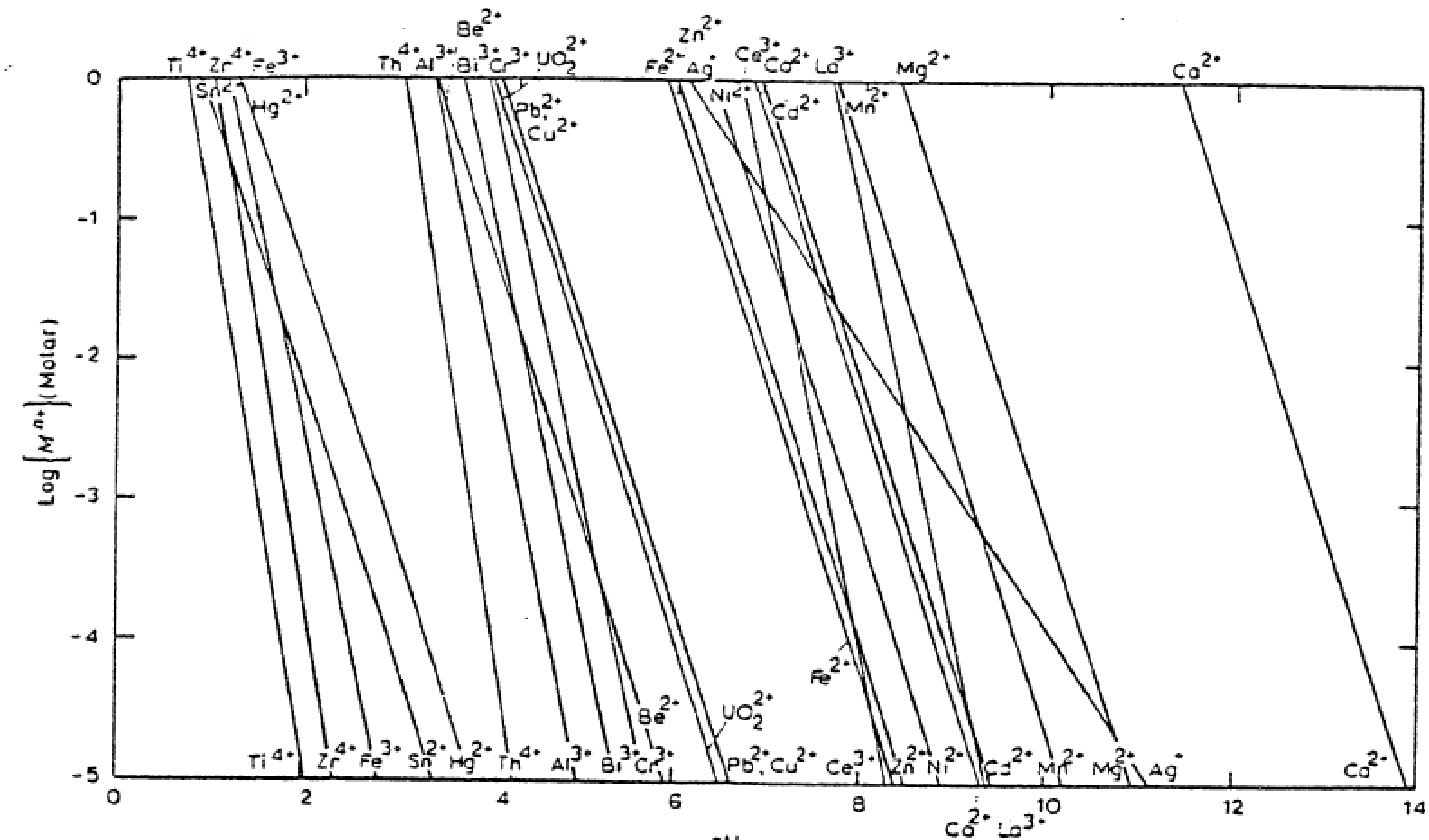


Fig. 1 Hydroxide precipitation diagram, 25°C

Developing a Hydrometallurgical Flowsheet
Sulphide precipitations, what is possible?

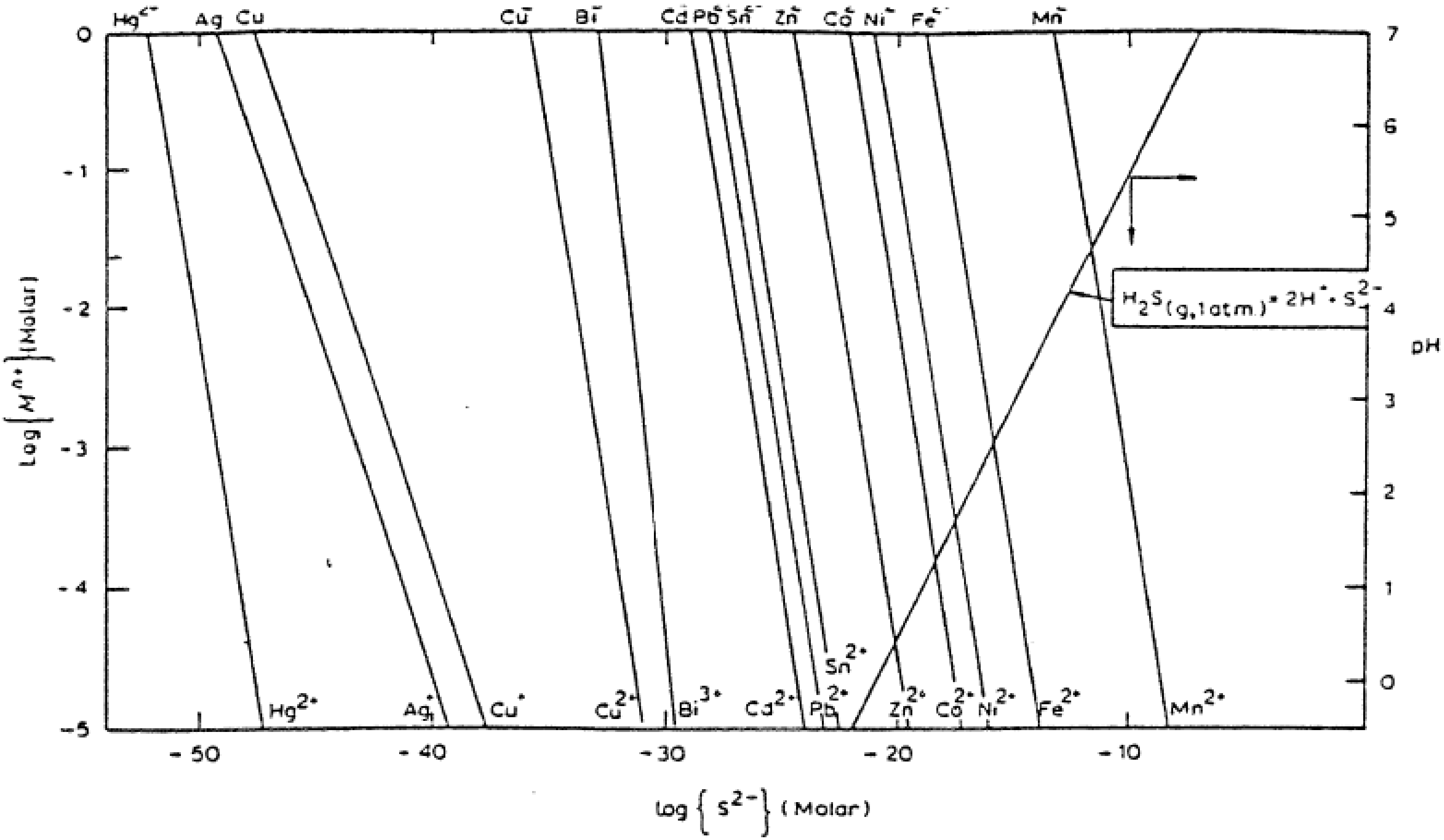
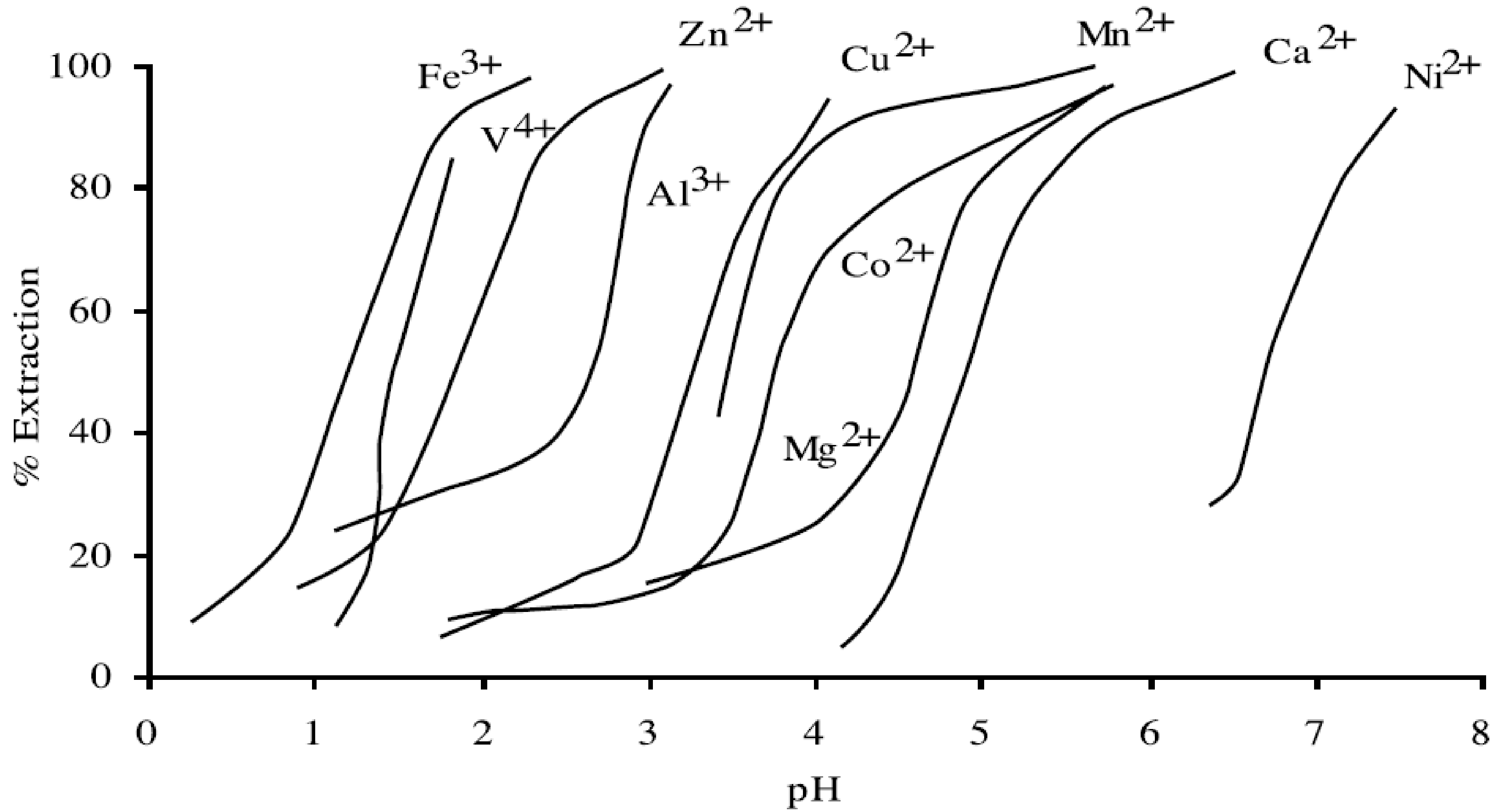


Fig. 2 Sulphide precipitation diagram, 25°C

Developing a Hydrometallurgical Flowsheet
SX (here: Cyanex272), what is possible?

Figure 3 – Extraction of Metals by CYANEX 272 Extractant from Sulfate Solutions



Developing a Hydrometallurgical Flowsheet
Technology development exercises...

- **Objective?**
- **Literature & contacts** — Look at solution chemistry, any fatal flaws?
- **Bench scale tests** (synthetic or actual solution) — Look at equilibria and kinetics, and other key parameters
- **Continuous tests** — Confirm bench scale result
- **Mini-plant integrated** — Produce real(istic) solutions, accumulations, characterize products and wastes. Env.Ass. PFS – Prefeasibility Study (+/- 30%)
- **Pilot plant** — More realistic balances, water balance, products. Design data. Env.Ass. Oper. training. FFS/BFS – Final (Bankable) Feas. Study (+/-15%)
- **Comm Plant design**

Developing a Hydrometallurgical Flowsheet

Example 1: VALE Voiceys Bay Mine, Long Harbour Ni-conc. Leach-SX-EW plant, 50 000 T/a Ni

- Voiceys Bay Ni-resource in Labrador, Canada discovered by Diamond Fields in 1995
- Purchased by INCO Ltd. (VALE) in 1996 in competition with Falconbridge Ltd. for C$4.3bn
- Started bench scale development in 1998
- Concluded negotiations with province to process all ore (Ni-equiv.) in N.Foundland in around 2002
- Minipilot-plant (1/10 000) operated in 2003-2004 at INCO-labs, Mississagua, Ontario

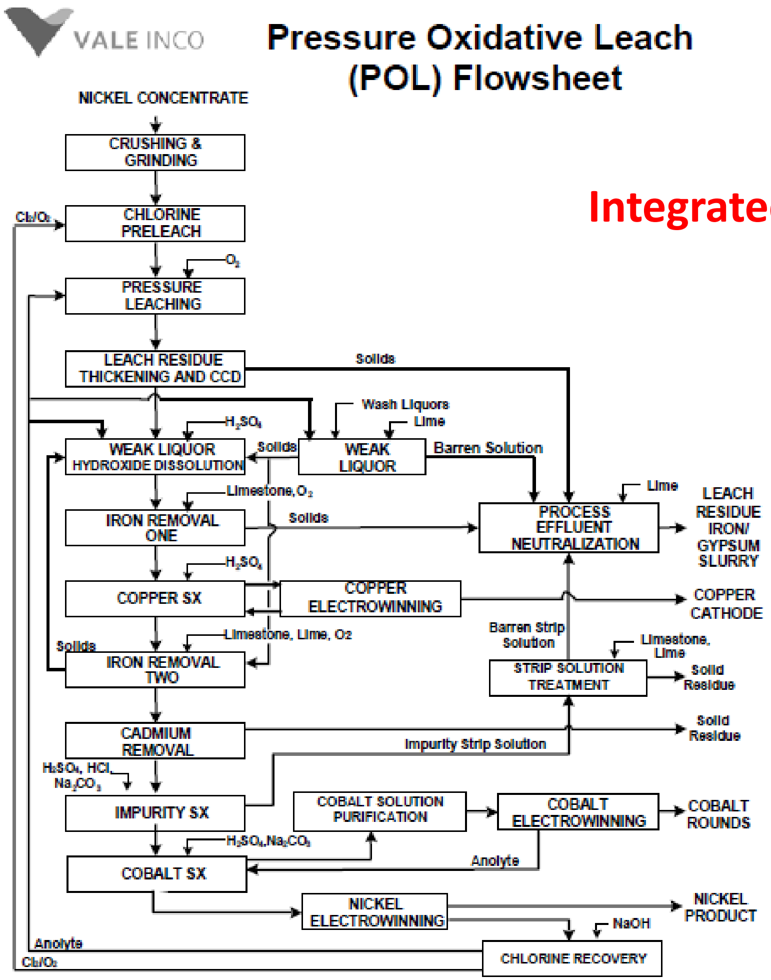
Developing a Hydrometallurgical Flowsheet

Example 1: VALE Voiceys Bay Mine, Long Harbour Ni-conc. Leach-SX-EW plant, 50 000 T/a Ni

- Demo-plant (1/100) built and operated in N.Foundland in 2005-2008
- Mine started production in 2007
- VALE board approved Long Harbour project in 2009
- Detailed engineering 2009-2012
- Construction of plant started in 2012
- Commissioning in late 2014, but key equipment lacking
- Final plant planned to be ready in late 2016
- Approved Capex Long Harbour: US$2.3bn, final Capex: ~US$5bn

Developing a Hydrometallurgical Flowsheet

VALE Long Harbour: Ni-concentrate leach-SX-EW flowsheet



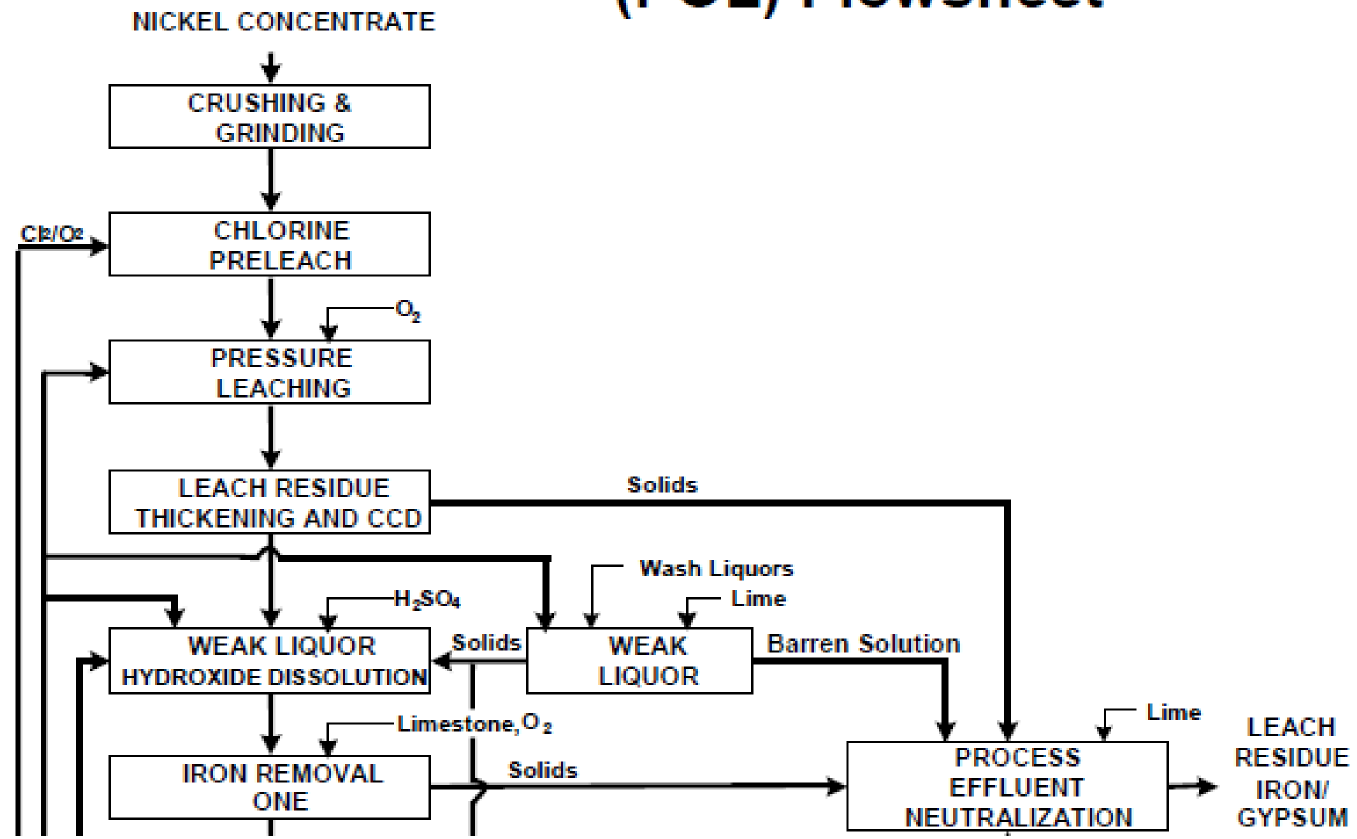
Integrated SO4/Cl circuit

Developing a Hydrometallurgical Flowsheet

VALE Long Harbour: Flowsheet first part

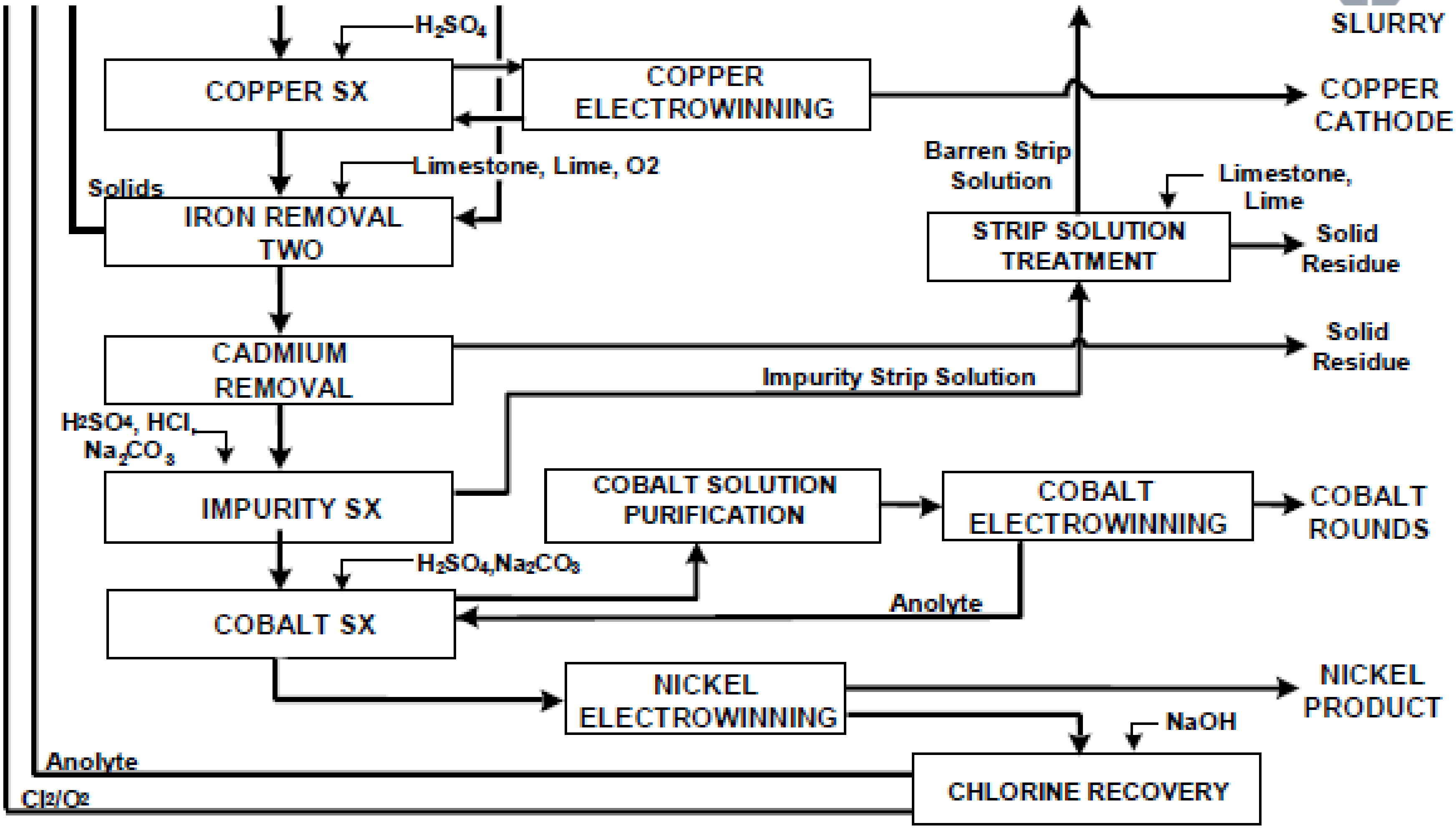
VALE INCO

Pressure Oxidative Leach (POL) Flowsheet



Developing a Hydrometallurgical Flowsheet

VALE Long Harbour: flowsheet second part



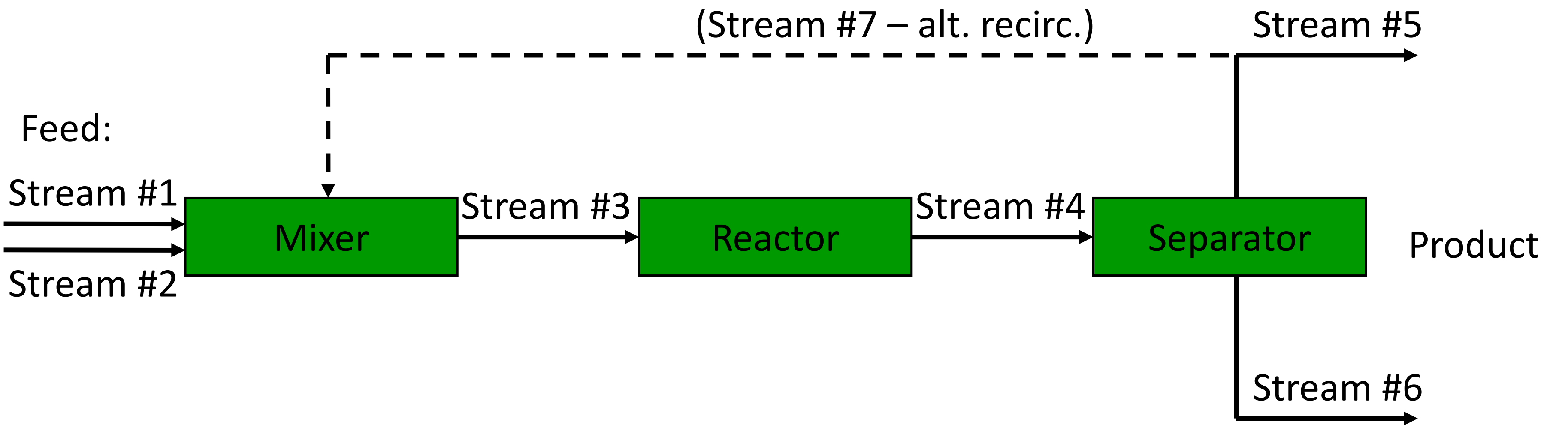
Solvent extraction in Hydrometallurgy

VALE Long Harbour operations in New Foundland, Canada

Developing a Hydrometallurgical Flowsheet
Basic building block in a flowsheet: separation

<u>Most operations contain the following steps:</u>
Mixing (mixing several streams together)
Chemical reaction (chemicals react in a reactor)
Separation (tow – or more phases are separated)

Two (or all three) sequential steps may take place in the same equipment unit.



Developing a Hydrometallurgical Flowsheet

Example 2: Nikkelverk Feed mixture and electrolyte (anion)

- Ni-matte sammensetning (typisk vekt-%)

Ni	Cu	Co	Fe	S	Minors
56%	**17%**	**2%**	**2.5%**	**22%**	**PGM's, Au, Ag, As, Pb, Mn, Zn, Te, Bi, Sb, Si, ...**

- Hovedelementene Ni, Cu, S i råstoffet (matte):
- Ni: Ni_3S_2
- Cu: Cu_2S (stabile faser i sulfidsmelte @1.250 °C)

- Transport og reaksjons/behandlingsmedie (fase):
- Elektrolytter (vandige metallsalt oppløsninger)
- Anion for metallsaltene må velges

Developing a Hydrometallurgical Flowsheet Chemistry: Leach and metal winning for Ni

- <u>Nikkel-elektrolytt:</u>
- $NiCl_2$(aq)
    - Cl^- (klorid) som anion, vann (aq) transportmedie

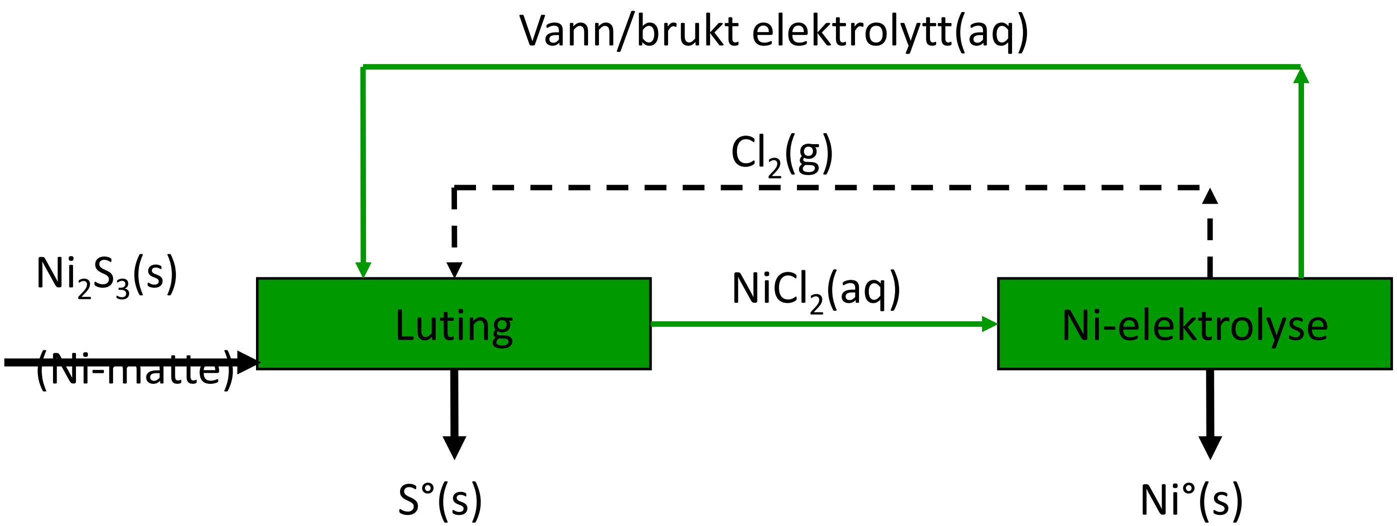
- <u>Utvinningsteknologi:</u>
- Elektrolyse: $NiCl_2$(aq) = Ni°(s) + Cl_2(g)

- <u>Elektrolytt-produksjon:</u>
- Luting: Ni_3S_2(s) + 3 Cl_2(g) = 3 $NiCl_2$(aq) + 2 S°(s)

- <u>Netto reaksjon:</u>
- Luting+elektrolyse: Ni_3S_2(s) = 3 Ni°(S) + 2 S°(s)

Developing a Hydrometallurgical Flowsheet

First version of the flowsheet for Ni: Front and back end



$Ni_3S_2(s) + 3\ Cl_2(g) =$
$3\ NiCl_2(aq) + 2\ S°(s)$

$NiCl_2(aq) = Ni°(s) + Cl_2(g)$

We see the metal winning stage regenerates the leachant, ready to be recycled.
In a fully recyclable process, the net reaction of the main steps eliminates the leachant:

Net reaction: $Ni_3S_2(s) = 3\ Ni°(S) + 2\ S°(s)$

Developing a Hydrometallurgical Flowsheet

Chemistry: Leach and metal winning for Cu

- <u>Kobber-elektrolytt:</u>
- $CuSO_4$(aq)
  - SO_4^{2-} (sulfat) som anion, vann (aq) transportmedie

- <u>Utvinningsteknologi:</u>
- Elektrolyse: $CuSO_4(aq) + H_2O = Cu°(s) + H_2SO_4(aq) + ½O_2(g)$

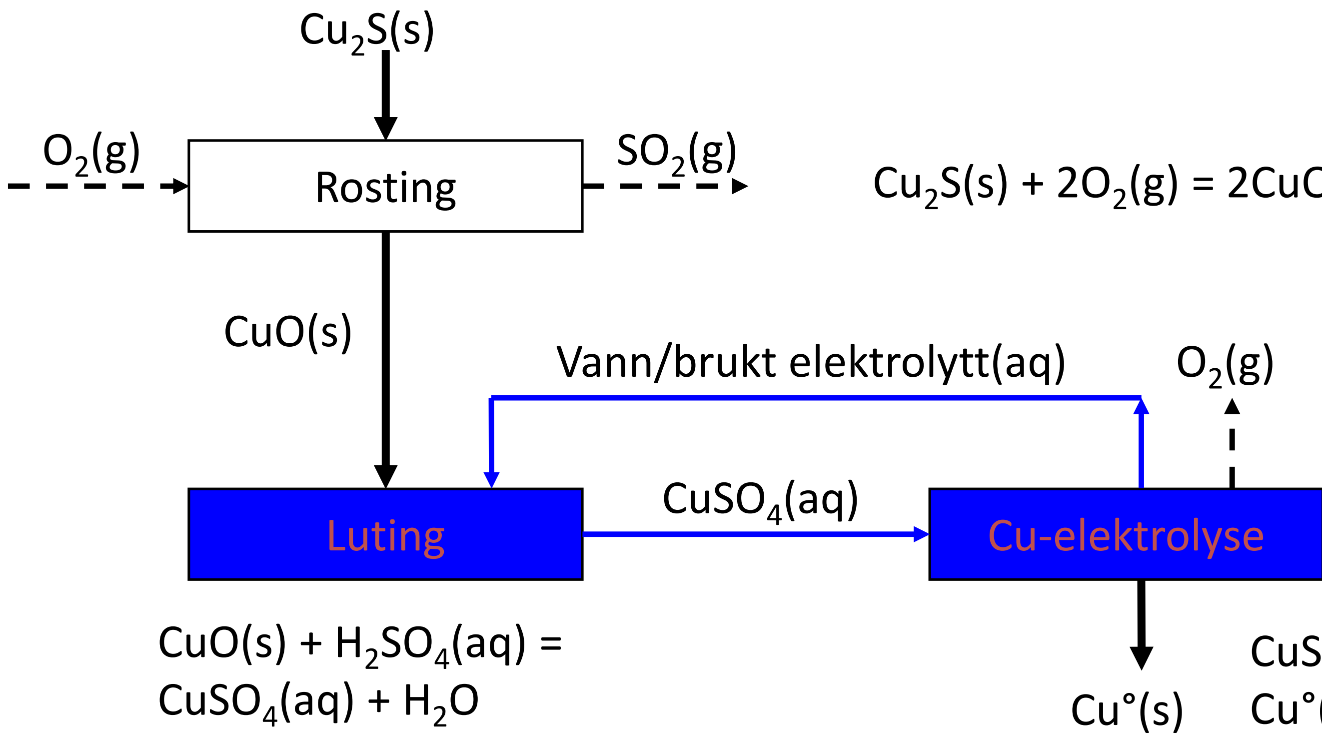
- <u>Elektrolytt-produksjon:</u>
- Luting: $CuO(s) + H_2SO_4(aq) = CuSO_4(aq) + H_2O$ (Cu_2S uløselig i svovelsyre)

- <u>Konvertering av sulfid til oksyd:</u>
- Rosting: $Cu_2S(s) + 2O_2(g) = 2\ CuO(S) + SO_2(g)$

- <u>Netto reaksjon:</u>
- Rosting+luting+el.lyse: $½Cu_2S(s) + ½O_2(g) = Cu°(s) + ½SO_2(g)$

Developing a Hydrometallurgical Flowsheet

First version of the flowsheet for Cu: Front and back end



$Cu_2S(s) + 2O_2(g) = 2CuO(s) + SO_2(g)$

$CuO(s) + H_2SO_4(aq) =$
$CuSO_4(aq) + H_2O$

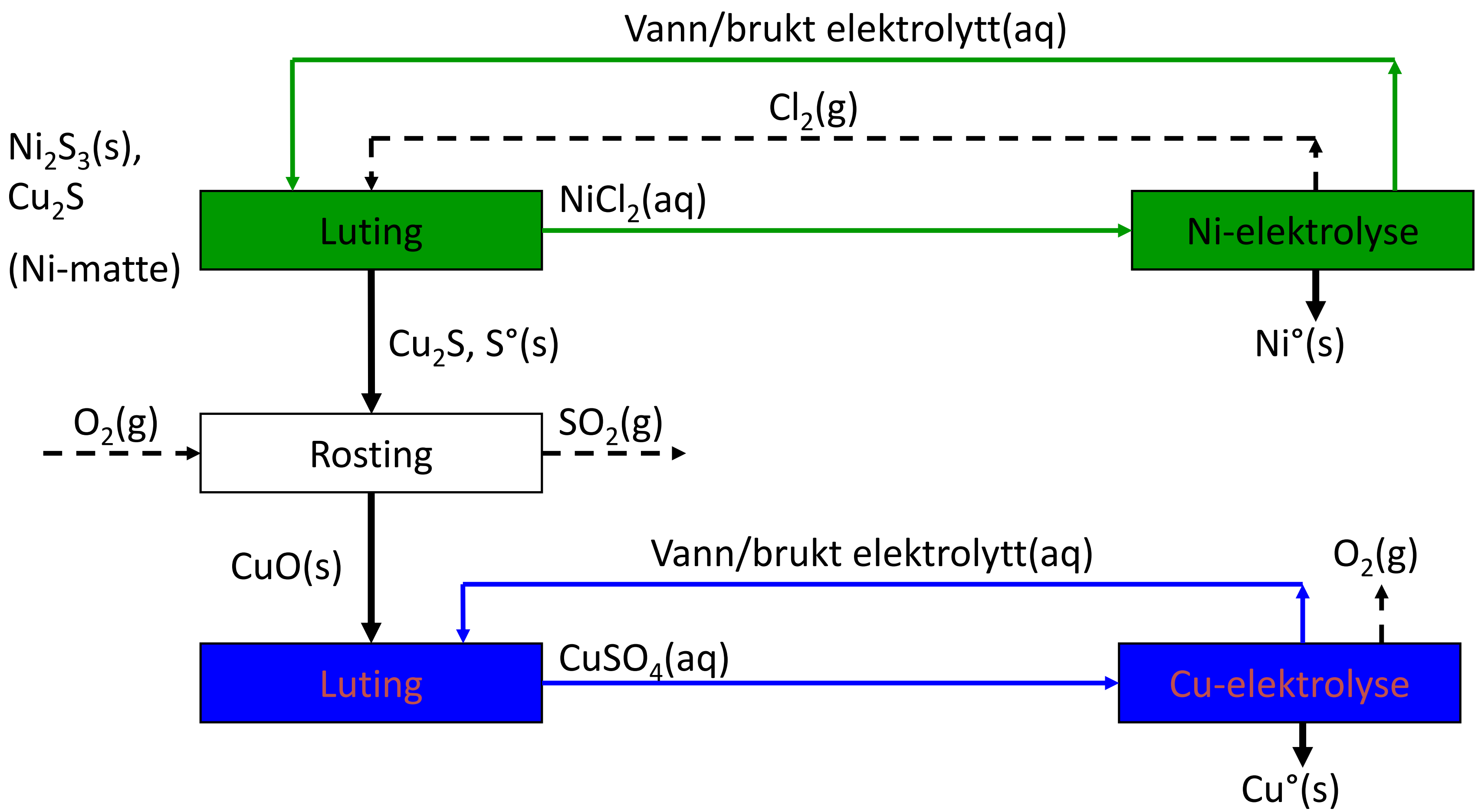
$CuSO_4(aq) + H_2O =$
$Cu°(s) + H_2SO_4(aq) + ½O_2(g)$

Also in this case, the metal winning stage regenerates the leachant, ready to be recycled:

Net reaction: $½Cu_2S(s) + ½O_2(g) = Cu°(s) + ½SO_2(g)$

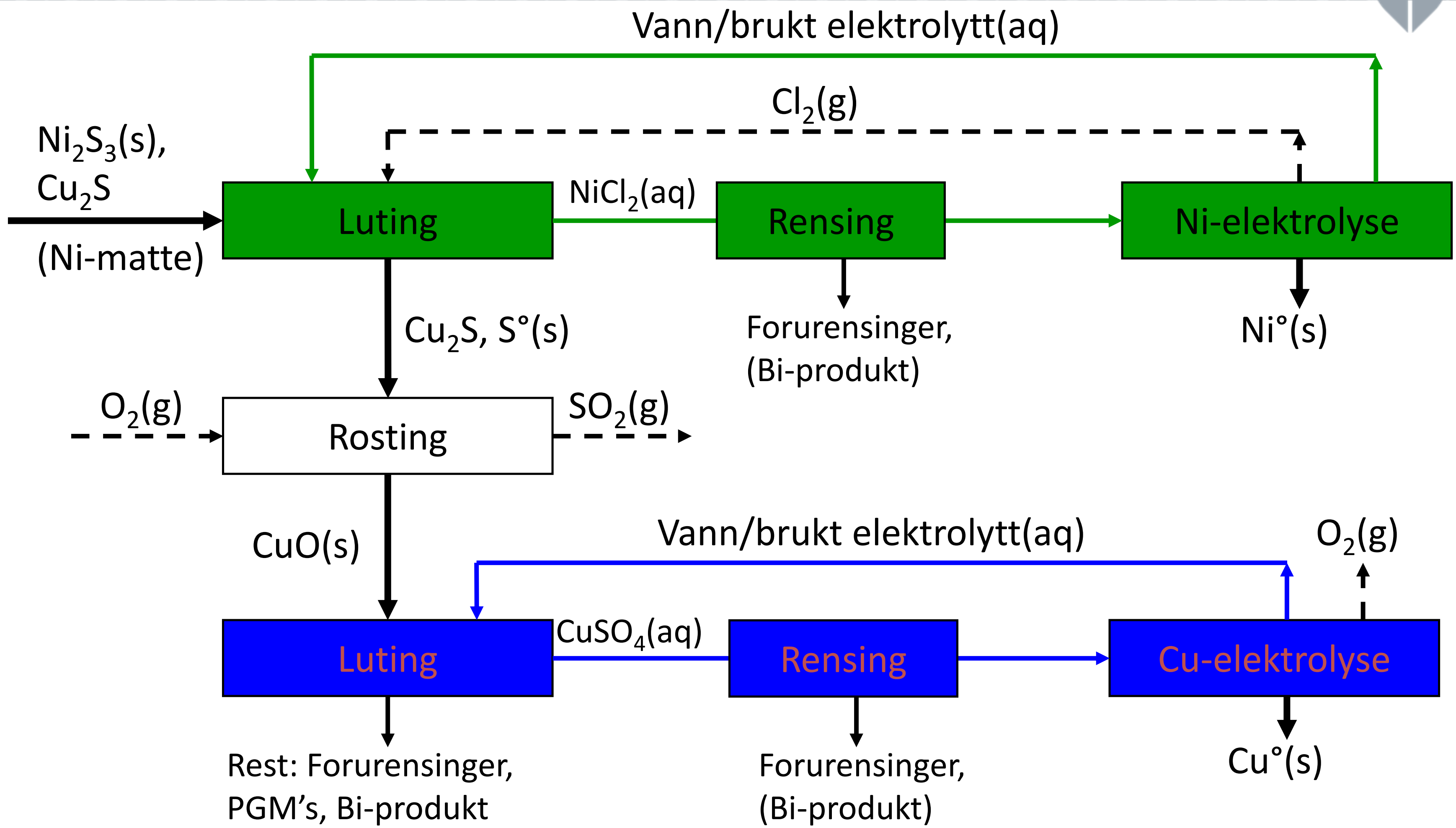
Developing a Hydrometallurgical Flowsheet

First version of an integrated flowsheet with two products



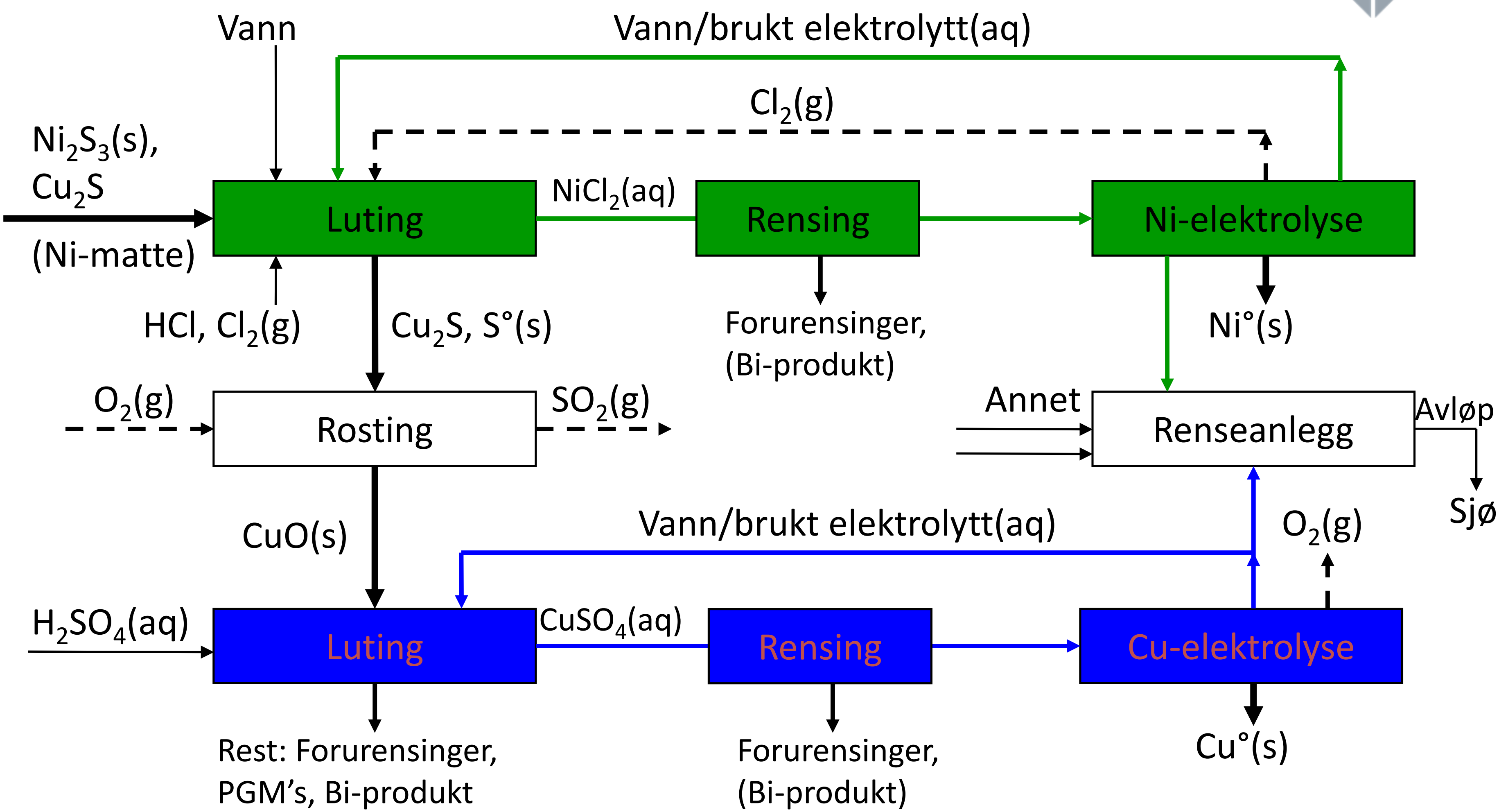
Developing a Hydrometallurgical Flowsheet

The feed does contain other impurities. We need purification



Developing a Hydrometallurgical Flowsheet

The electrolytes see accumulation of inert, metallic salts. Can be controlled by bleeding to an effluent treatment plant.



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Developing a Hydrometallurgical Flowsheet

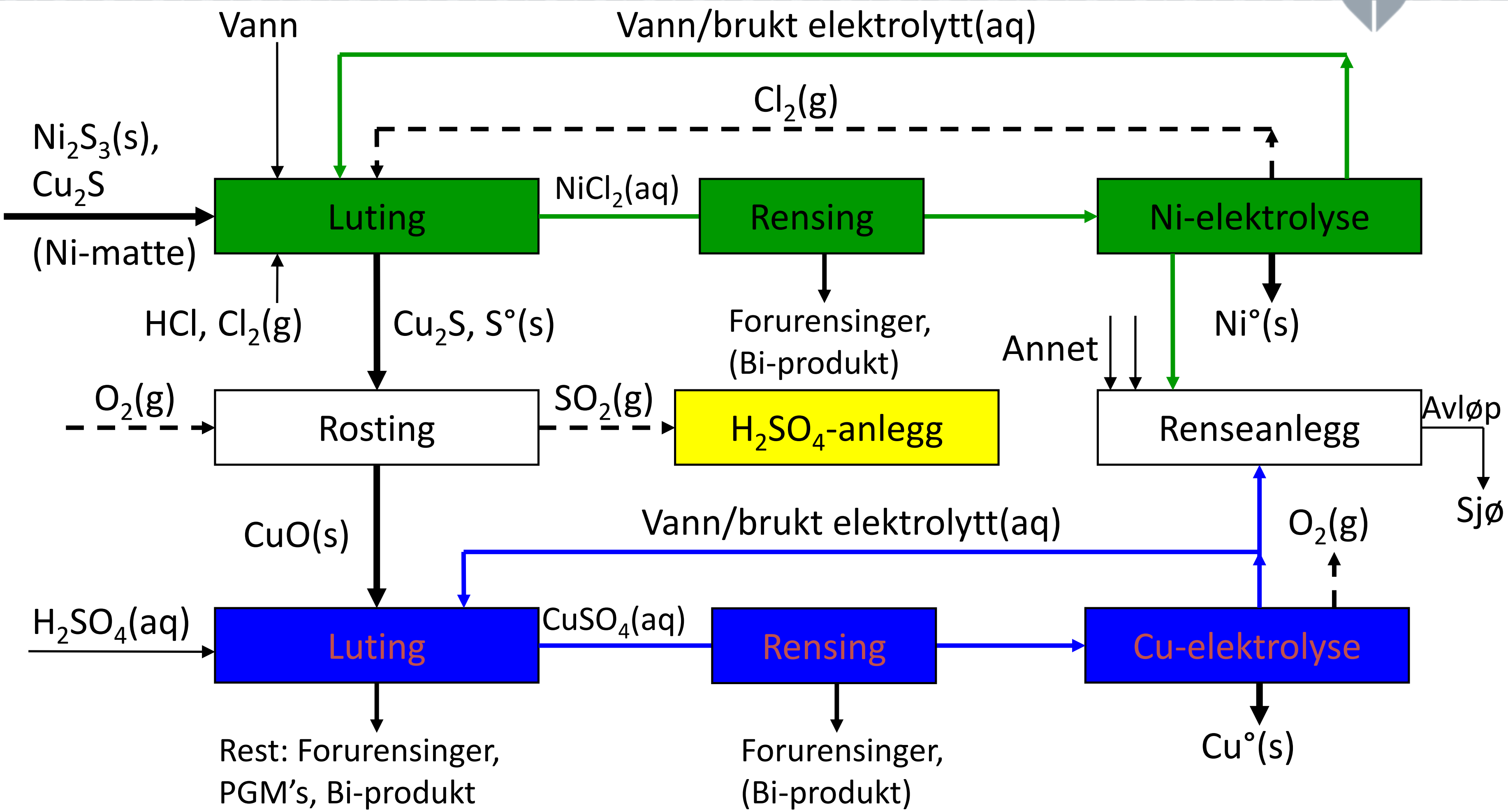
SO2(g) from roasting is not (normally) recovered as is, but further converted to H2SO4 in an acid plant

- <u>Konvertering:</u>
- $SO_2(g) + ½O_2(g) = SO_3(g)$, $\Delta H_r = -99$ kJ/mol

- <u>Absorbsjon:</u>
- $SO_3(g) + H_2O(l) = H_2SO_4(l)$, $\Delta H_r = -132$ kJ/mol

- (Sterkt eksoterme prosesser – genererer varme)

Developing a Hydrometallurgical Flowsheet
A "final" frowsheet (simplified)



Developing a Hydrometallurgical Flowsheet Summary Glencore Nikkelverk

- Nickel and copper refineries with electrowinning uses closed loop processes as far as possible
  - Note that it is energy in the form of electric power (as DC to EW) that drives the flowsheet when it regenerates the leachant and its chemical potential
  - They use consumable chemicals to some extent, but limited
  - They produce as little as possible wastes and try to recover/recycle/convert these to by-products