Hydromet-seminar at IFE, March 2017

The Nickel Laterite Industry with a Focus on Hydrometallurgy

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Nickel industry in perspective…

- Natural resource-industries (peak production in mln tonnes per year):
  - **Coal: 8 200**
  - **Limestone: 5 000**
  - **Crude Oil: 4 000**
  - **Natural Gas: 2 600**
  - **Grains: 2 500**
  - **Iron ore: 2 300**
  - **Steel: 1 700**
  - **S/S-equiv.: 70**
  - **Al: 60**
  - **Cu: 20**
  - **Zn: 13**
  - **Pb: 4.7**
  - **Ni: 2.0**
  - **Co: 0.1**

China consumes ~40-50% of many of these commodities, except grains, crude oil, natural gas and S/H_2SO_4.

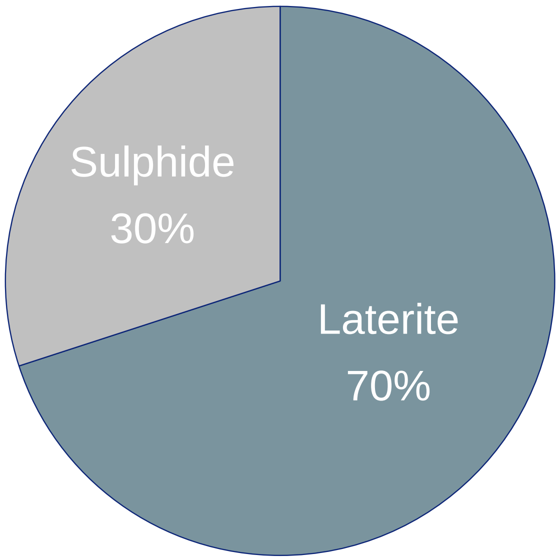
But the price picture is inverse, Ni is ~200 times more expensive than coal…

Global nickel laterite resources

(Source, G.W.Bacon, Inco 2004)

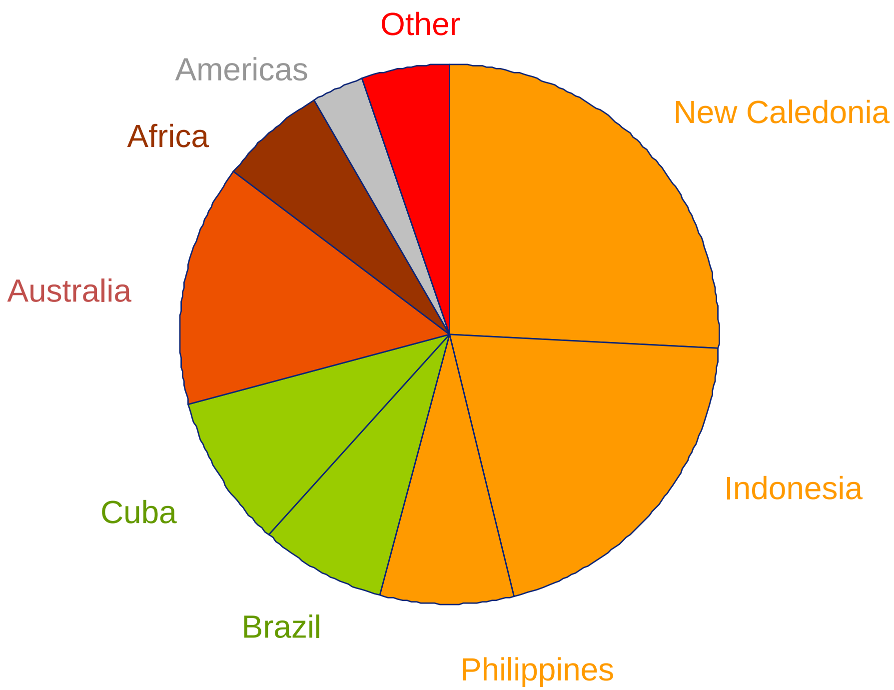
Global Nickel Resources

230 Mt Contained Nickel



Laterite Resources by Region

161 Mt Contained Nickel



R/P = 230/2.3 ~ 100 yrs

Apparantly no lack of resources…

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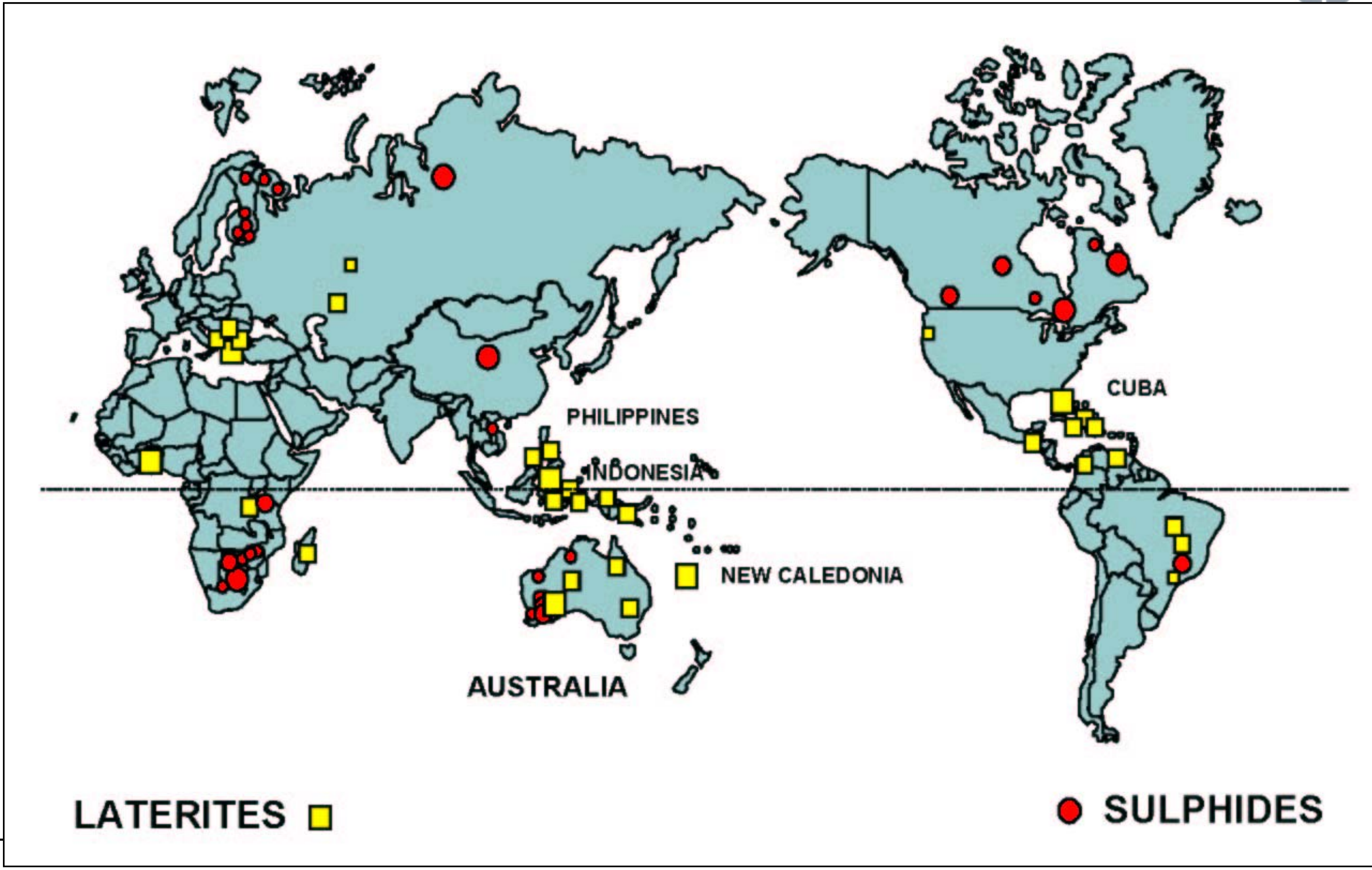
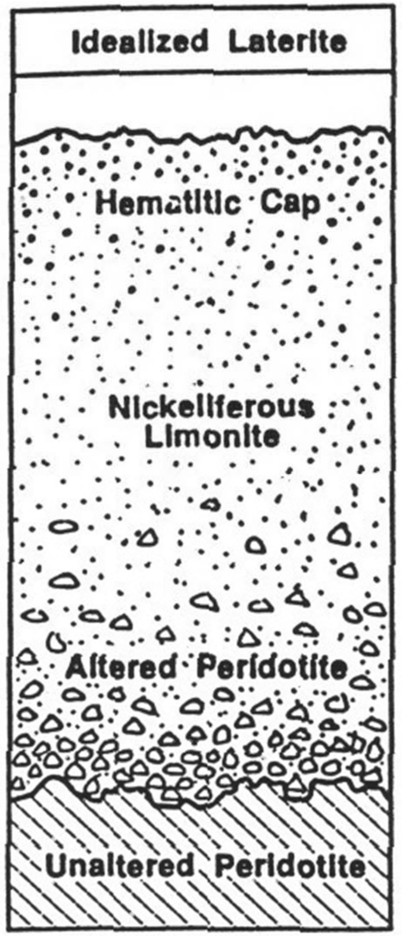
Distribution of global nickel resources



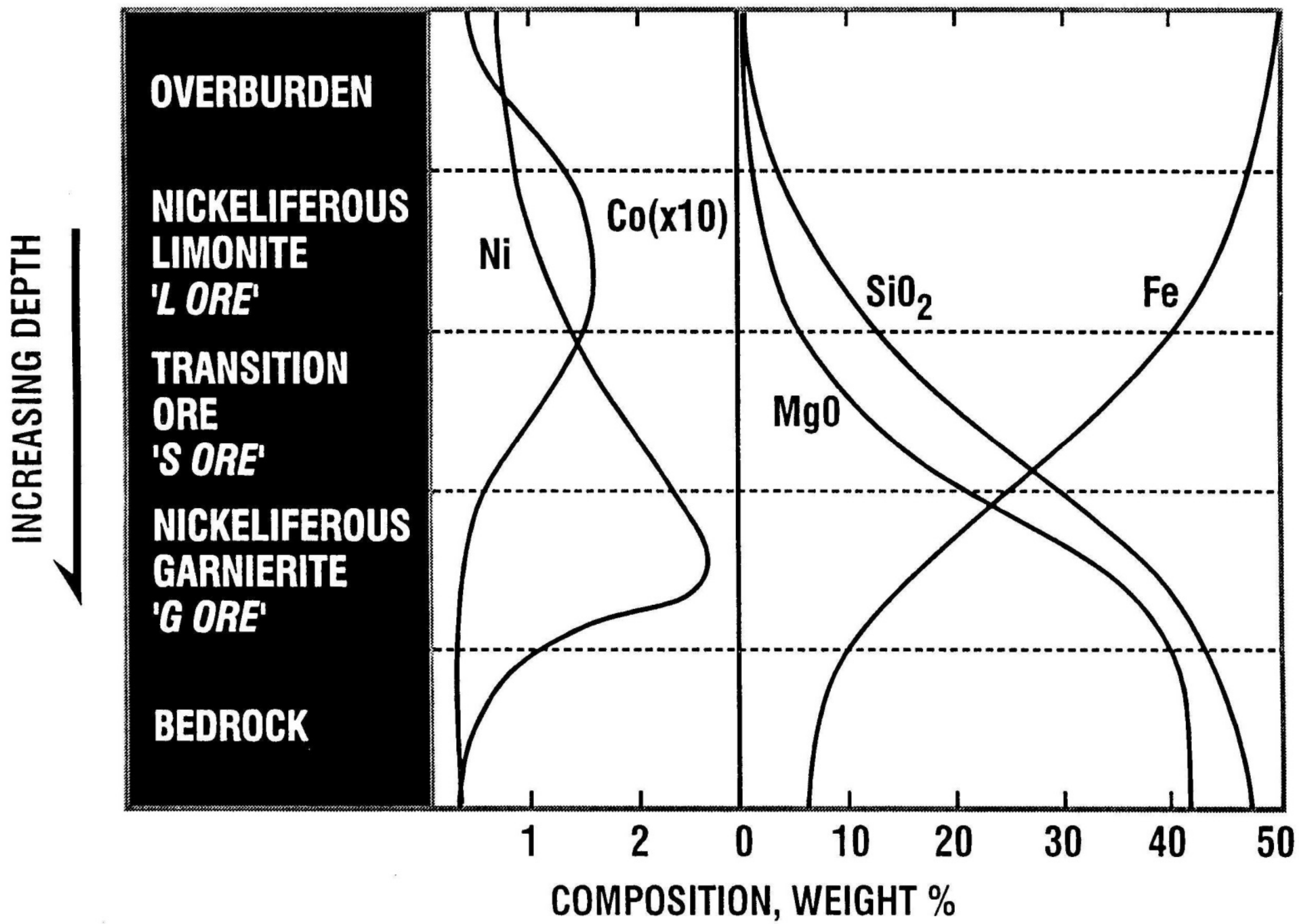
Typical profile for laterite ore, applicable technology



<table>
<tr><th colspan="6">Approximate Analysis (%)</th><th rowspan="2">Extractive Procedure</th></tr>
<tr><th>Ni</th><th>Co</th><th>Fe</th><th>Cr_2O_3</th><th>MgO</th><th>SiO_2</th></tr>
<tr><td><0.8</td><td><0.1</td><td>>50.0</td><td>>1.0</td><td><0.5</td><td></td><td>Overburden to Stockpile</td></tr>
<tr><td>0.8 to 1.5</td><td>0.1 to 0.2</td><td>40.0 to 50.0</td><td>2.0 to 5.0</td><td>0.5 to 5.0</td><td>0 to 10.0</td><td>Hydrometallurgy</td></tr>
<tr><td>1.5 to 1.8</td><td rowspan="2">0.02 to 0.1</td><td>25.0 to 40.0</td><td rowspan="2">1.0 to 2.0</td><td>5.0 to 15.0</td><td>10.0 to 30.0</td><td>Hydrometallurgy to Pyrometallurgy</td></tr>
<tr><td>1.8 to 3.0</td><td>10.0 to 25.0</td><td>15.0 to 35.0</td><td>30.0 to 50.0</td><td>Pyrometallurgy</td></tr>
<tr><td>0.25</td><td>0.01 to 0.02</td><td>5.0</td><td>0.2 to 1.0</td><td>35.0 to 45.0</td><td></td><td>Left In-Situ</td></tr>
</table>

”Peridotite” = Mineralclass $(X_a,Y_b)SiO_4$, or $XO(Y_c,Z_d)SiO_4$, example. olivine, X=Mg

Illustrated with concentration profiles



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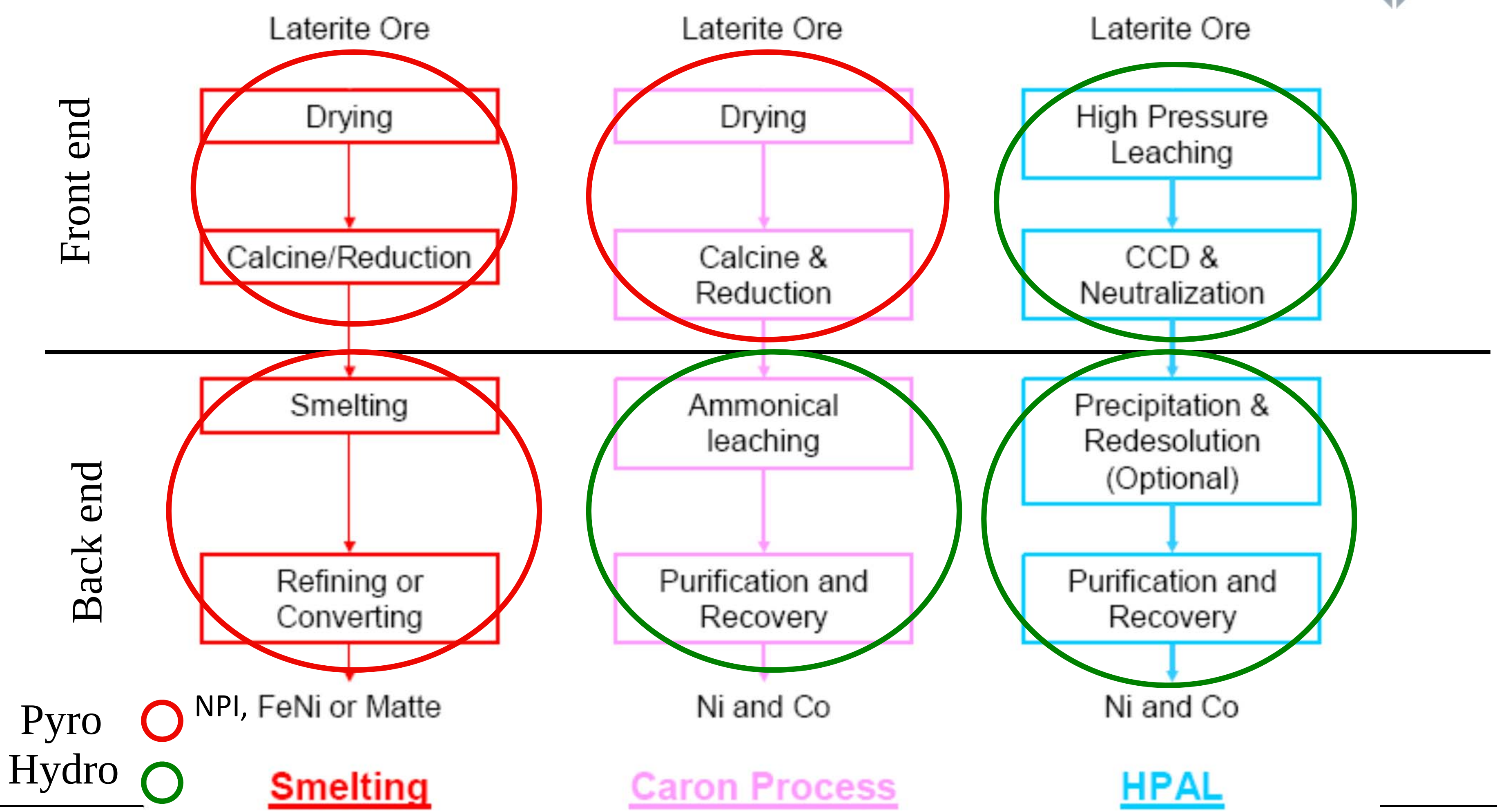
Laterite Nickel Production - Principal Technologies



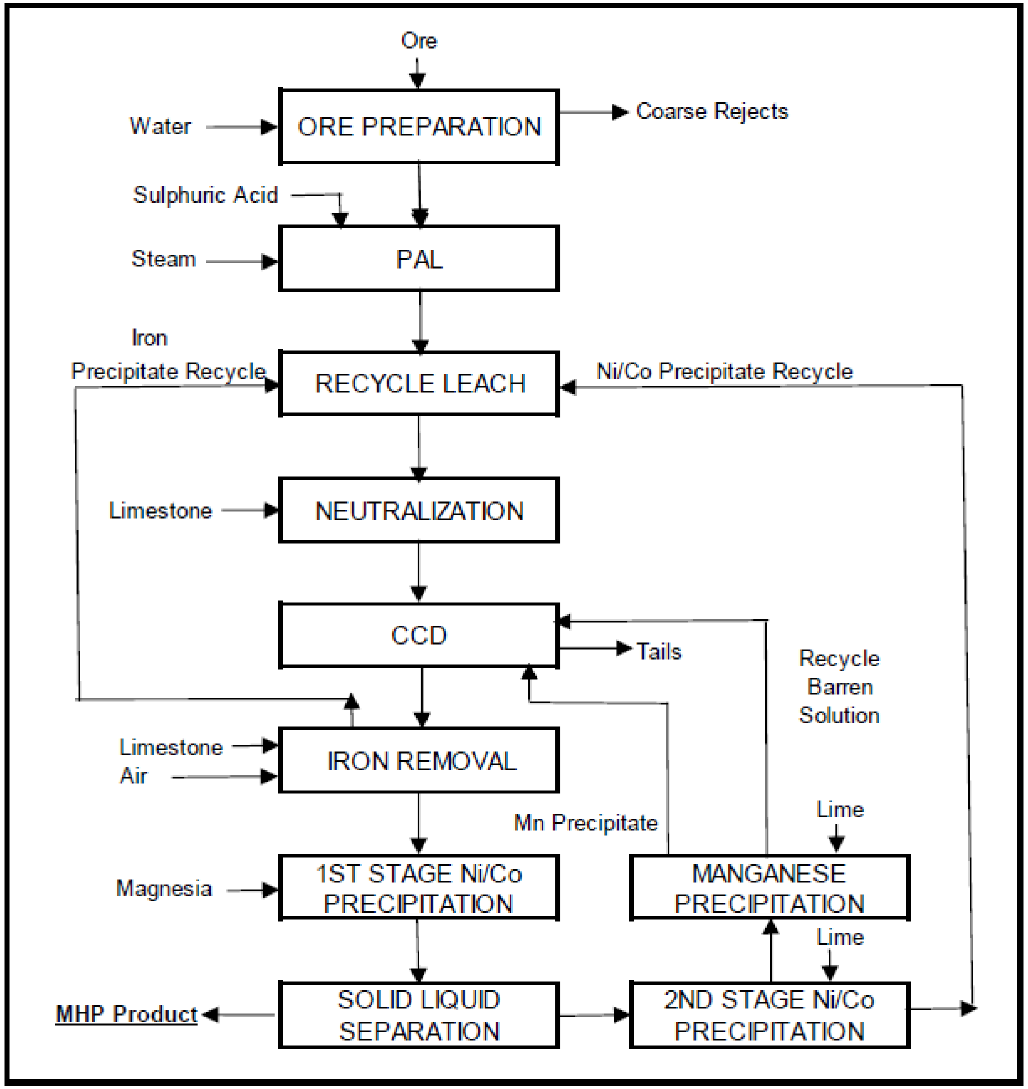
Disadvantage for laterites vs. sulphide nickel ores

- A sulphide ore can usually easily be upgraded in Ni-concentration through a combination of comminution methods, like
  - Grinding
  - Milling
  - Classification
  - Flotation
  - Magnetic separation
  - And similar methods

  - Ni-sulphide ores usually contain between 0.5 – 3% Ni
  - "Ni-concentrates" (from upgrading) normally contain between 5 – 20% Ni
  - An concentration ratio of 5-10 times is obtained.

- Not so with lateritic nickel ores, particularly the limonite type
- Typical grades in commercial mining operations:
  - Limonite: 1.0 - 1.7% Ni
  - Saprolite: 1.5 - 3% Ni

HPAL principal flowsheet for Limonite ores
Front end (up to intermediate/concentrate)



Intermediate options:

MSP:

- Mixed Sulphide Precipitation
- Use H2S(g), low pressure

MHP:

- Mixed Hydroxide Precipitation
- Use "activated" MgO

Direct SX:

- One example - Cyanex301
- Other example – DEHPA+Versatic10 (not in oper.)

HPAL Flowsheet, Main chemistry
Acid leaching

- Solubilize Ni and Co
- Keep Fe, Al (and some other elements) in residue
- Reach low free acid concentration in solution

Ni and Co:

- $MeO + H_2SO_4 = MeSO_4 + H_2O$, Me = Ni, Co

Fe:

- Step 1: $2FeO(OH) + 3H_2SO_4 = Fe_2(SO_4)_3 + 4H_2O$
- Step 2: $2Fe(SO_4)_3 + 3H_2O = Fe_2O_3 + 3H_2SO_4$
- Net: $2FeO(OH) = Fe_2O_3 + H_2O$
- Fe may also form some $Fe_xO_y(SO_4)_z$, basic sulphates

HPAL Flowsheet, Main chemistry
Intermediate precipitation

- Remove dissolved Ni and Co from pregnant leach solution
- In a form acceptable to a refinery
  - Both chemically (like impurity content) and physically

Mixed Sulphide Precipitation (MSP):

- $MeSO_4 + H_2S(g) = MeS(s) + H_2SO_4$, Me = Ni, Co, others

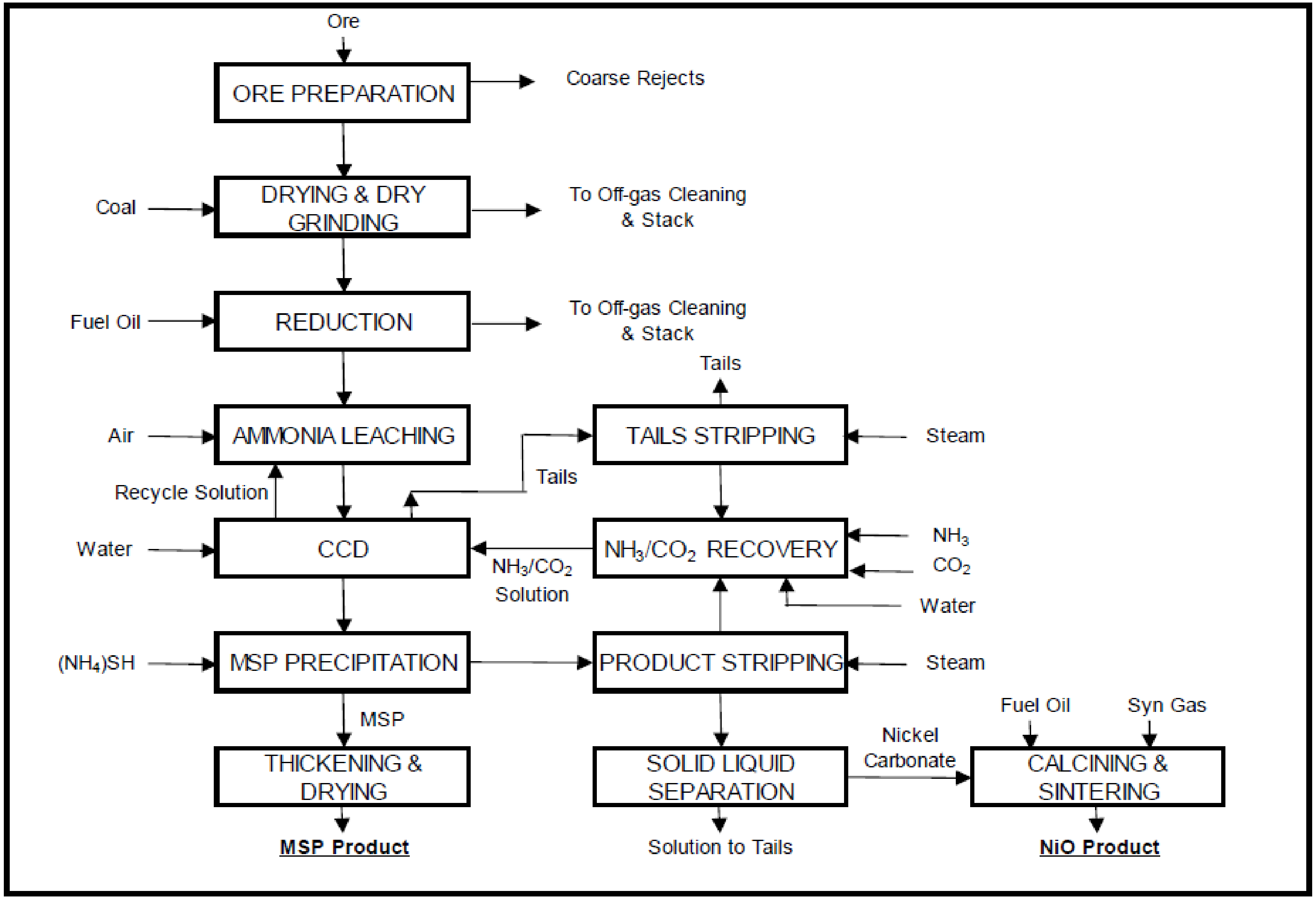
Mixed Hydroxide Precipitation (MHP):

- $MeSO_4 + MgO(s) = Me(OH)_2(s) + MgSO_4$, Me = Ni, Co, others

Comments:

- MSP:
  - Technically more challenging
  - Better acceptance of MSP vs. MHP, can easily be fed into Ni-matte refineries

Caron principal flowsheet for Limonite ores



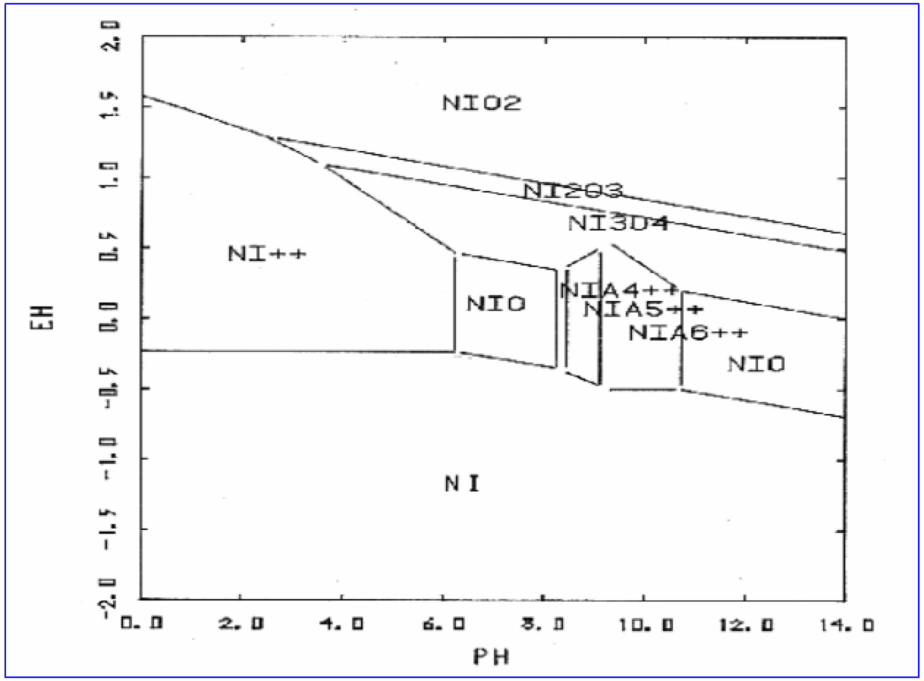
Caron Flowsheet, Main chemistry
1. Reducing roast

- Selectively metallize Ni and Co
- Partial reduction of iron to magnetite
- A small amount of iron is also metallized
- Metallic phase is a Ni-Fe-Co alloy, Ni/Fe ratio ≈ ½

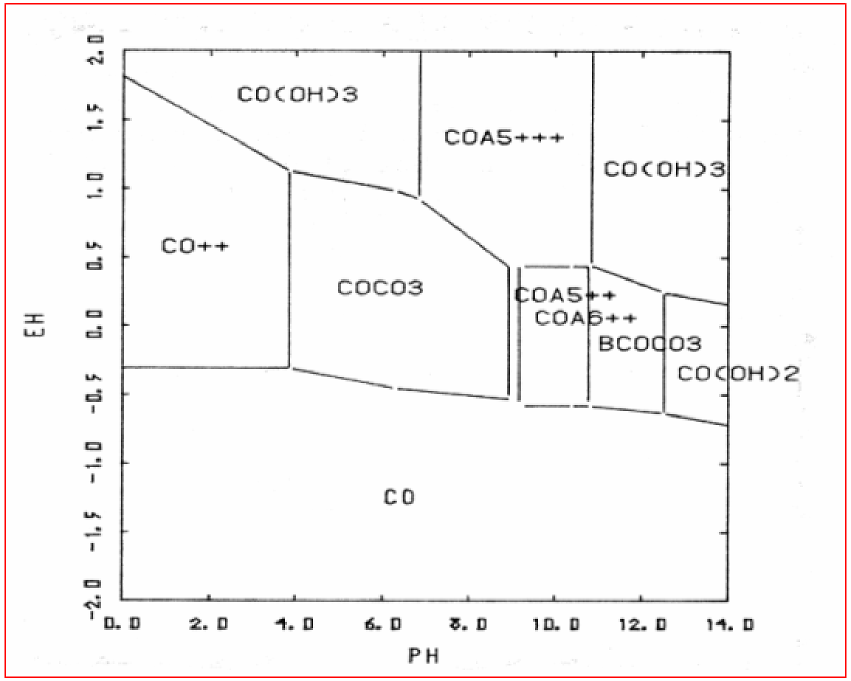
- $3\ Fe_2O_3 + CO = 2\ Fe_3O_4 + CO_2$
- $NiO + CO = Ni + CO_2$
- $Fe_3O_4 + CO = 3\ Fe + CO_2$
- $CoO + CO = Co + CO_2$
- $Fe_3O_4 + CO = FeO + CO_2$

Caron Flowsheet, Main chemistry
Ni and Co solubility in NH3-solutions

Ni-NH_3-H_2O system: [Ni] = 1 M, [N] = 1M



Co-NH_3-CO_3-H_2O System



Caron Flowsheet, Main chemistry
Oxidative leach and complex ion formation

- <u>Subreactions:</u>
- $M = M^{2+} + 2\ e-$
- $M^{2+} + 6\ NH_3 = M(NH_3)_6^{2+}$
- $Co(NH_3)_6^{2+} = Co(NH_3)_6^{3+} + e^-$
- Role of Oxygen:
  - $O_2 + 2\ H_2O + 4\ e- = 4\ OH^-$

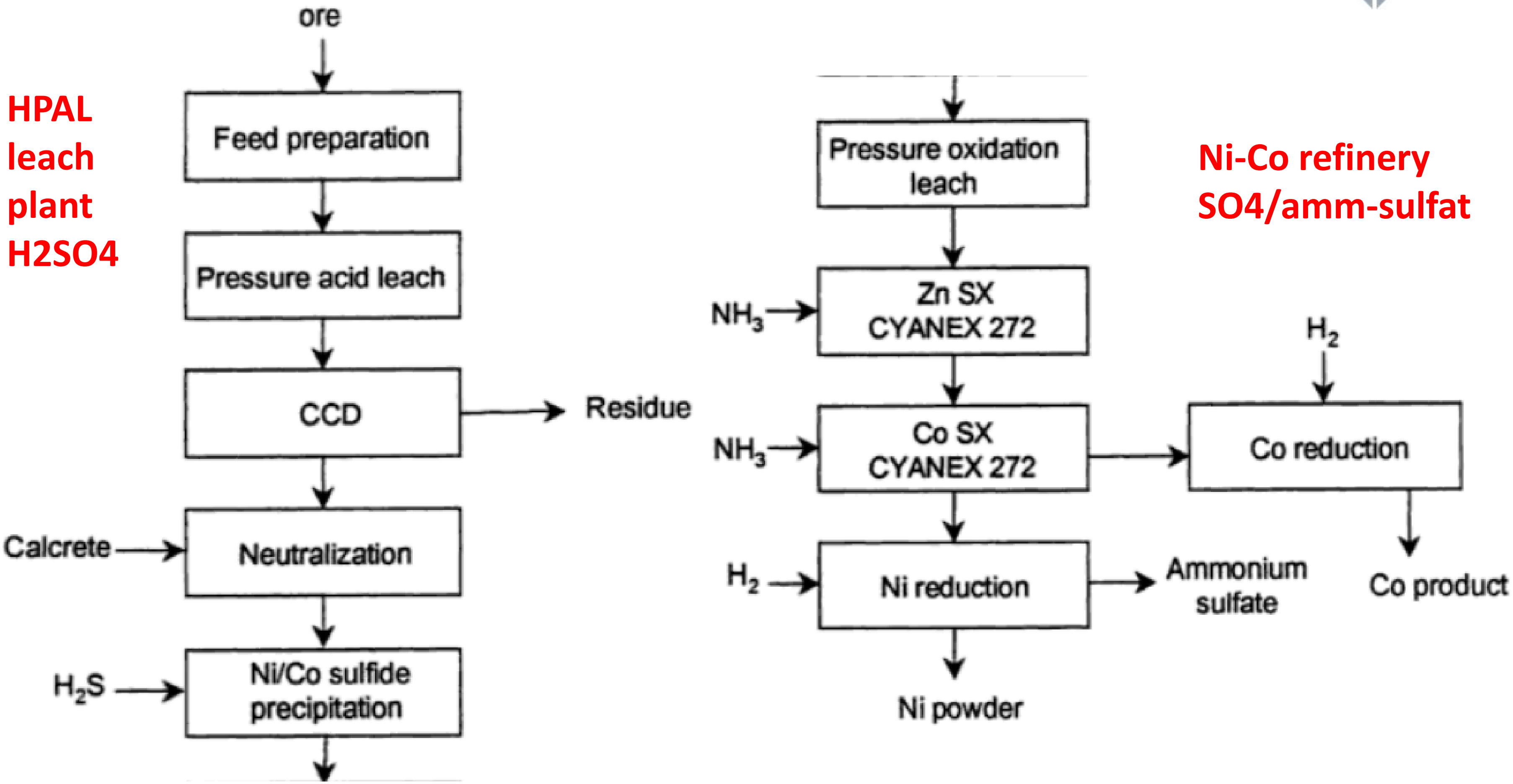
- <u>Buffersystem NH_3-CO_2:</u>
- $NH_3(g) + CO_2(g) + H_2O = (NH_4)_2CO_3 = 2NH_4^+ + CO_3^{2-}$.
- 120 g/l NH_3 + 100 g/l CO_2 form ca. 2 M $(NH_4)_2CO_3$ and 2.5-3 M ”free” NH_3.

- <u>Net leach reaction:</u>
- $M(s) + ½\ O_2(g) + 2\ NH_4^+ + 4NH_3 = M(NH_3)_6^{2+} + H_2O$
- Salt i solution: $M(NH_3)_6^{2+}$ (kation) + CO_3^{2-} (anion).

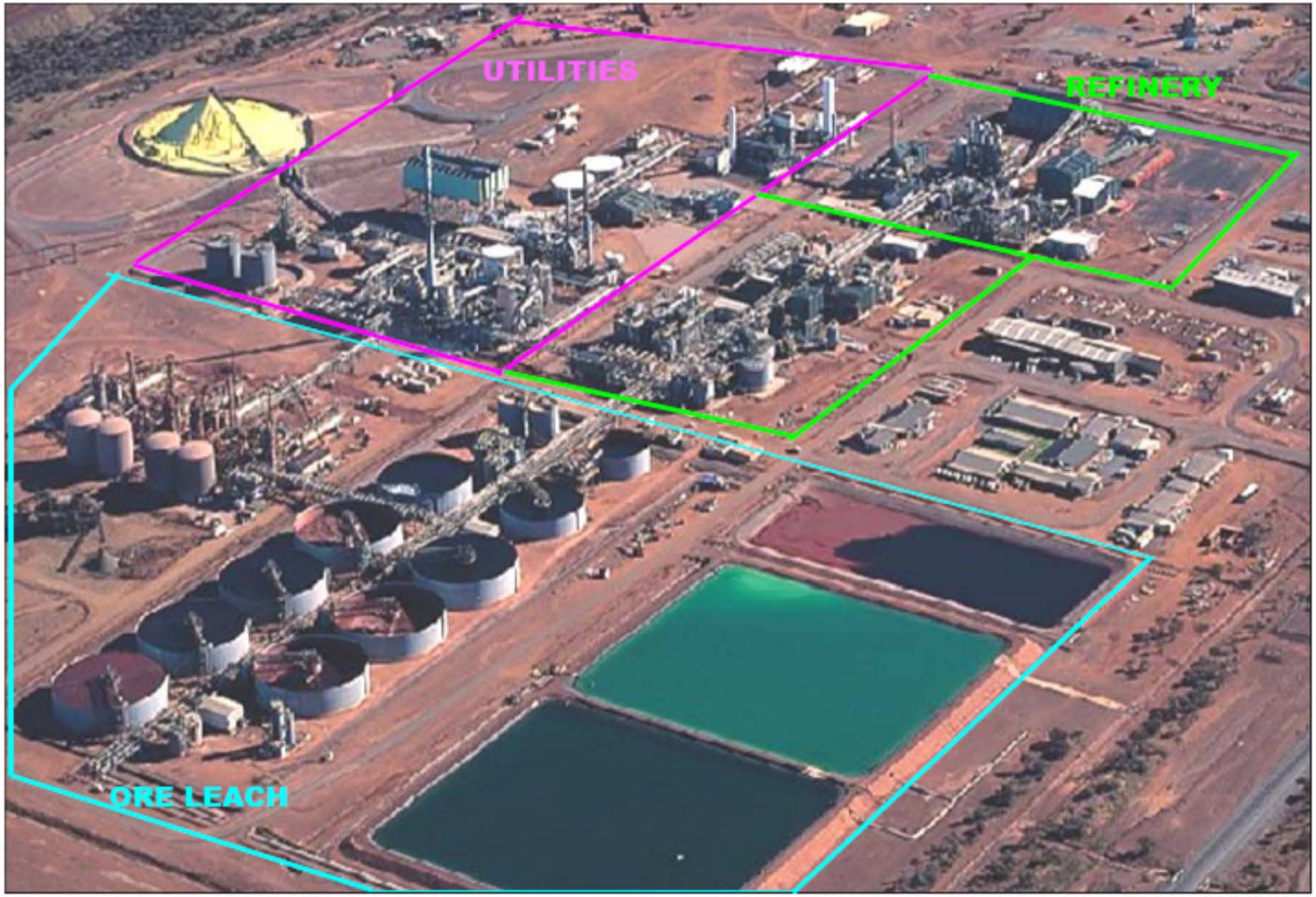
Glencore "Murrin Murrin", W.Australia: 45 000 T/a Ni HPAL Laterite operations

HPAL leach plant H2SO4

Ni-Co refinery SO4/amm-sulfat

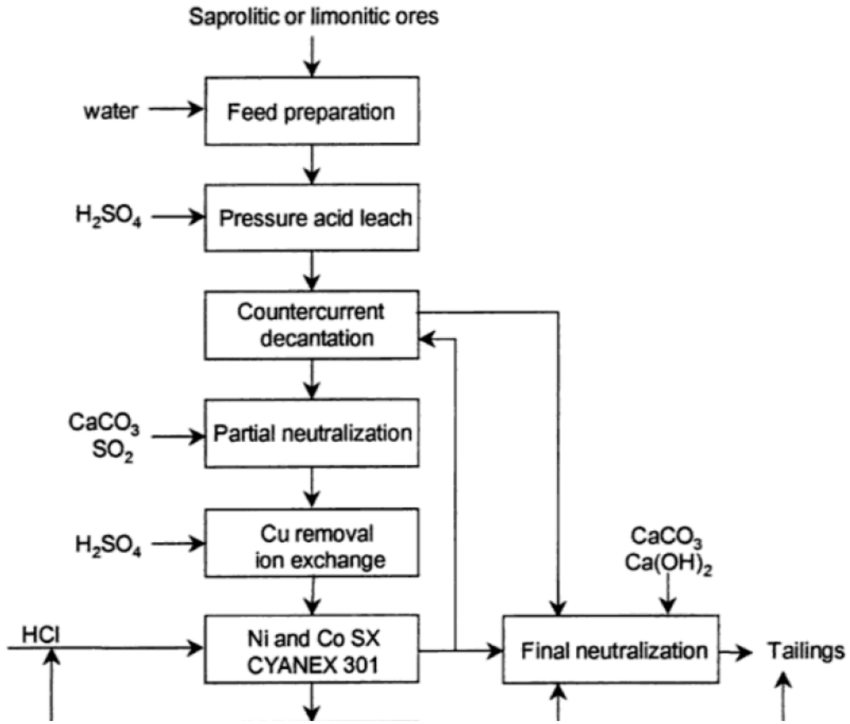


Glencore "Murrin Murrin" operations, metallurgical site

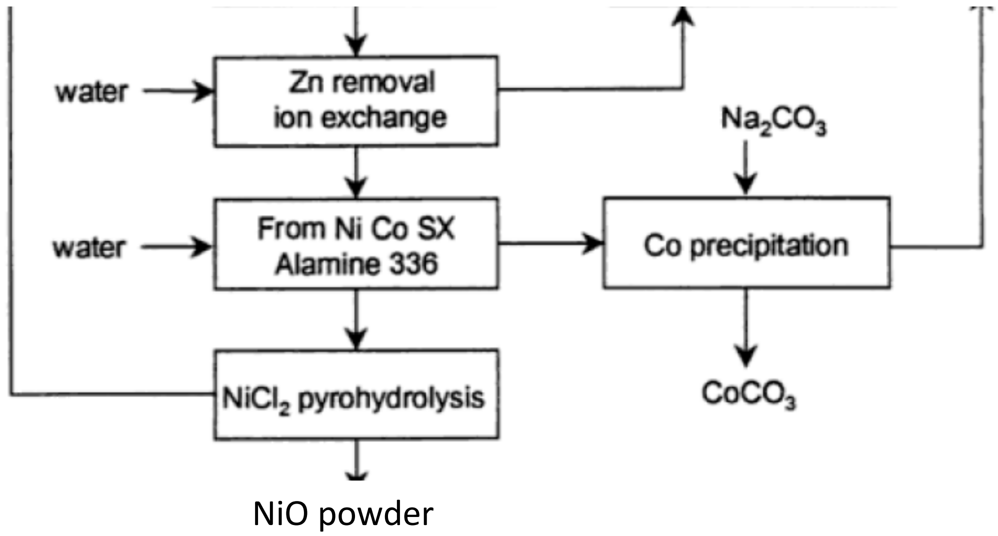


VALE "Goro", New Caledonia: 50 000 T/a Ni laterite HPAL with Cl-based refinery

HPAL leach plant H2SO4



Ni-Co refinery Cl/HCl



VALE “Goro”, New Caledonia, metallurgical site

C.Palmer, Queensland Nickel, Q., Australia: 32 000 T/a Ni Caron plant (NH3) with Ni-SX

Integrated NH3/(NH4)2CO3 circuit

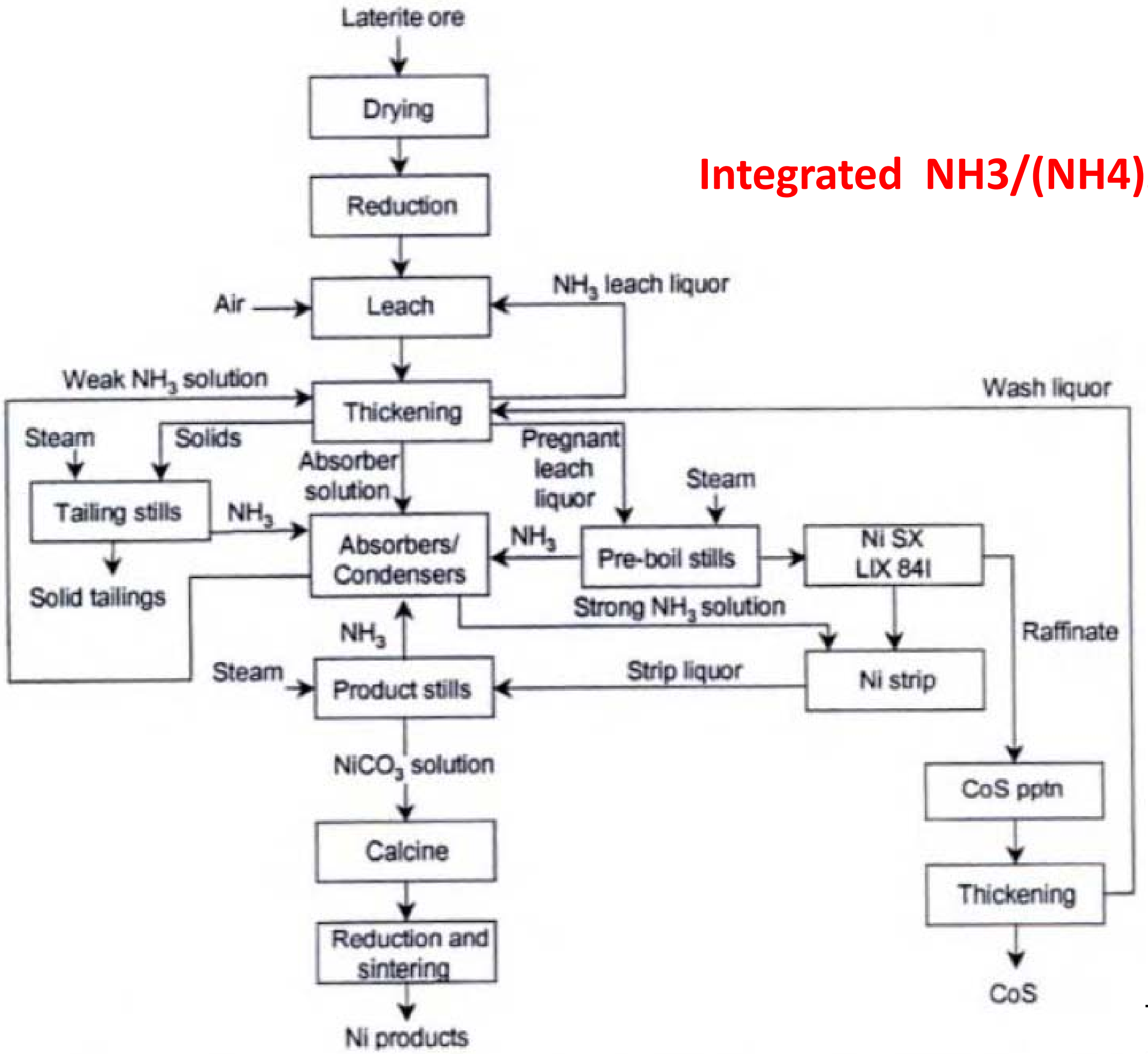


Figure 10 Flow sheet of the Queensland Nickel Industries' process. (From Ref. 53.)

Queensland Nickel operations, metallurgical site ca. mid-2000

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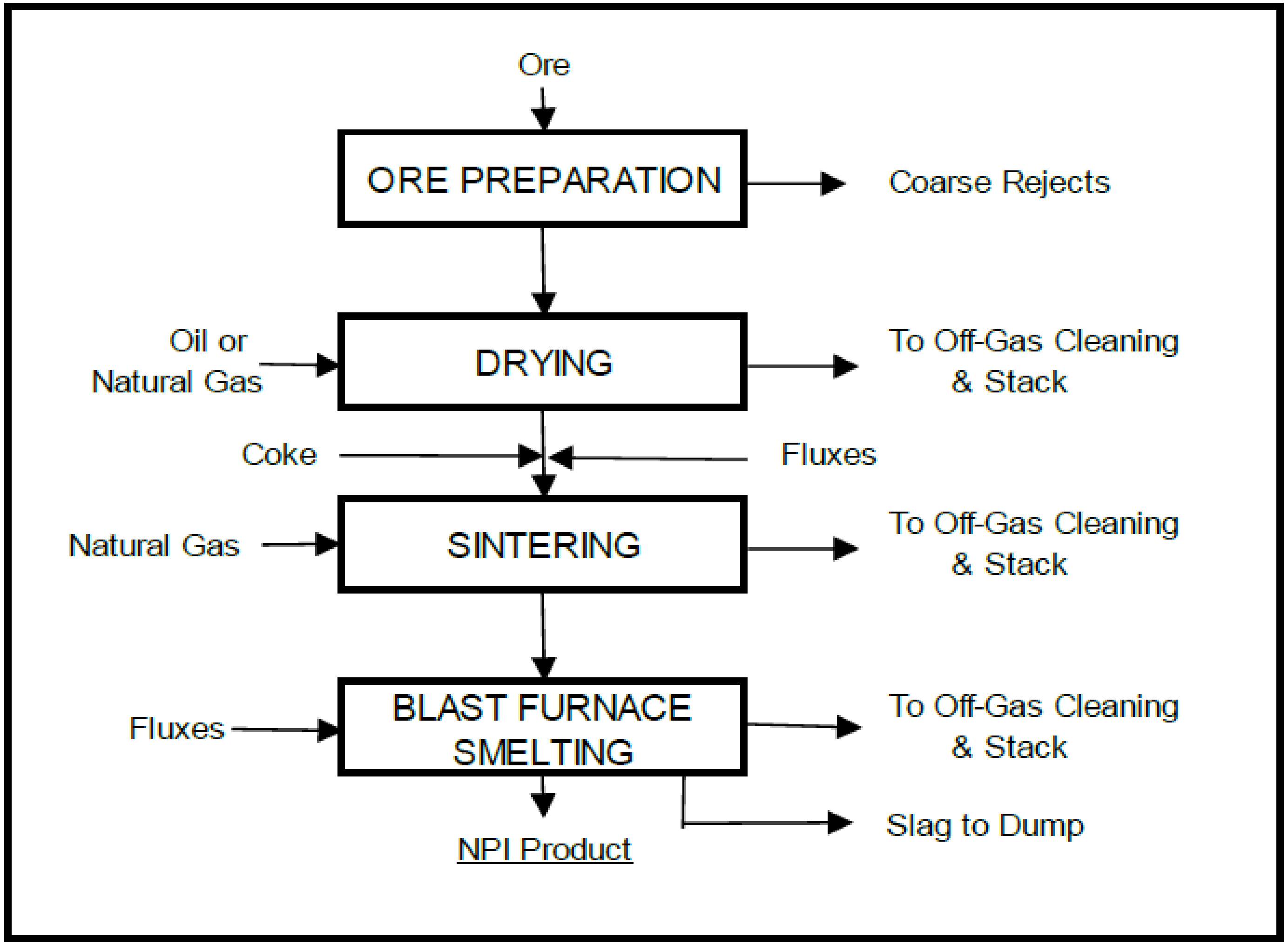
Nickel Pig Iron (NPI) flowsheet, here with blast furnace.



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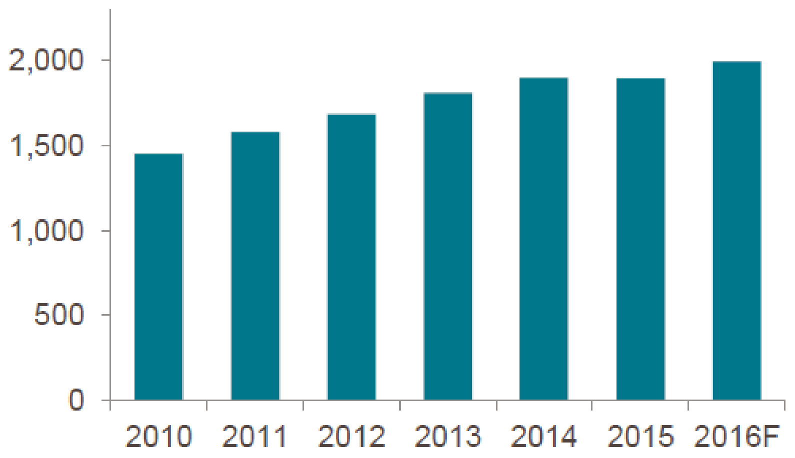
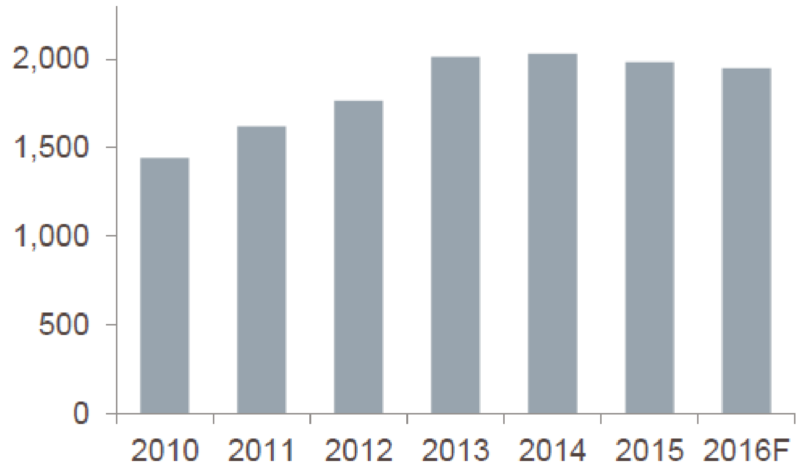
Global nickel market and NPI's influence

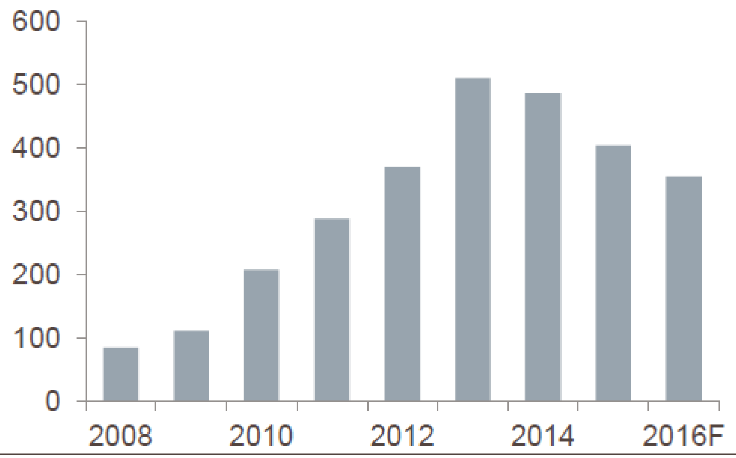
2010 – 2016 Primary nickel demand (kt Ni)



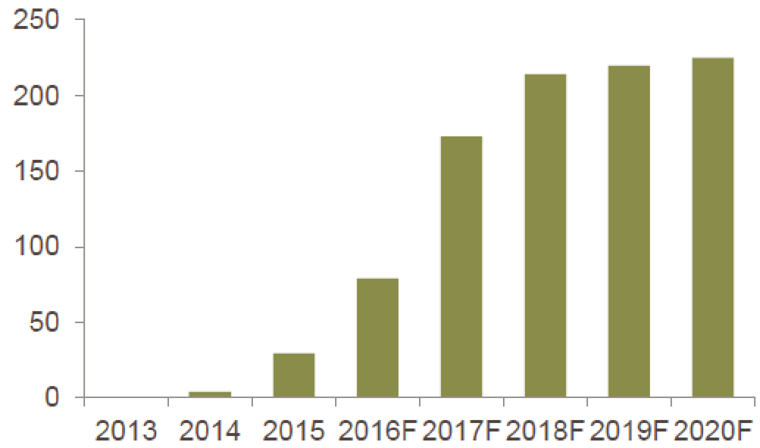
2010 – 2016 Global Nickel supply (kt Ni)



2008 – 2016 China NPI Output



2013 – 2020 Indonesian NPI supply (kt Ni)



Source: Glencore