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LIFE CYCLE INVENTORIES DEVELOPMENT USING PROCESS SIMULATION FOR NICKEL SUPPLY FOR BATTERIES

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IFP Energies nouvelles

université de BORDEAUX
CyVi The Life Cycle Group

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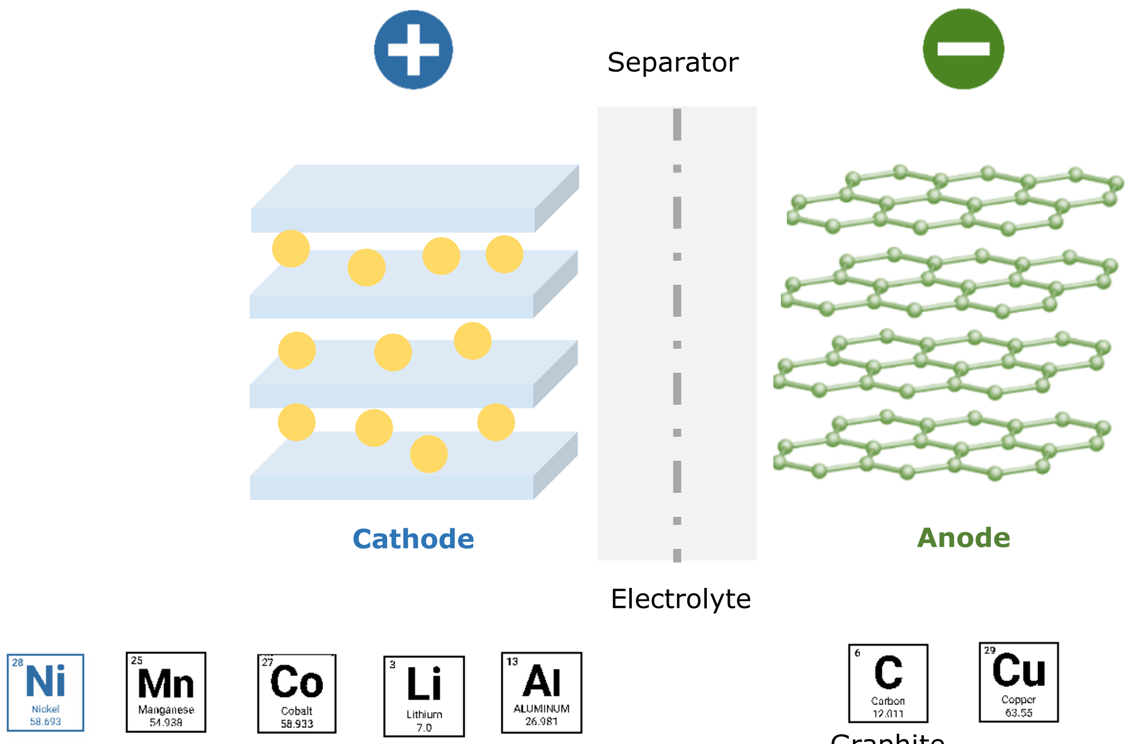
HELMHOLTZ-INSTITUT FREIBERG FÜR RESSOURCENTECHNOLOGIE

Context

Lithium-ion Batteries (LIBs)

LIBs for a fast energy transition → Electric vehicles (EVs)

Lithium-ion cell



Graphite (≈20%)

14%
Ni content in a LIB

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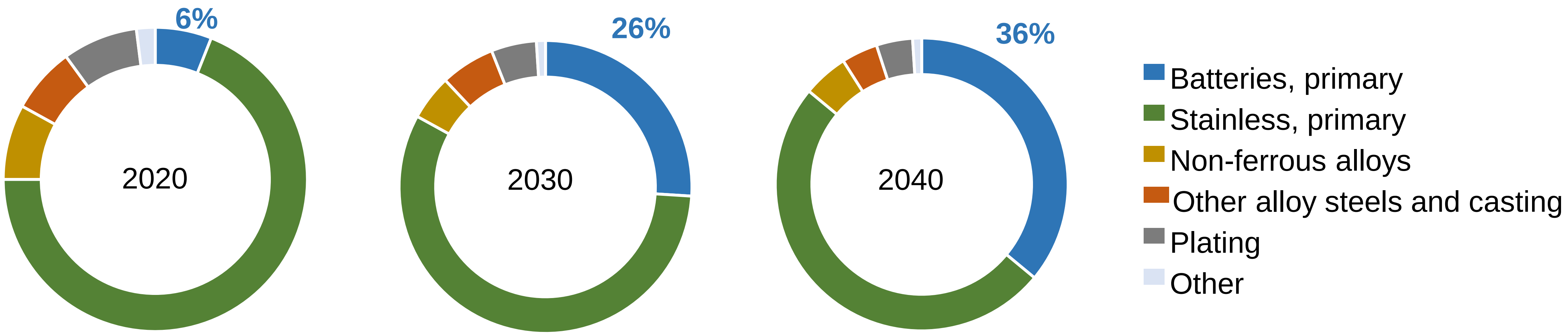
Nickel

Main resources	Reserves	For LIBs
Sulfate ores	World total[1](rounded) | 130,000,000 Mt	High purity nickel sulfate | $NiSO_4$
Laterite ores	Top production and reserves | Indonesia	

Market demand share, by first-use sector[2]



[1]USGS
[2]Roskill, 2020

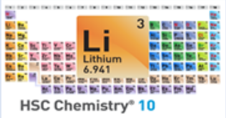
Aina Mas Fons' Thesis

Objective

Integrate process modelling and LCA to assess the **environmental impact of producing battery-grade nickel sulfate** through two distinct routes at varying TRL

(Primary) **Data**

Foreground data | **Process simulation**



HSC Chemistry

Multiple models

- Mass balancing, model fitting , sizing and scaling-up
- Simulation/Optimization
- Foreground process scenarios

Background data | ecoinvent

Goal and scope

Life cycle inventory

Life cycle impact assessment

Interpretation

Collaboration

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Ni extraction from laterites

I . Mining an mineral preparation

Indonesia

Laterite ores

- Limonite
- Saprolite

II . Production of MHP cake

Indonesia

- Through HPAL (TRL 8-9)
- Through bioleaching (TRL 3-4)

III . Production of $NiSO_4$

China *OR* Europe

- Selective acid leaching

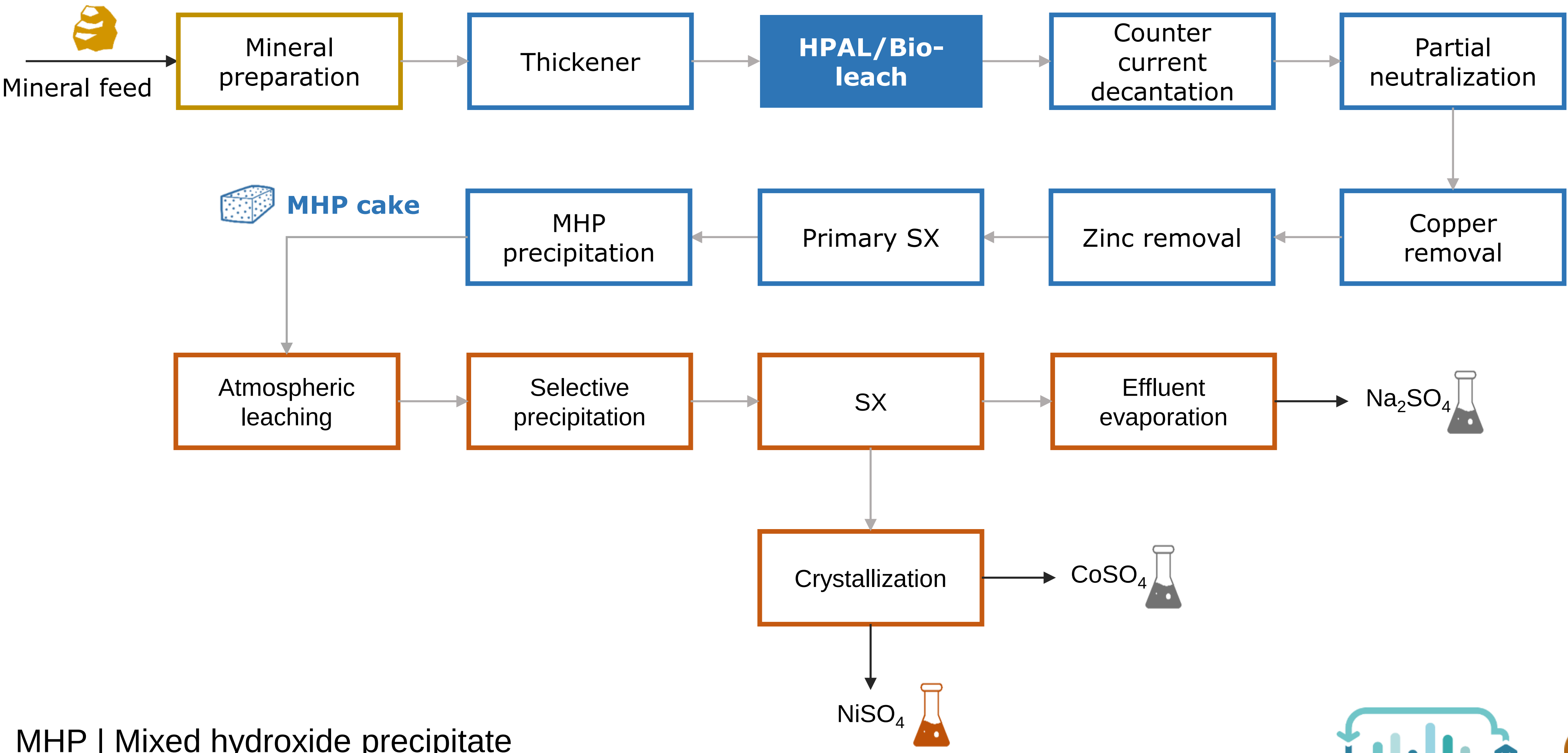
Limonite ore composition

	wt.%		wt.%		wt.%		wt.%
Goethite*	72,2	Chromite	1,4	Serpentine	5,6	Chlorite	0,3
Magnetite	5,6	Gibbsite	1,4	Talc	4,1	Asbolane*	0,02
Hematite*	0,8	Bayerite	0,9	Quartz	7,5	Others	0,1

**Ni containing mineral (Total NiO ~2.7%)*

Aina Mas Fons' Thesis

Ni extraction from laterites - Flowsheet



MHP | Mixed hydroxide precipitate

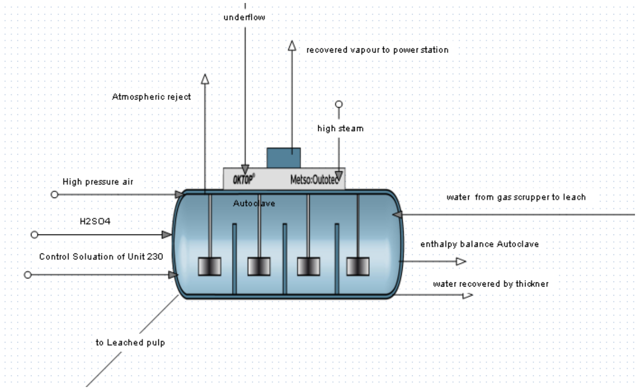
Nickel extraction from laterites

High pressure acid leaching (HPAL)

Main characteristics

Main hydrometallurgical way for high-grade ores

- Based on acid dissolution of Fe oxides (mainly Goethite),
- Requires sulfuric acid to dissolve iron oxides and other minerals
- High pressure achieved by injecting pressurized air and steam in the autoclave
- High energy consumption (to keep high pressure and temperature)



$$FeOOH(s) + 3H^{+}(aq) = Fe^{3+}(aq) + 2H_2O(aq). \ldots \quad (1)$$

$$AlOOH(s) + 3H^{+}(aq.) = Al^{3+}(aq.) + 2H_2O(aq.). \ldots \quad (2)$$

$$NiO(s) + 2H^{+}(aq.) = Ni^{2+}(aq.) + H_2O(aq.) \ldots \quad (3)$$

$$CoO(s) + 2H^{+}(aq.) = Co_2^{+}(aq.) + H_2O(aq.). \ldots \quad (4)$$

$$2Fe^{3+}(aq.) + 3H_2O(aq.) = Fe_2O_3(s) + 6H+(aq.) \ldots \quad (5)$$

$$Fe^{3+}(aq.) + SO_4^{2-} + H_2O(aq.) = FeOHSO_4(s) + H^{+}(aq.) \ldots \quad (6)$$

$$2FeOHSO_4(s) + H_2O\ (aq.) = Fe_2O_3(s) + 2SO_4^{2-} + 4H^{+}(aq.) \ldots \quad (7)$$

$$3Al^{3+}(aq.) + 2SO_4^{2-} + 7H_2O\ (aq.) = (H_3O)Al_3(SO_4)_2(OH)_6(s) + 5H^{+}(aq.) \ldots \quad (8)$$

$$Al^{3+}(aq.) + SO_4^{2-} + H_2O\ (aq.) = AlOHSO_4(s) + H^{+}(aq.) \ldots \quad (9)$$

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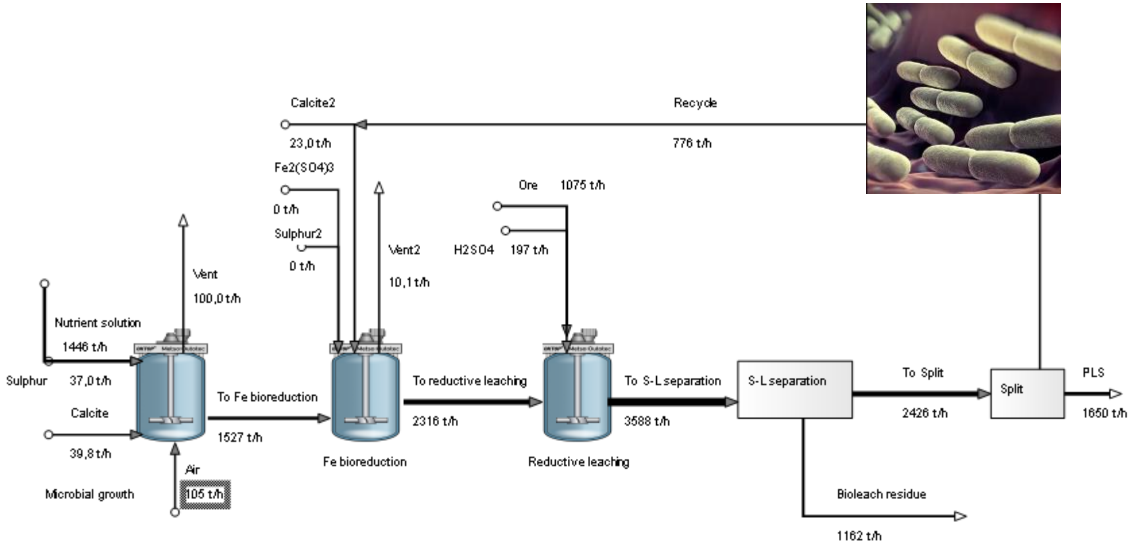
Reductive bioleaching



Reductive bioleaching

New biological pathway to extract Ni and Co

- Based on the use of acidophilic bacteria to reduce iron and manganese oxides
- Three main steps:
  - Microbial growth in aerobic conditions (air injection) supported by the oxidation of sulfur → $S^0 + O_2 + H_2O \rightarrow H_2SO_4$ (1)
  - Fe bio-reduction by the same bacteria but in anaerobic conditions → $6Fe^{3+} + S^0 + 4H_2O \rightarrow 6Fe^{2+} + SO_4^{2-} + 8H^+$ (2)
  - Reductive leaching of manganese oxides and increase of the goethite acid leaching →

$$FeOOH + 3H^+ \leftrightarrow Fe^{3+} + 2H_2O \quad (3)$$

$$MnO_2 + 2Fe^{2+} + 4H^+ \rightarrow Mn^{2+} + 2Fe^{3+} + 2H_2O \quad (4)$$

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Methodology

Chemical analysis + estimated mineralogy

Modelled Mineralogy, considering main Ni and Co carries and distribution

For HPAL (TRL 8-9)

For Bioleaching (TRL 3-4)

Building of the HPAL model using primary data

Combination of experimental data and literature

Selection of main fluxes for LCI

Life cycle impact assessment and scenario comparison

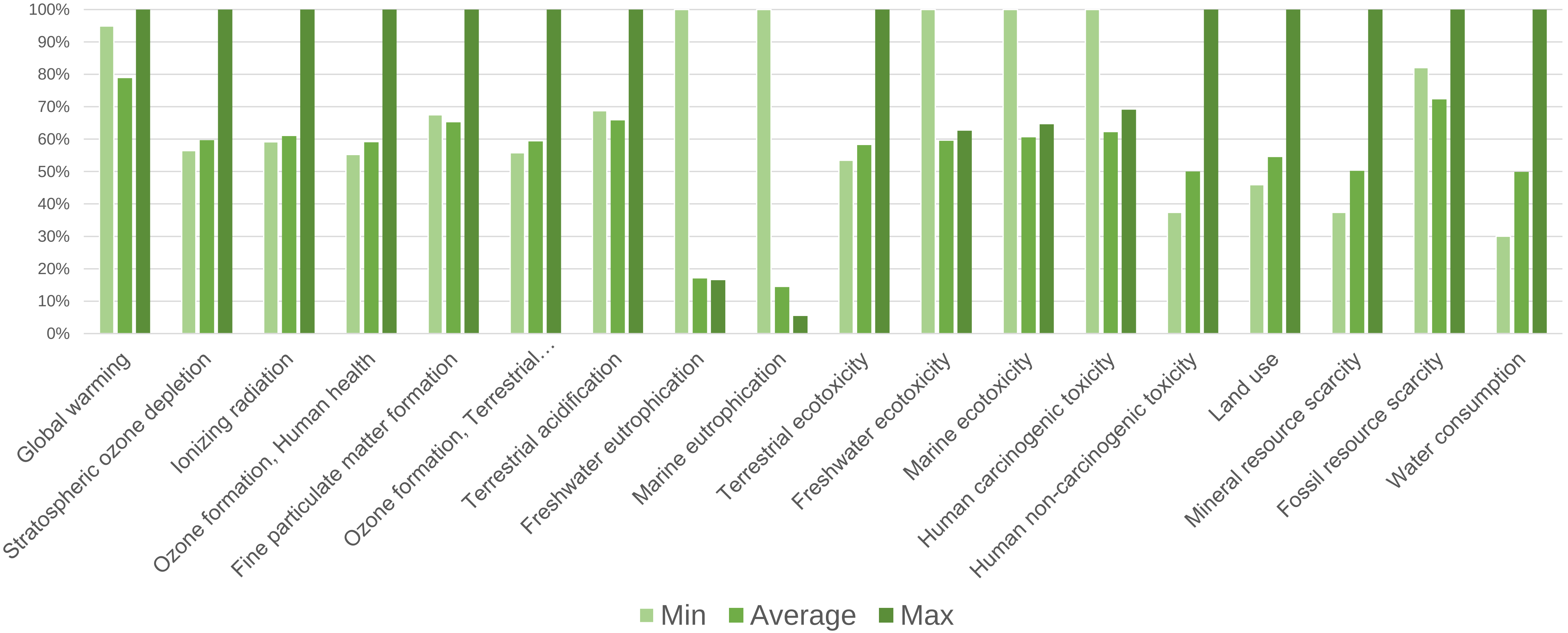
Three scenarios in terms of Ni dissolution yield:

- Maximum (80%)
- Average (54%)
- Minimum (9%)

Preliminary results

Bioleaching scenarios

ReCiPe 2016 Midpoint (H)

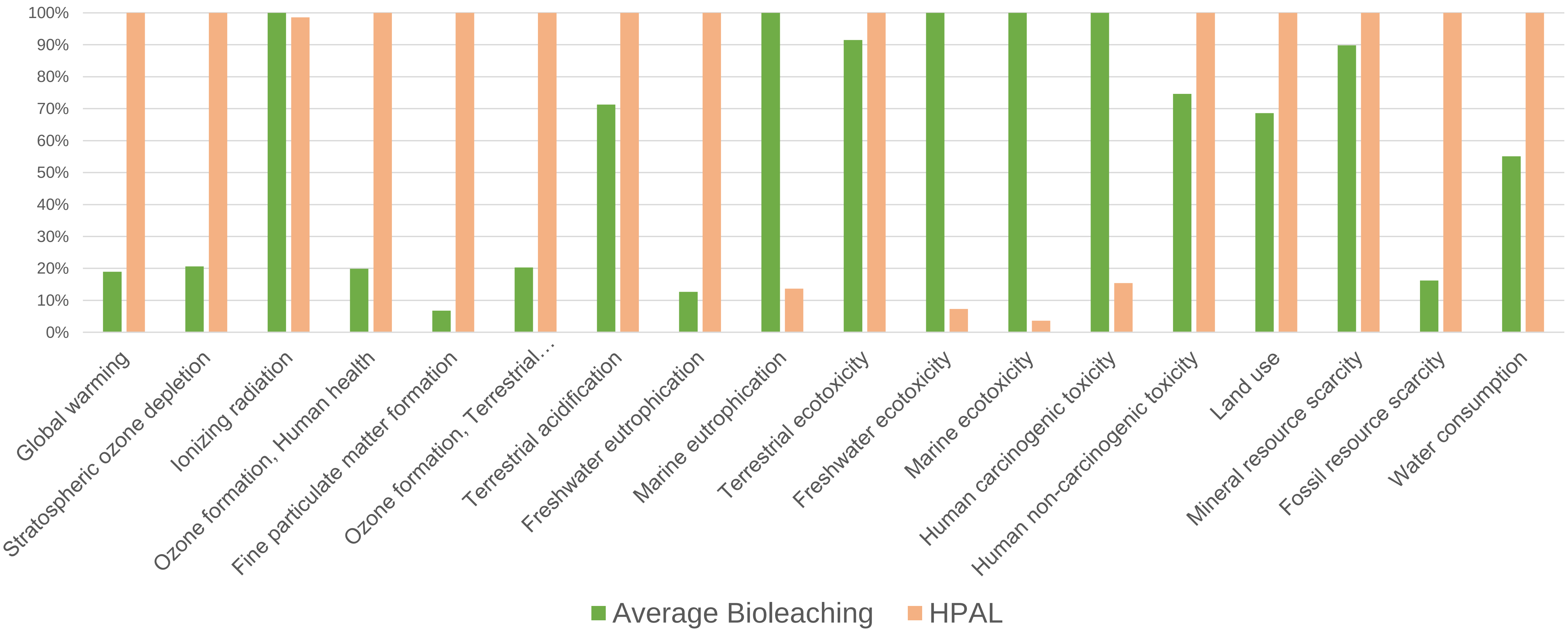


Functional unit | Production of 1kg $NiSO_4$

Preliminary results

Bioleaching vs HPAL

ReCiPe 2016 Midpoint (H)



Functional unit | Production of 1kg $NiSO_4$
At equivalent Ni production 25 – 30 t/h

Preliminary conclusions

Environmental impact "hotspots"

- In general, HPAL has greater environmental impacts, particularly regarding global warming, terrestrial acidification and ecotoxicity, land use and resource scarcity. The main reason for this is the high energy consumption of the process and the important amount of acid per ore mass

- Reductive bioleaching impacts are higher for impact categories related to water acidification and ecotoxicity. This is related to:
    - The use and disposal of nutrients necessary for bacteria (mainly NH_4^+ and PO_4^{3-}),
    - The use of calcite for pH control, which increases the presence of SO_4^{2-} in solid residues

- Therefore, a reduction of nutrient consumption, their recycling in the process and/or their valorization will decrease these impacts

- These results serve to identify the environmental impact hotspots and the parameters to optimize for enhancing the environmental performance of bioleaching compared to HPAL

Process simulation may help to fill the lack of data for low TRL technologies and, in turn, LCA may facilitate the eco-conception of processes at low TRL

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Q&A

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