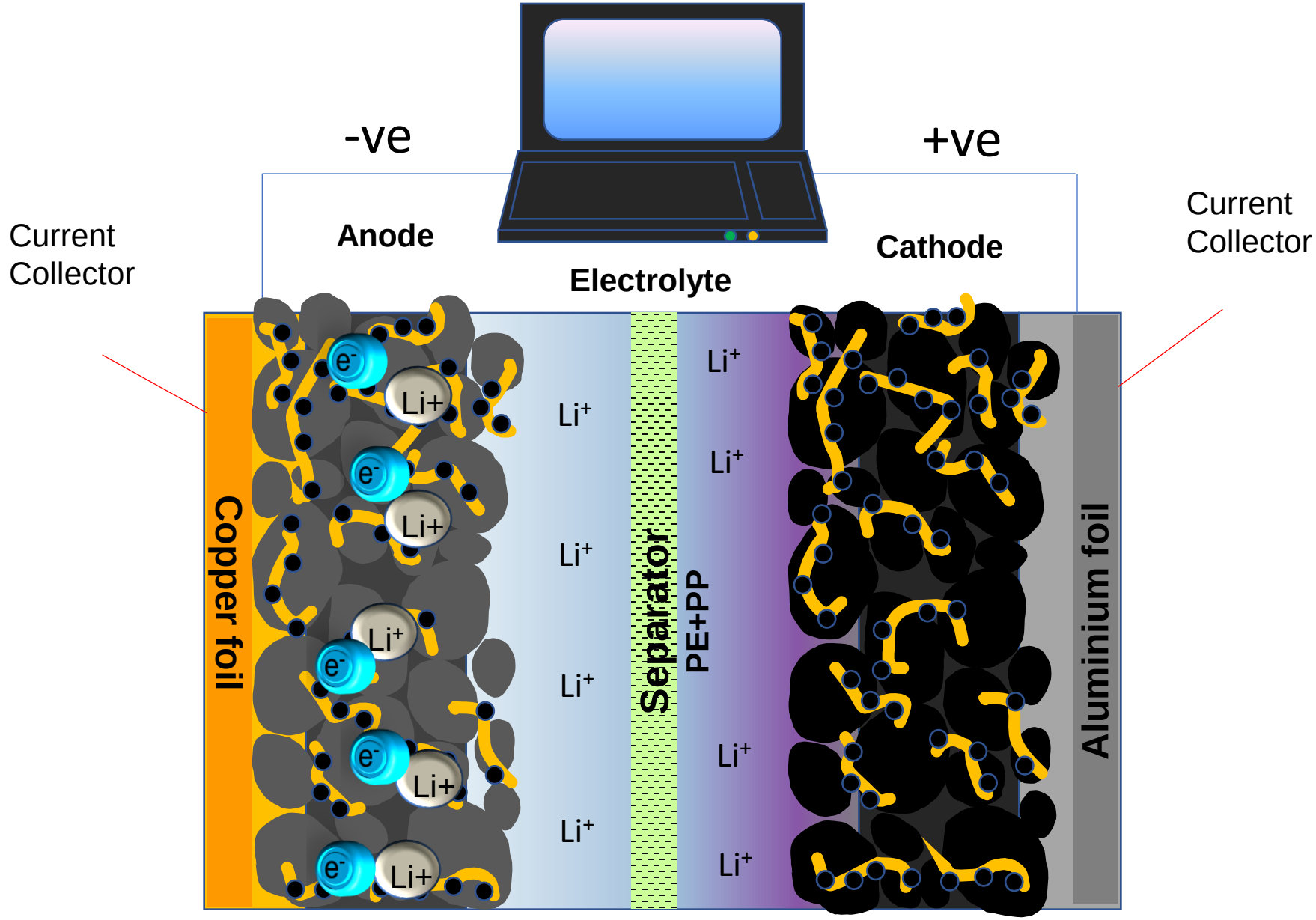
UNIVERSITY OF BIRMINGHAM

Critical Minerals and Sustainable Batteries?

Prof Emma Kendrick

University of Birmingham

24th Feb 2025



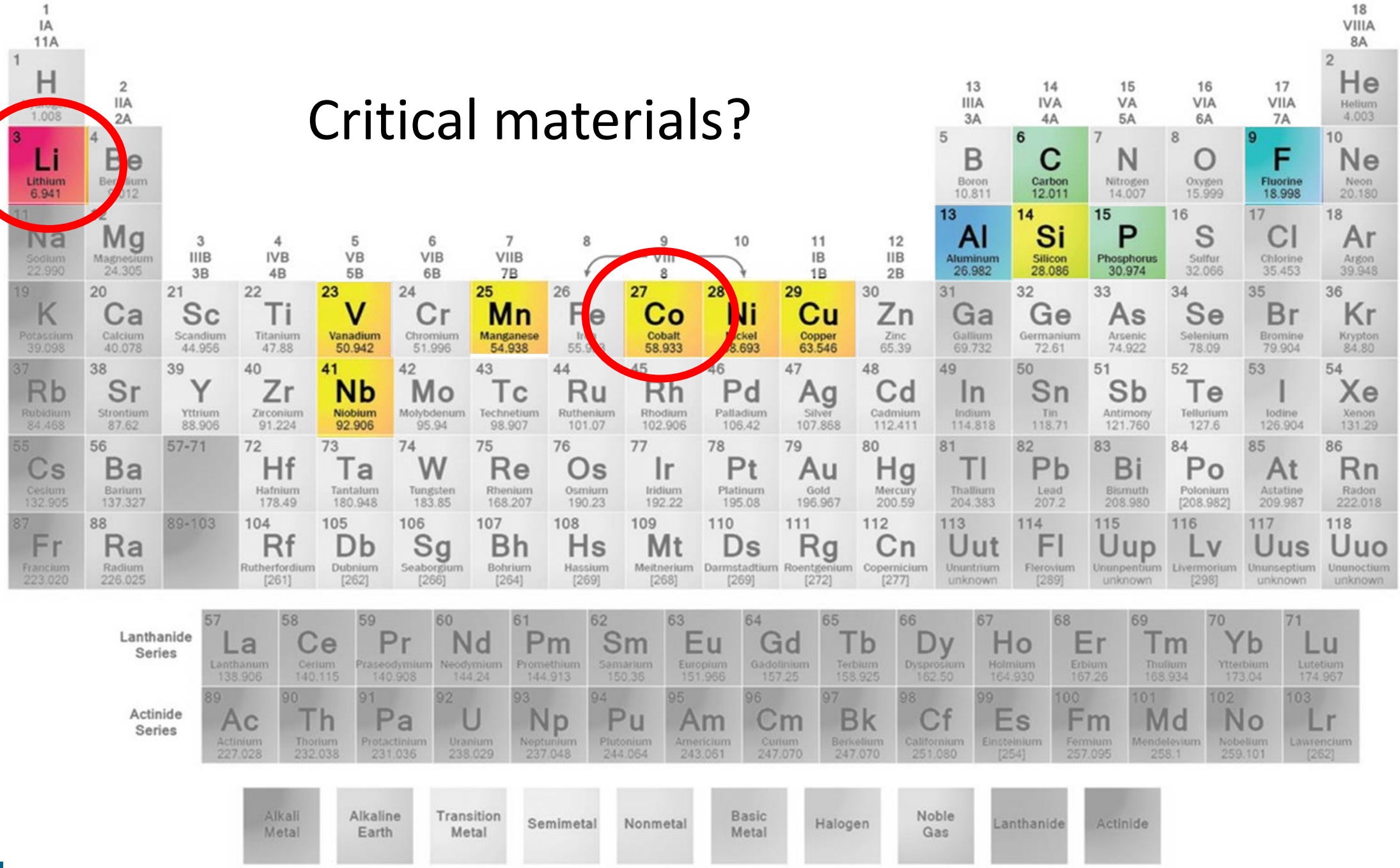
$C_6Li \rightarrow C_6 + Li^+ + e^-$

$Li_{0.5}Ni_{1/3}Mn_{1/3}Co_{1/3}O_2 + e^- \rightarrow Li_{1.0}Ni_{1/3}Mn_{1/3}Co_{1/3}O_2$

$Ni^{4+} + e^- \rightarrow Ni^{3+}$

Credit: Richard Heap, Rob Sommerville

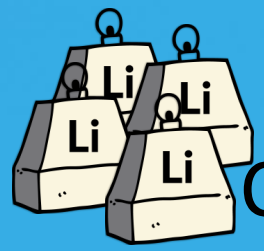
Figure 1. The Periodic Table of the Elements (Source: Science Notes and Projects)



Lithium Mining & Refining

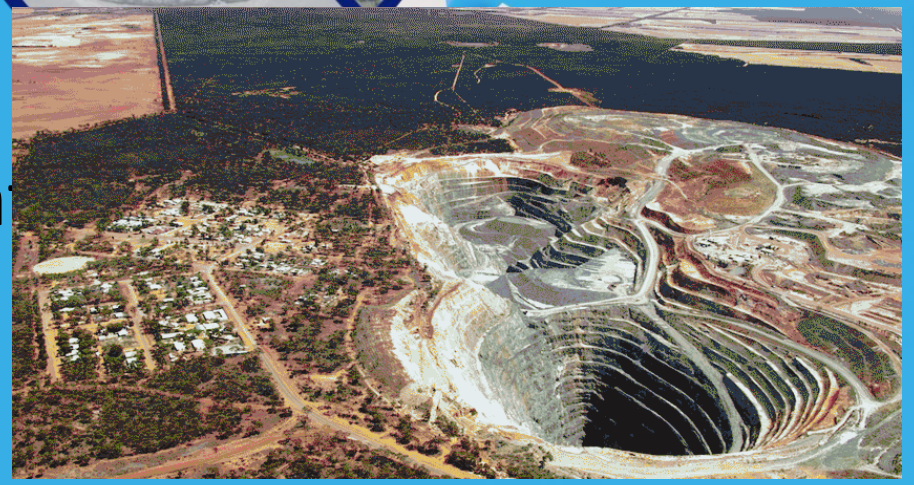
China has ca. 60% refining capacity! Extracted here!

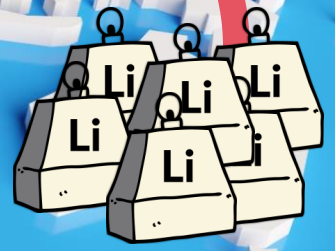
China



Chile

Argen





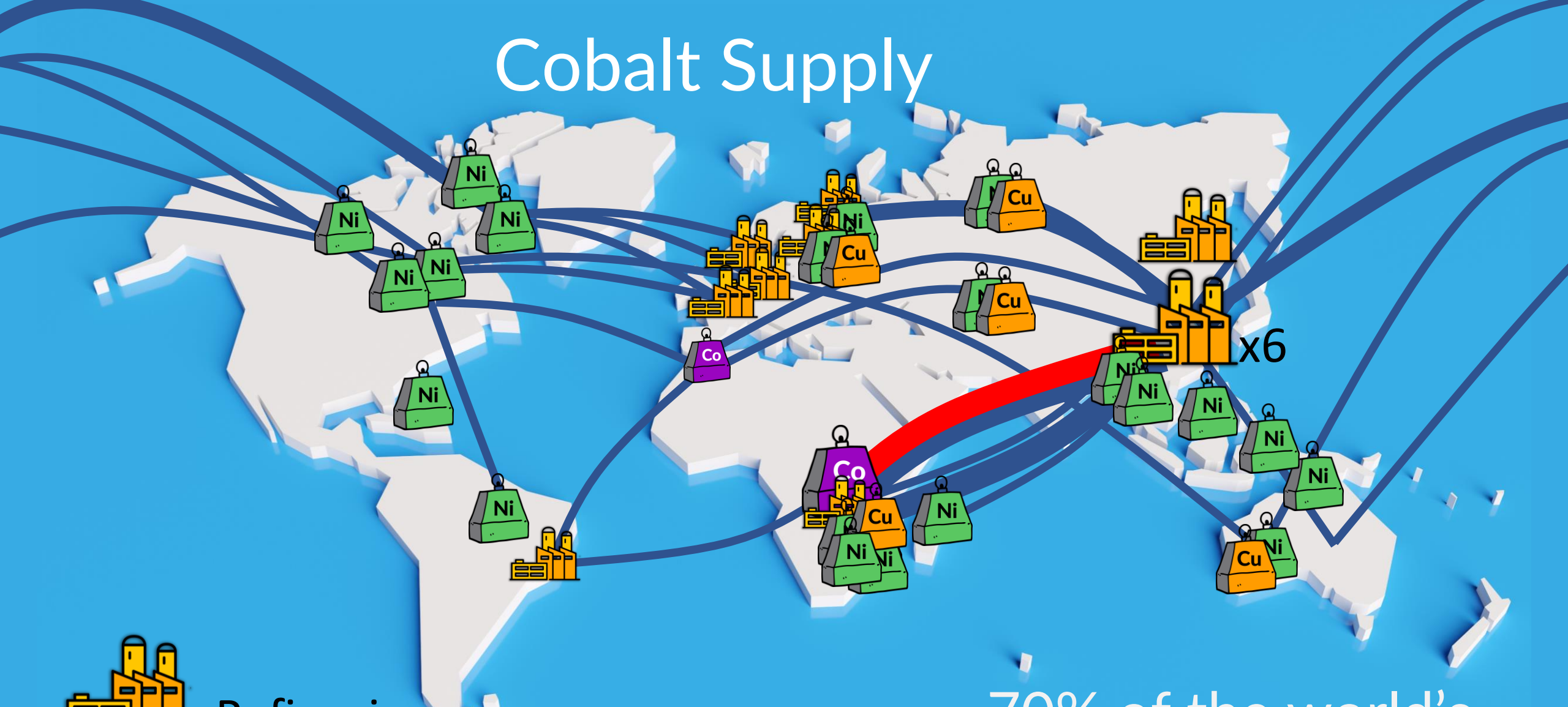
Australia

Key 

= Amount mined 10,000 tonnes

Credit – Elizabeth Driscoll

Cobalt Supply



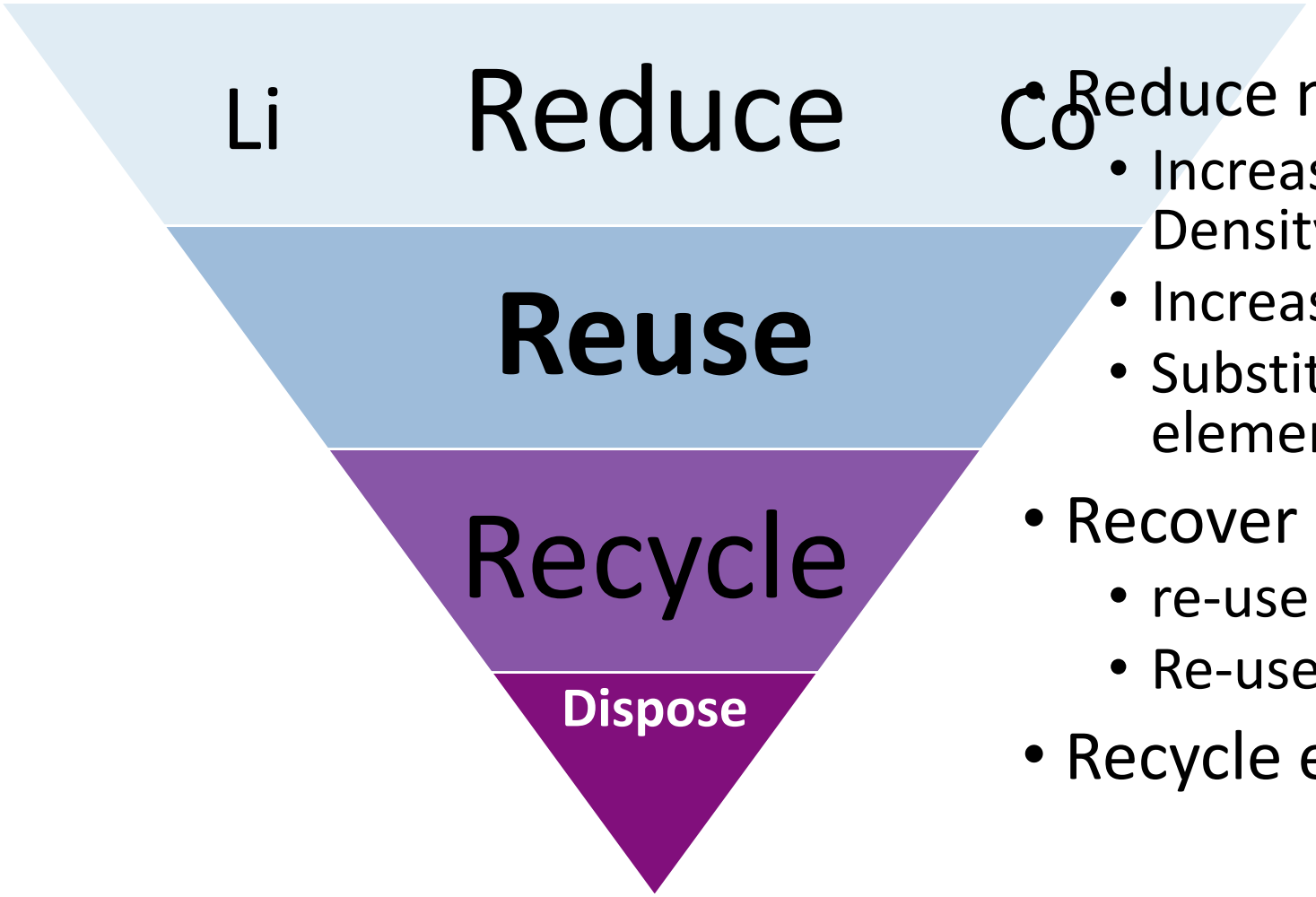
Refineries
Cobalt Ores/Concentrates
Cobalt Mattes/Intermediates

70% of the world's Co is from the DRC

Reference: S. van den Brink *et al.*, Resource, Conservation and Recycling, 2020, 156, 10473. Graphics adapted from Adobe Stock.

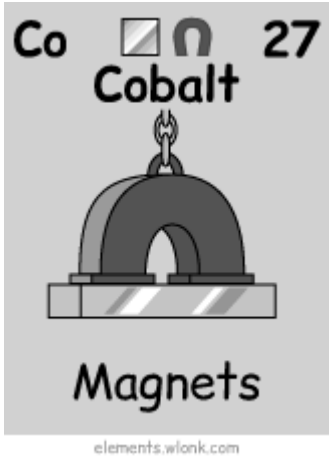
Credit – Elizabeth Driscoll

Waste Hierarchy – Towards Sustainability

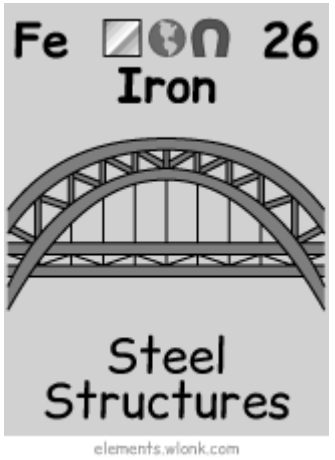


- Reduce materials
  - Increase Energy Density
  - Increase Life-time
  - Substitute for other elements
- Recover materials
  - re-use cells
  - Re-use materials
- Recycle elements

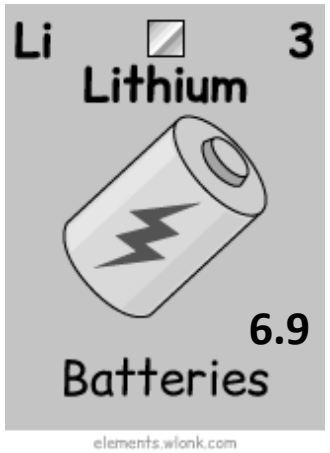
Reduce - Substitution

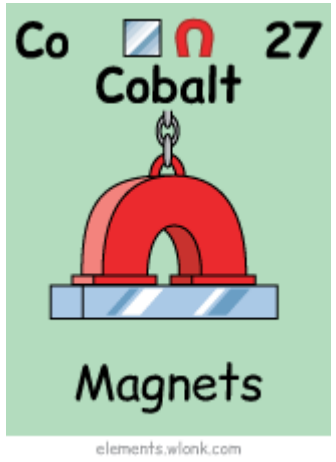


	Li	Na
Size: Pauling ionic radii	65	95
Weight : Atomic weight	6.941	22.99
Voltage vs SHE (V)	-3.04	-2.71
Volumetric capacity (mAh/cm^3)	2066	1128
Gravimetric capacity (mAh/g)	3861	1165
Melting point (°C)	180.5	97.7
Compound	Li_2CO_3	Na_2CO_3

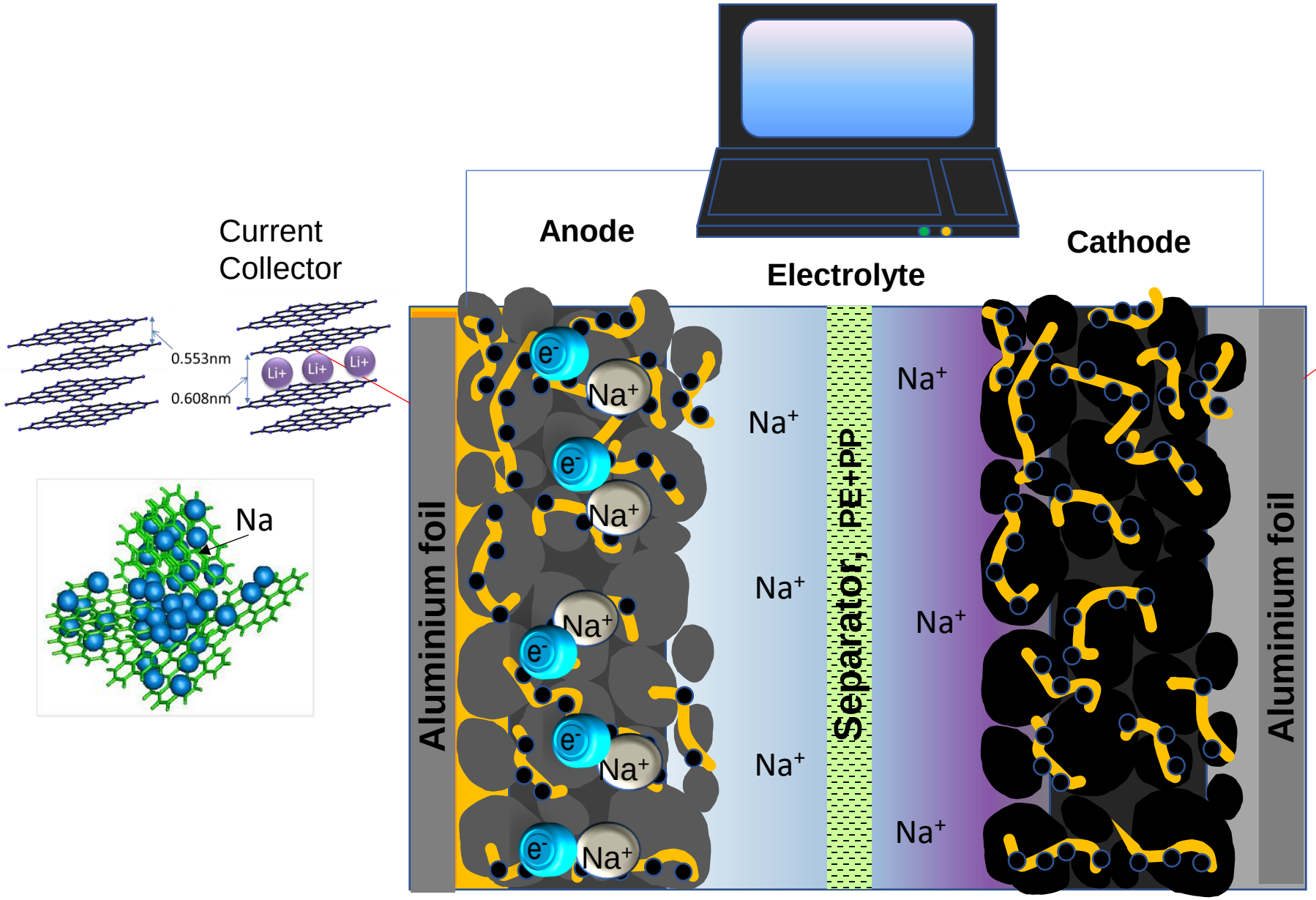


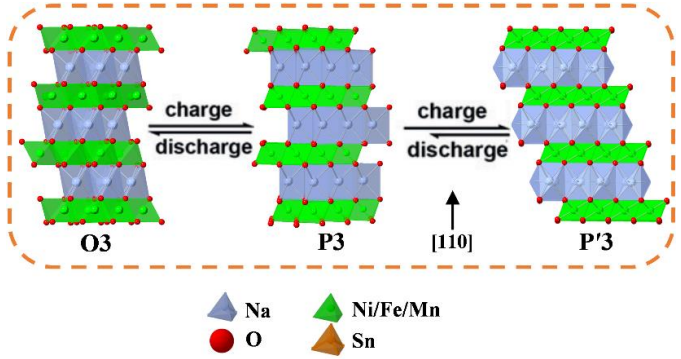
Reduce - Substitution





	Co	Fe
Geographical availability	DR Congo	AU / Brazil / China / India
Extraction and Refining	China	Global
Earth Crust Abundance (ppm)	25	56300
Voltage vs SHE (V) $M^{3+} + e^- \rightarrow M^{2+}$	+1.92	+0.77
Atomic Weight	58.9	55.8
Ore	2º from Ni/Cu	Iron oxides
$/mt	51,500	106





Song et al. *Chem. Mater.* 2022, 34, 9, 4153−4165, https://doi.org/10.1021/acs.chemmater.2c00522

Graphite $C_6Li \rightarrow C_6^+ + Li^+ + e^-$

Hard Carbon $C_xNa \rightarrow C_x^+ + Na^+ + e^-$

$Na_{0.5}Ni_{1/3}Mn_{1/3}Fe_{1/3}O_2 + e^- \rightarrow Na_{1.0}Ni_{1/3}Mn_{1/3}Fe_{1/3}O_2$

$Ni^{4+} + e^- \rightarrow Ni^{3+}$

Waste Hierarchy

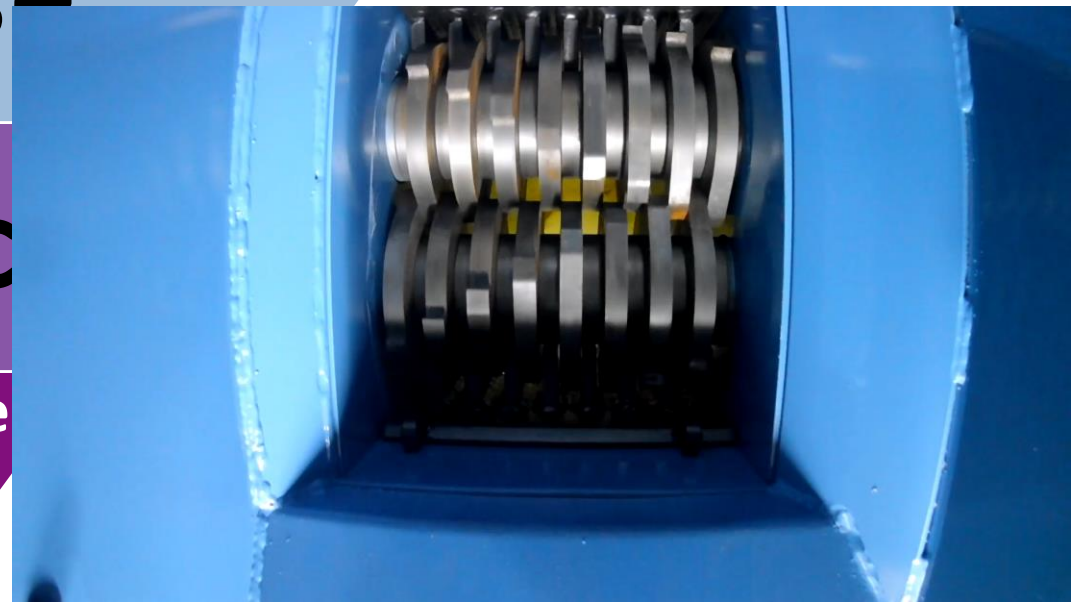
Li

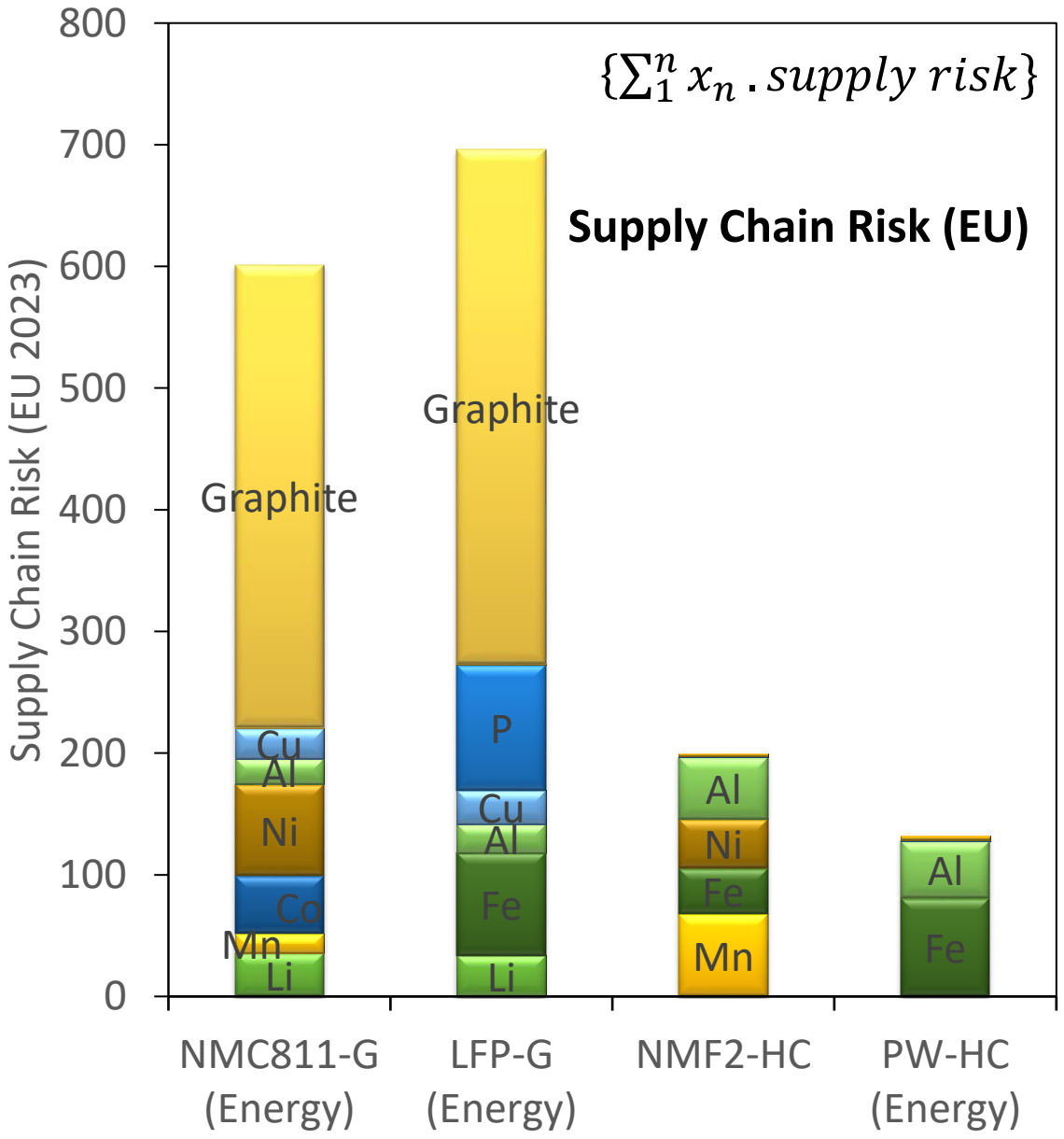
Reduc

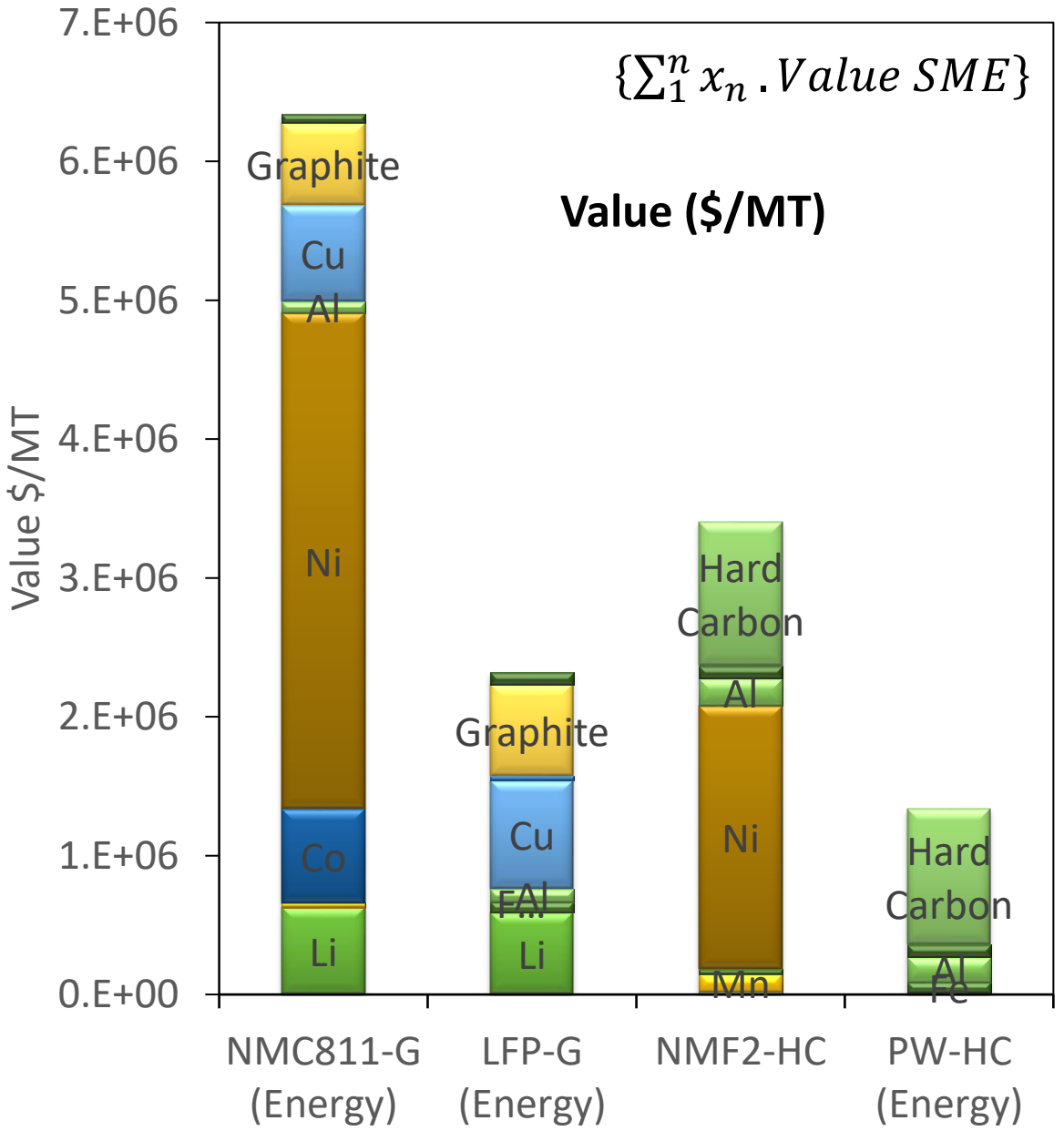
Reus

Recyc

Dispose







Stephens, Isabella D. R. and Slater, Peter Raymond and Kendrick, Emma, A Perspective on Cell Bill of Materials Using Batpac JPS, 2025, https://doi.org/10.1016/j.jpowsour.2025.236170

Energy Materials Group

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birmingham-energy-materials-group

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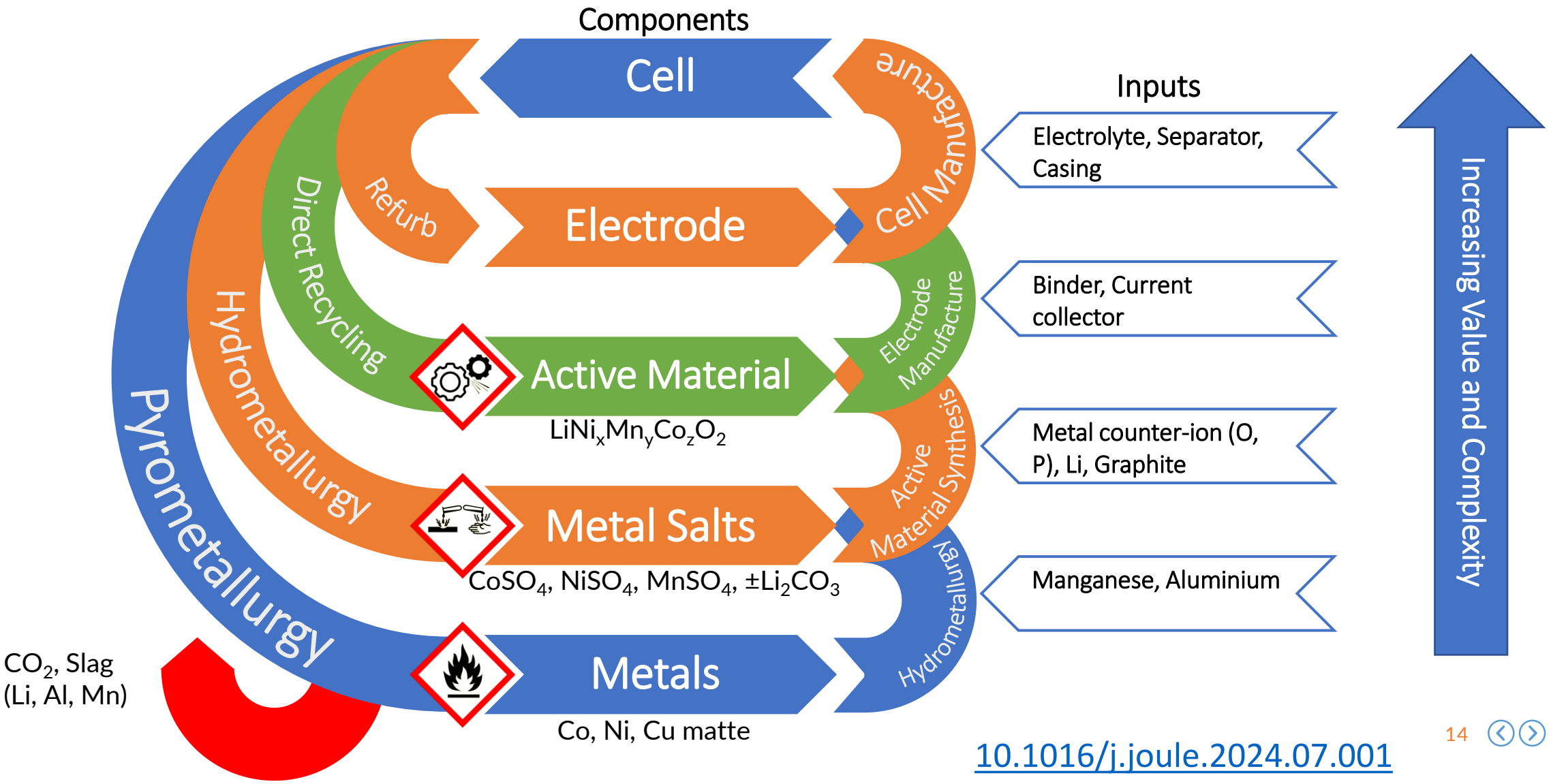
WISPER 2025

- Free event (but spaces limited to 100!)
- One day workshop for women in science working in energy research
- Open to all, but early career women are particularly encouraged to attend/participate.
- Combination of invited talks, contributed, round-table session and a poster session.
- Full details at: https://wisper2025.my.canva.site/

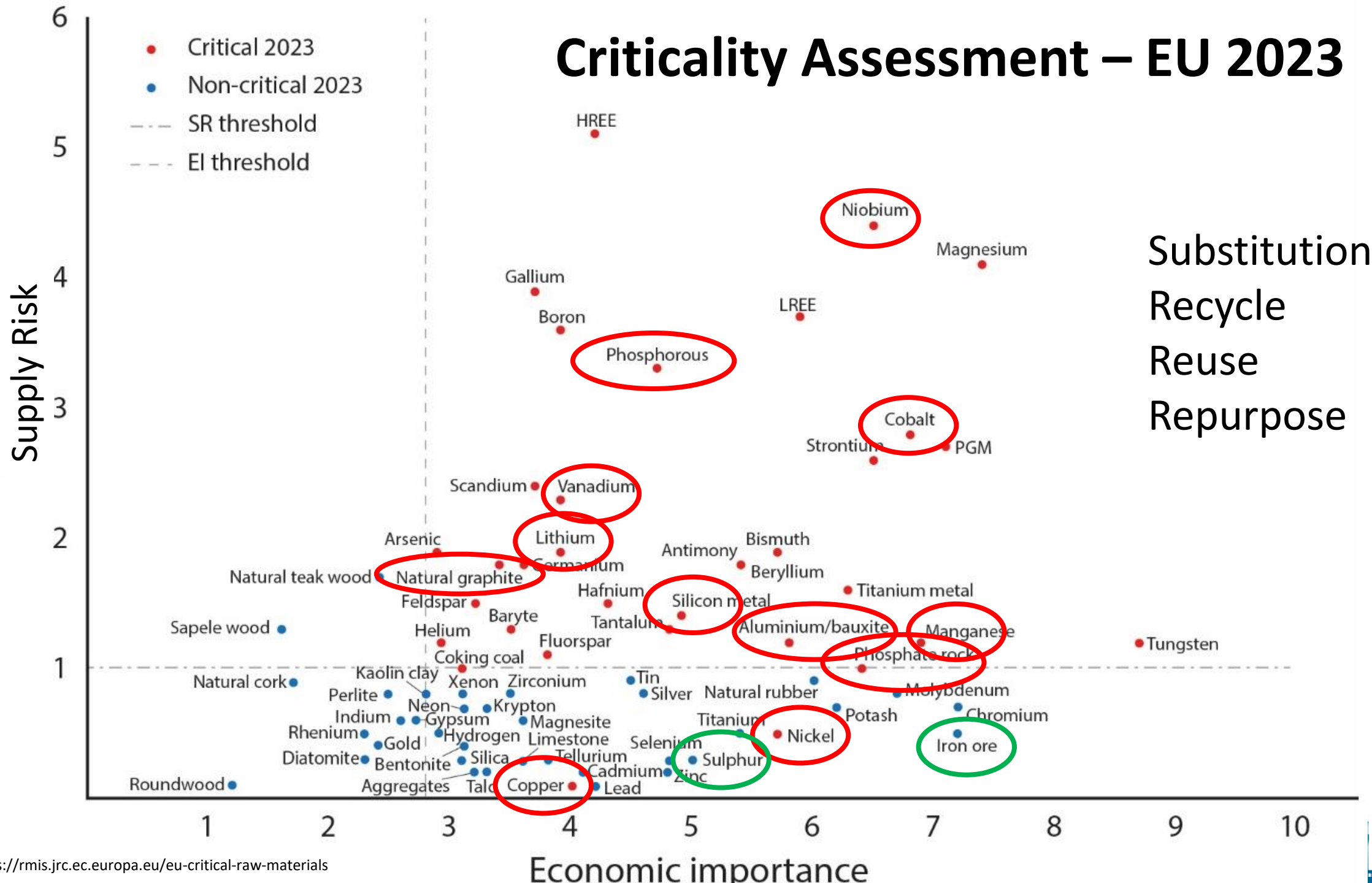
LinkedIn: IOM3 Energy Materials Group

RECYCLING ROUTES



10.1016/j.joule.2024.07.001

Criticality Assessment – EU 2023



Substitution
Recycle
Reuse
Repurpose

https://rmis.jrc.ec.europa.eu/eu-critical-raw-materials

Sustainable Batteries