MEInetwork23 Seminar #4:

New Energy Commodities and Critical Minerals

Speaker: **A/Prof. Mohan Yellishetty**
Associate Professor, Resources Engineering
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Moderator: **Prof. Robin Batterham**
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10 August 2023

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MEI*network*23 Seminar Series

Seminar topic	Month
Crude oil and product supply chains - Nicholas James, VIVA Energy	*Recording available online*
Uranium mining and refining	*Recording available online*
Energy commodity trading	*Recording available online*
New energy commodities and critical minerals	**10 August**
Fiscal policy to support future energy commodity exports	7 September

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MONASH University

THE UNIVERSITY OF MELBOURNE

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MEInetwork23 Seminar #4

on

"New energy commodities and critical minerals"

What, Why and How: Critical Minerals

I acknowledge and pay respects to the Traditional Owners and Elders - past, present and emerging - of the lands and waters on which we live and work.

Assoc Prof Mohan Yellishetty

Co-Convener, National Industry Working Group (Critical Minerals)
Australia-India Chamber of Commerce

Co-Founder, Critical Minerals Consortium, Monash University

Mohan.Yellishetty@monash.edu

GROUP OF EIGHT AUSTRALIA

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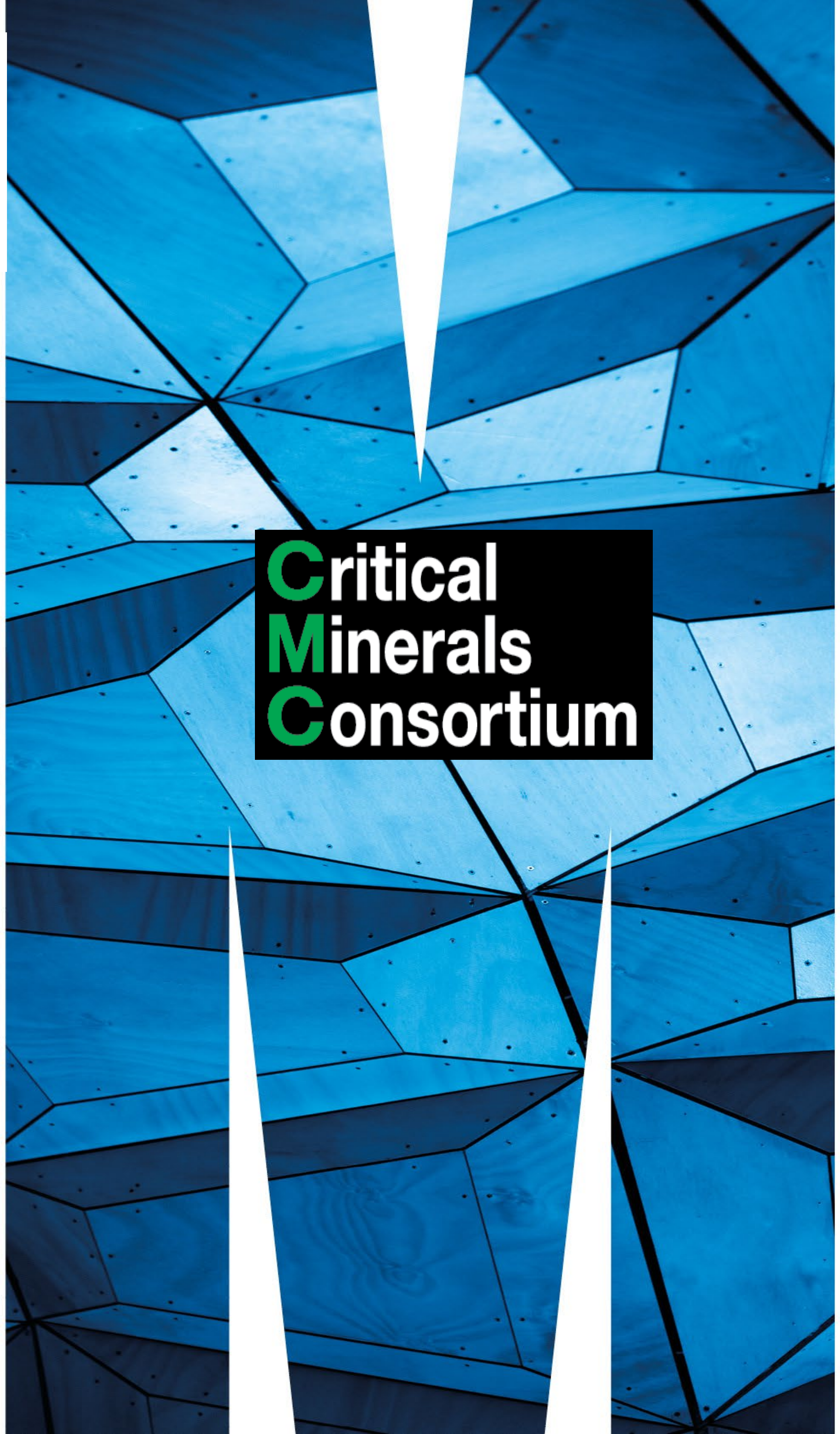
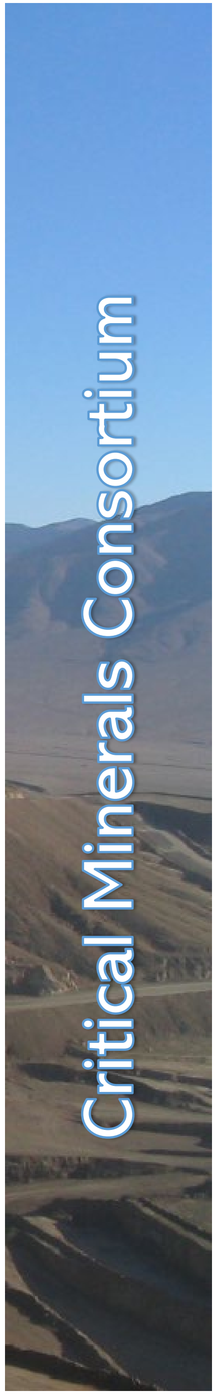
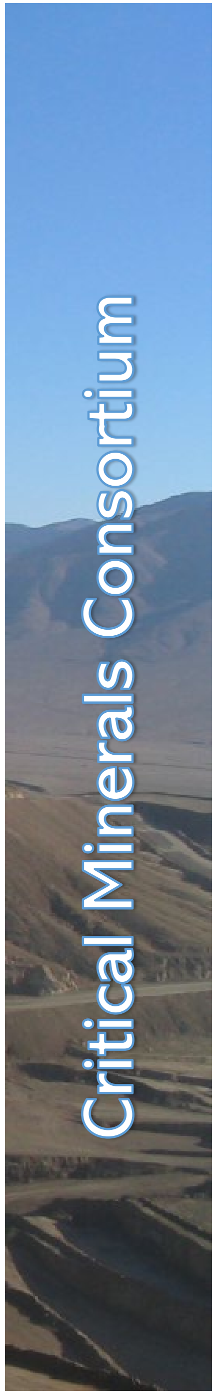




Presentation Overview

- Critical Minerals Consortium
- Critical minerals: association, significance, and concentration
- Demand drivers: Battery storage, EVs, Electrification and
- Clean Energy Metals: What we have?
- Clean Energy Metals: Production Vs Processing
- Recovering CRMs from Legacy Mines and Tailings
- Mining transitions & Mega mining trends
- Substitution & Recycling
- Critical Minerals International Alliance
- Final thoughts & Recommendations



Critical Minerals Consortium

Mission: To improve our understanding of minerals criticality and to provide advice, ideas and expertise to assist policy makers.

Expertise in critical minerals in the CMC: Thirty researchers from Monash University, RMIT University, Latrobe University, University of Queensland, CSIRO, University of Melbourne, Deakin University, University of NSW and Federation University.

criticalmineralsconsortium.org

Special Advisers

Stephen McIntosh
Non Executive Director,
Chalice Mining Limited
Show more

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The University of Melbourne
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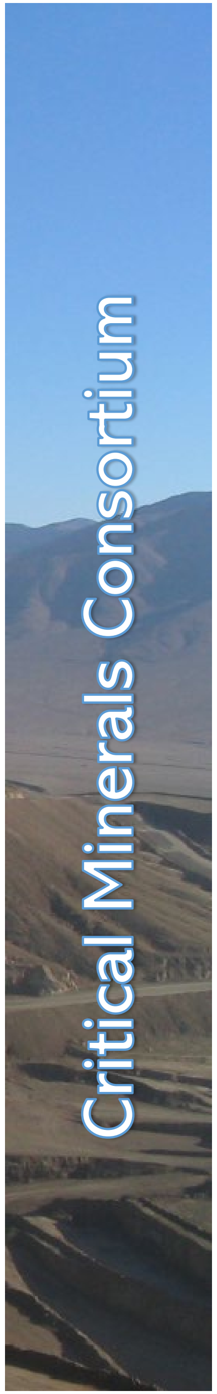
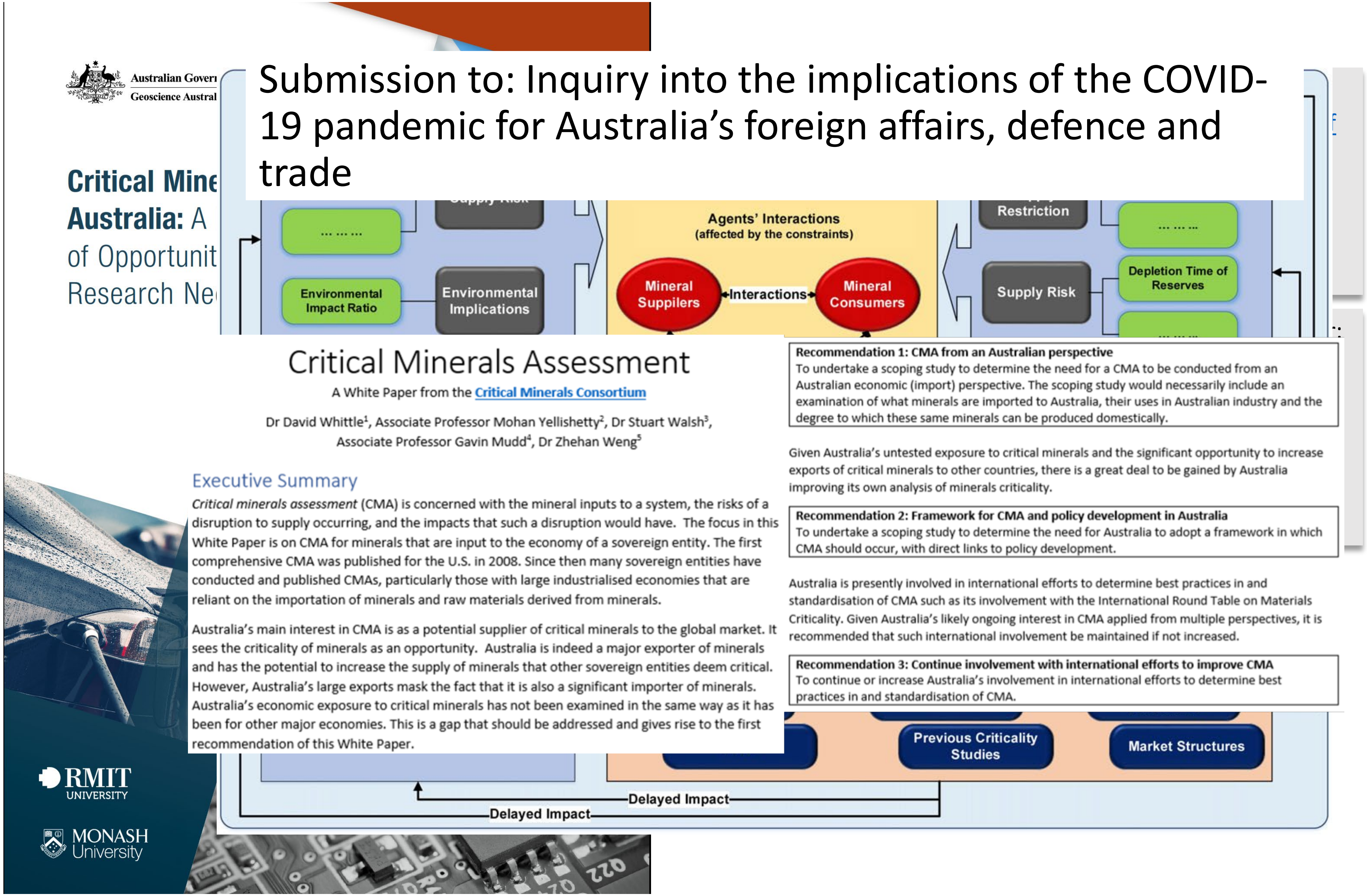


Critical Minerals Consortium - Milestones



Submission to: Inquiry into the implications of the COVID-19 pandemic for Australia's foreign affairs, defence and trade

Critical Minerals Assessment

A White Paper from the Critical Minerals Consortium

Dr David Whittle[1], Associate Professor Mohan Yellishetty[2], Dr Stuart Walsh[3], Associate Professor Gavin Mudd[4], Dr Zhehan Weng[5]

Executive Summary

Critical minerals assessment (CMA) is concerned with the mineral inputs to a system, the risks of a disruption to supply occurring, and the impacts that such a disruption would have. The focus in this White Paper is on CMA for minerals that are input to the economy of a sovereign entity. The first comprehensive CMA was published for the U.S. in 2008. Since then many sovereign entities have conducted and published CMAs, particularly those with large industrialised economies that are reliant on the importation of minerals and raw materials derived from minerals.

Australia's main interest in CMA is as a potential supplier of critical minerals to the global market. It sees the criticality of minerals as an opportunity. Australia is indeed a major exporter of minerals and has the potential to increase the supply of minerals that other sovereign entities deem critical. However, Australia's large exports mask the fact that it is also a significant importer of minerals. Australia's economic exposure to critical minerals has not been examined in the same way as it has been for other major economies. This is a gap that should be addressed and gives rise to the first recommendation of this White Paper.

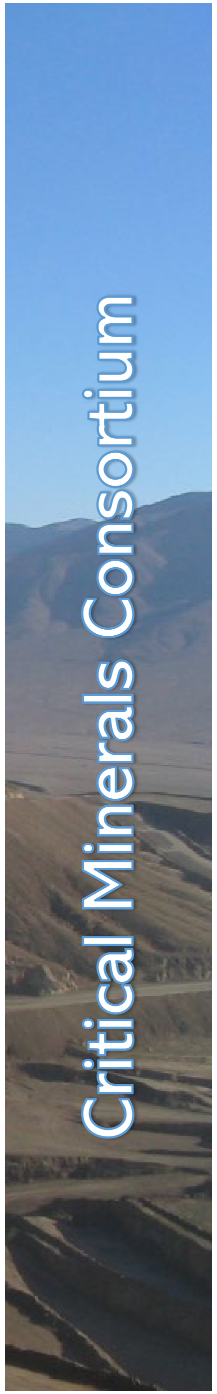
Recommendation 1: CMA from an Australian perspective
To undertake a scoping study to determine the need for a CMA to be conducted from an Australian economic (import) perspective. The scoping study would necessarily include an examination of what minerals are imported to Australia, their uses in Australian industry and the degree to which these same minerals can be produced domestically.

Given Australia's untested exposure to critical minerals and the significant opportunity to increase exports of critical minerals to other countries, there is a great deal to be gained by Australia improving its own analysis of minerals criticality.

Recommendation 2: Framework for CMA and policy development in Australia
To undertake a scoping study to determine the need for Australia to adopt a framework in which CMA should occur, with direct links to policy development.

Australia is presently involved in international efforts to determine best practices in and standardisation of CMA such as its involvement with the International Round Table on Materials Criticality. Given Australia's likely ongoing interest in CMA applied from multiple perspectives, it is recommended that such international involvement be maintained if not increased.

Recommendation 3: Continue involvement with international efforts to improve CMA
To continue or increase Australia's involvement in international efforts to determine best practices in and standardisation of CMA.



Critical next steps for critical minerals

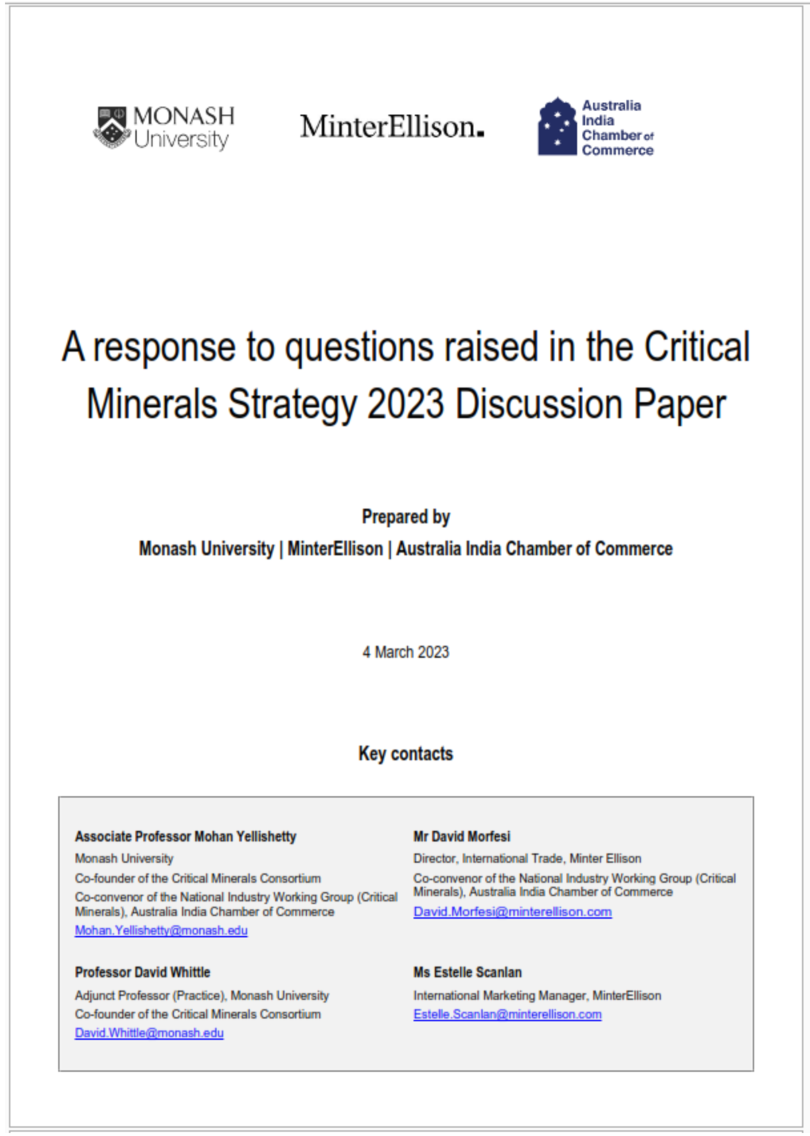
Monash University MinterEllison AICC

Key recommendations (for government):

- Develop a reverse perspective, identifying in detail the opportunities for prospective critical minerals suppliers.
- Consider marketability of minerals in framing ESG regulations and processes.
- Develop the workforce and attract international talent.
- Facilitate cross-border cooperation between governments, research institutions and industry.

Key insights (for government):

- Critical minerals are not necessarily ‘minerals’.
- There are many causes of minerals criticality in many complex, small and dynamic markets.
- The supply side for upstream critical minerals will mainly be made up of small and midsized enterprises.
- In framing interventions, the federal government should be cognisant of the differences by state and region.



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A response to questions raised in the Critical Minerals Strategy 2023 Discussion Paper

Prepared by

Monash University | MinterEllison | Australia India Chamber of Commerce

4 March 2023

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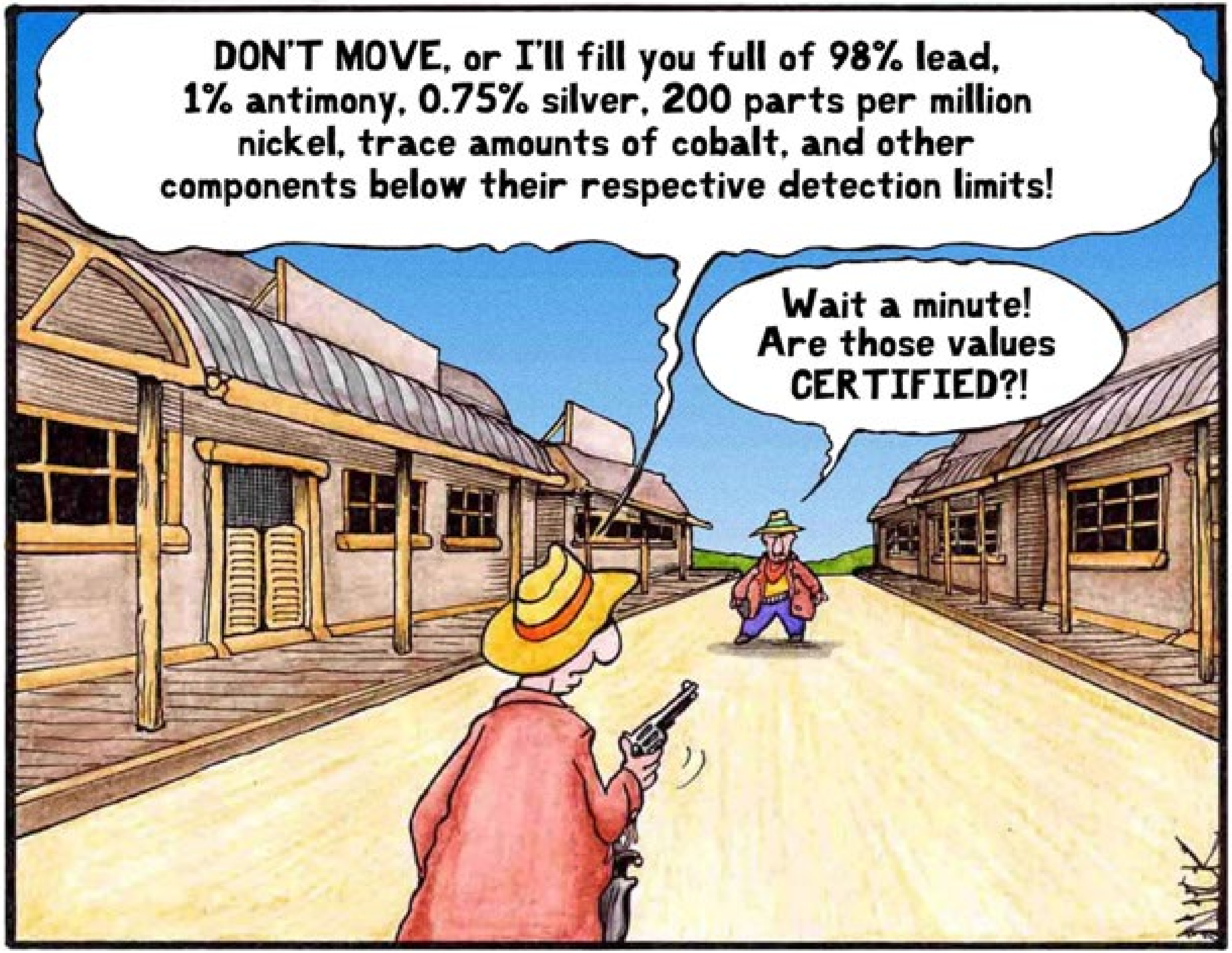
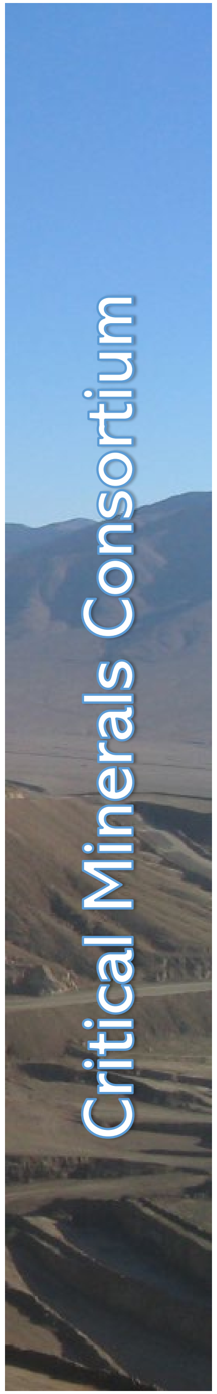


Analytical Chemists in the Wild West

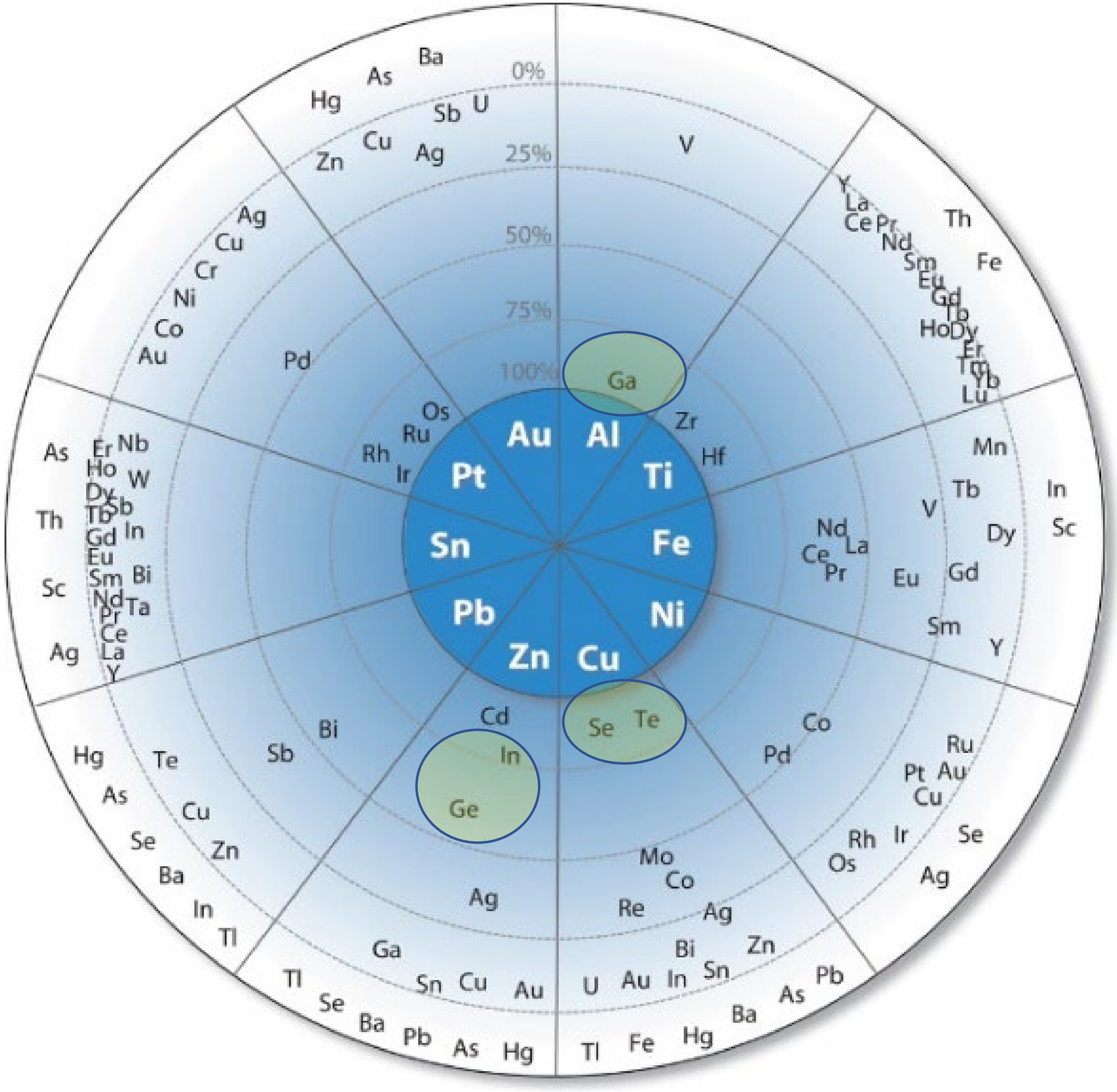


Critical Minerals

Building solar photovoltaic (PV) plants, wind farms and electric vehicles (EVs) generally requires a different mix of minerals than their fossil fuel based counterparts

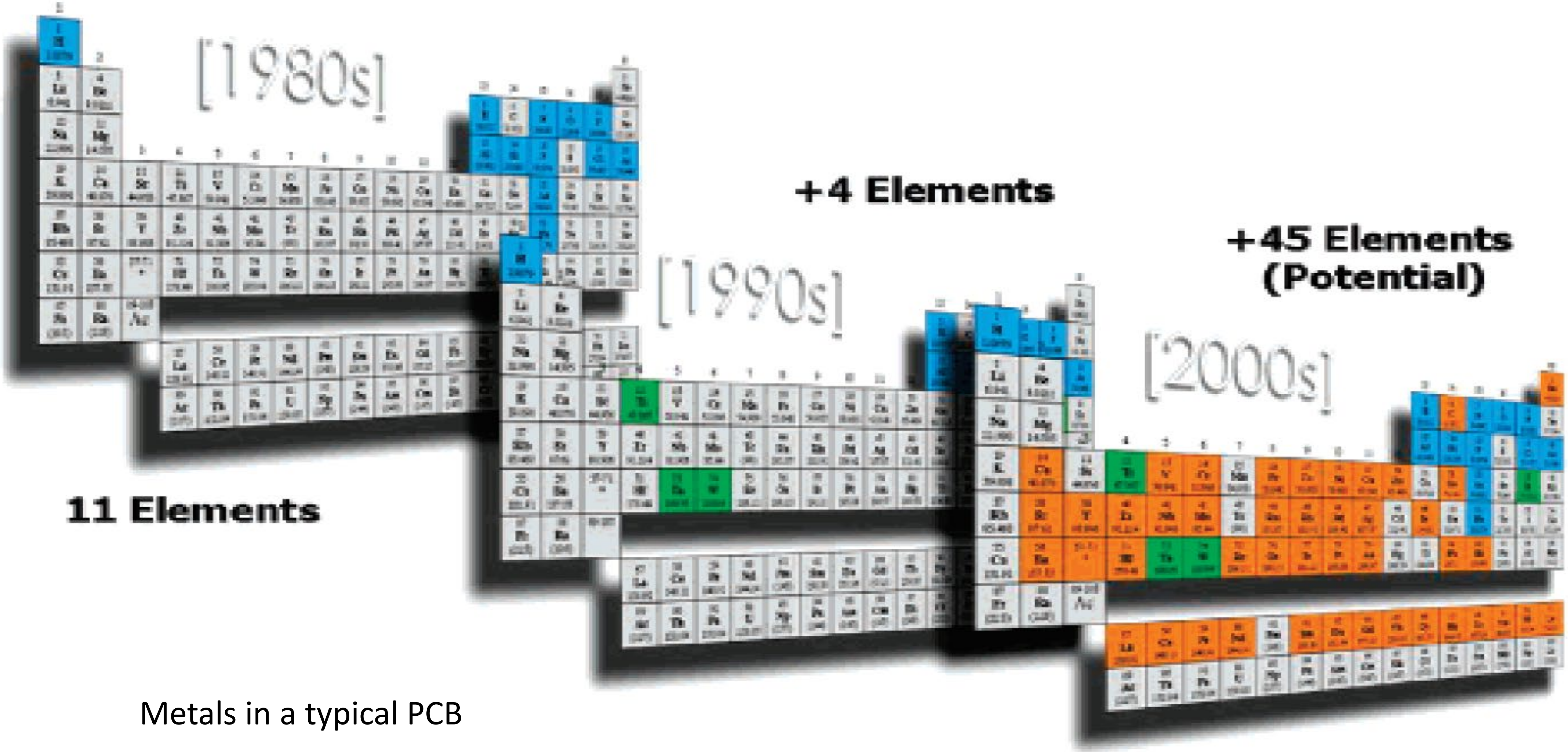
Critical Minerals (including REE) growing in importance in many domestic, medical, industrial and strategic applications because of their unique properties:

- Catalytic
- Metallurgical
- Nuclear
- Electrical
- Magnetic
- Luminescent



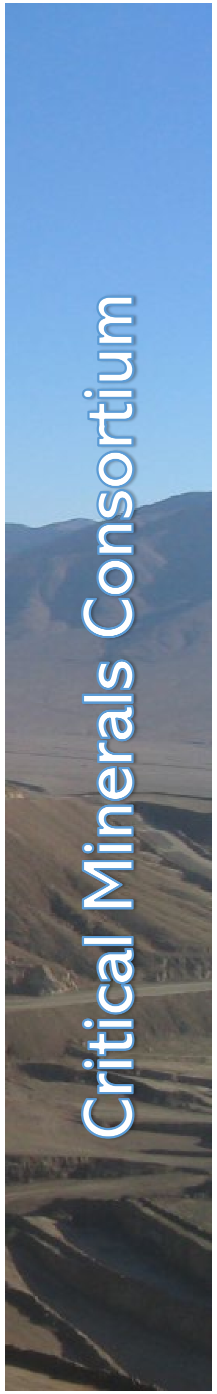
(Nassar et al., 2015).

Critical Minerals – significance



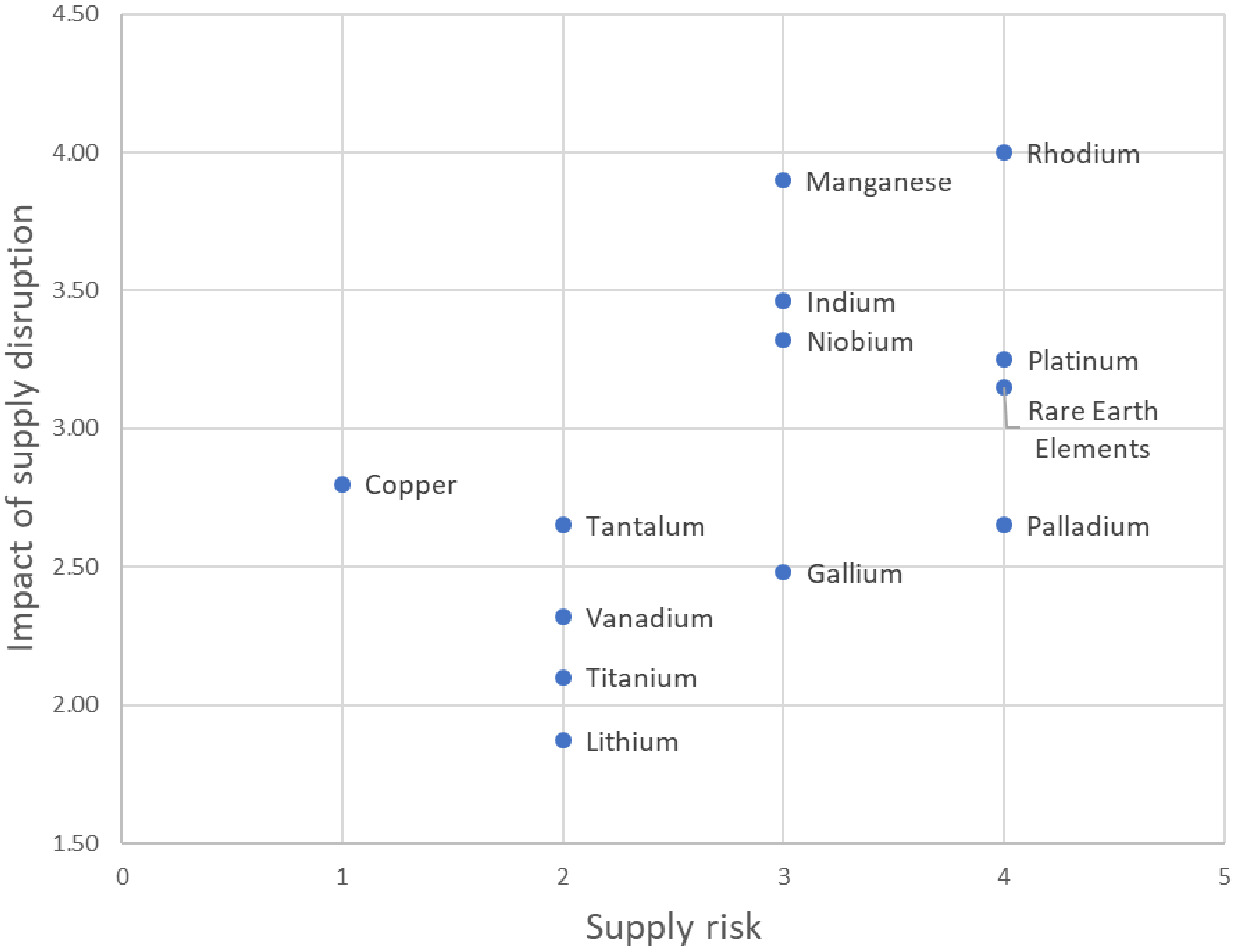
Metals in a typical PCB

Johnson et al. *Environ Sci Technol* **41**, 1759-1765 (2007)



Science, Economics – of CMs

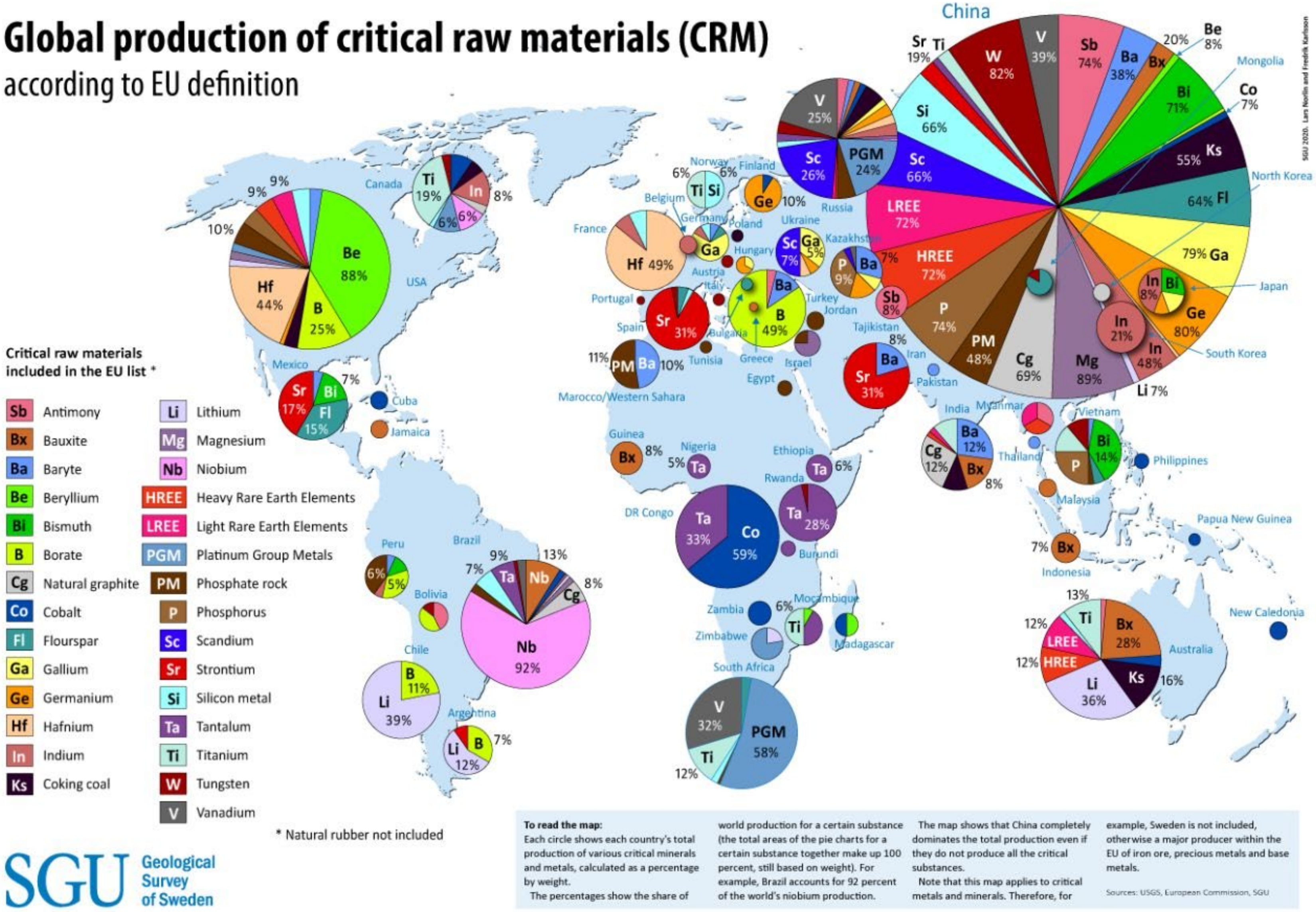
Minerals criticality assessment - basics



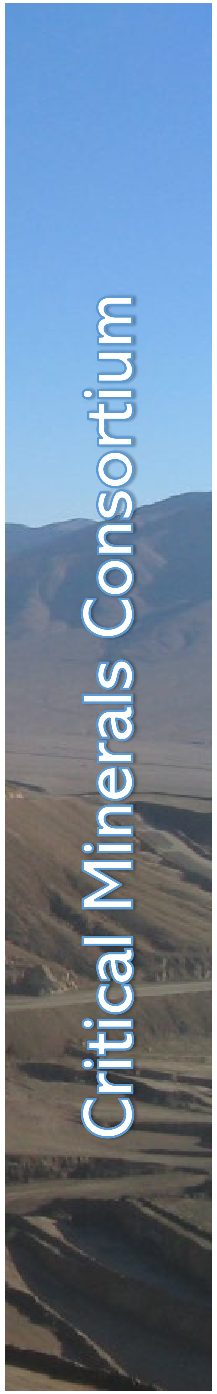
Source: National Research Council (2008). Minerals, critical minerals, and the US economy, National Academies Press.

Critical Minerals Consortium

Critical Minerals – and Geopolitics



Read: Got “critical minerals”? Hooray! But be careful! by Louis T. Wells



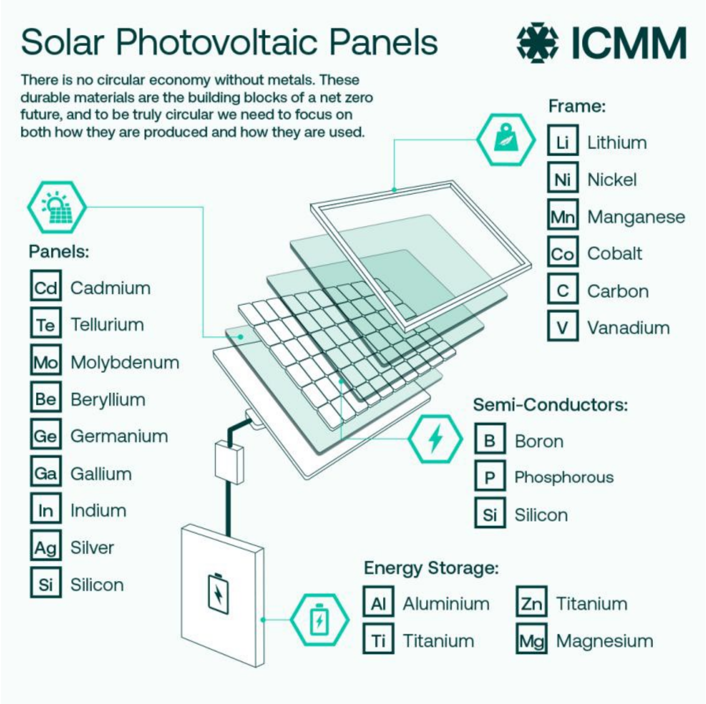
Critical Energy Minerals – What are they?

Batteries

- Li-ion [Li, Ni, Co, Mn, Graphite, High Purity Alumina]
- Vanadium

- **Electric Vehicles** (rare earths for EVs and wind turbines, magnesium for alloys)

- **Electrification**
  - solar PV inputs (Si, Ga, Ge, In)
  - electrolysers (Platinum Group Elements and Ti catalysts)



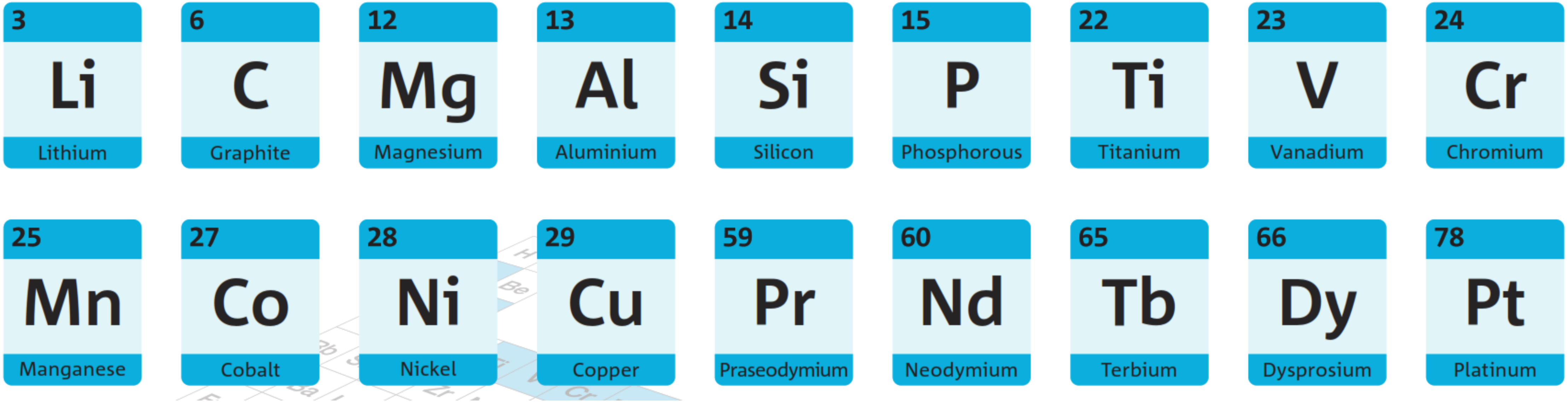
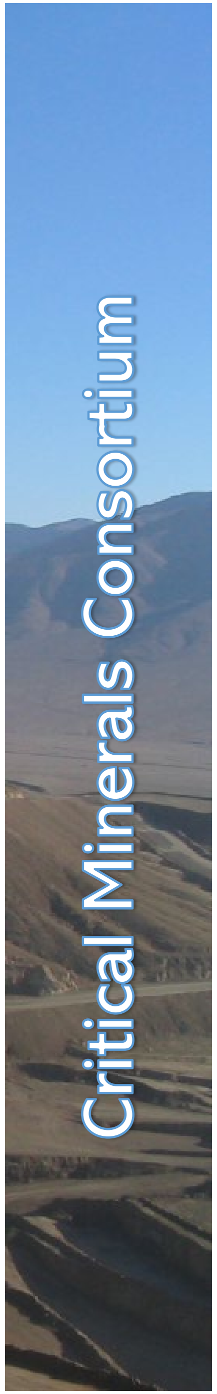
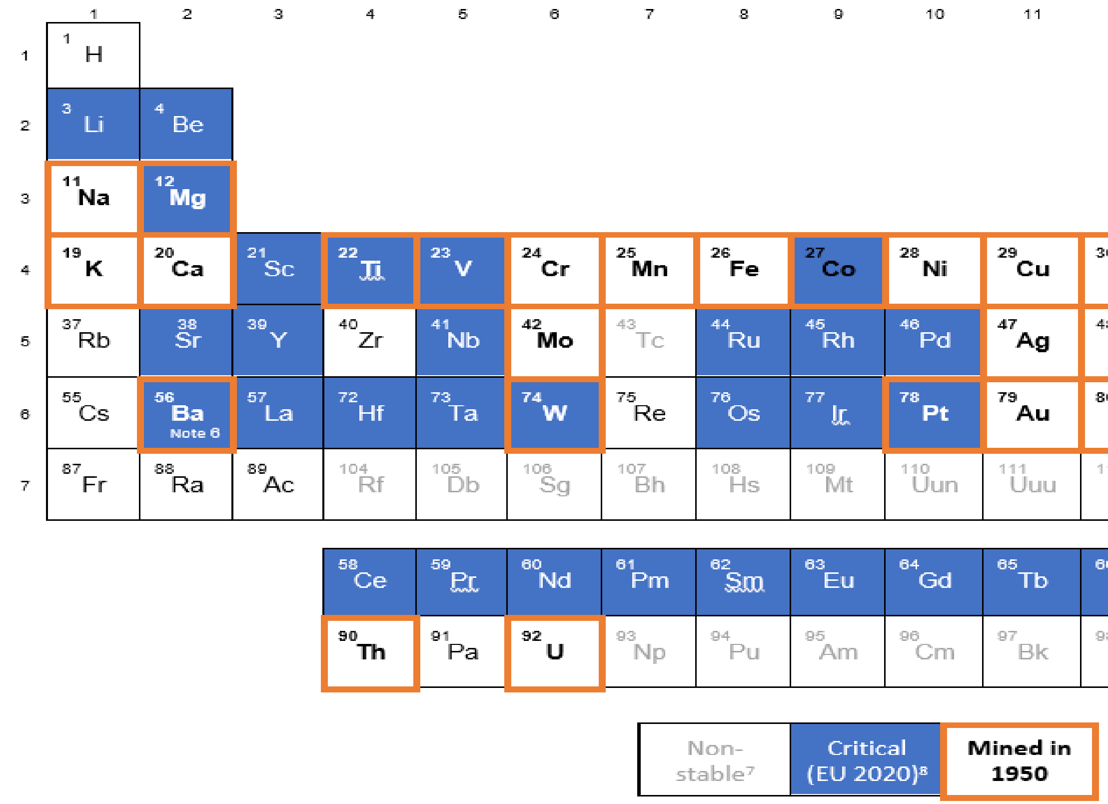


Figure Source: Bruce S, Delaval B, Moisi A, Ford J, West J, Loh J, Hayward J (2021) Critical Energy Minerals Roadmap. CSIRO, Australia.



EU Criticality Minerals

EU critical minerals and minerals mined in 1950



Adapted from (Lemiere 2012) with additional information from:

- Non-stable isotopes (Johnson 2017)
- EU critical minerals 2020 (European Commission 2020)

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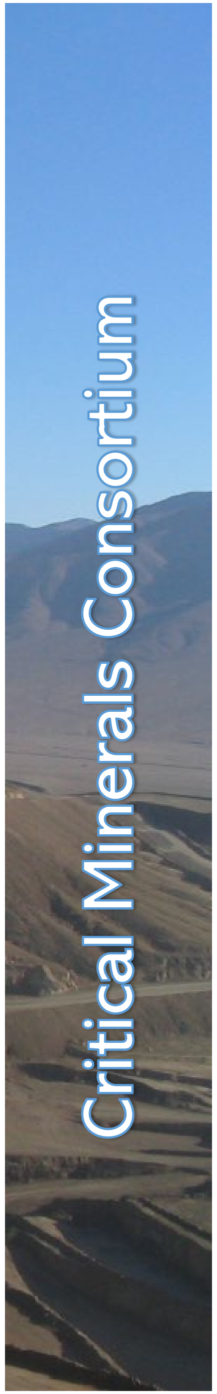
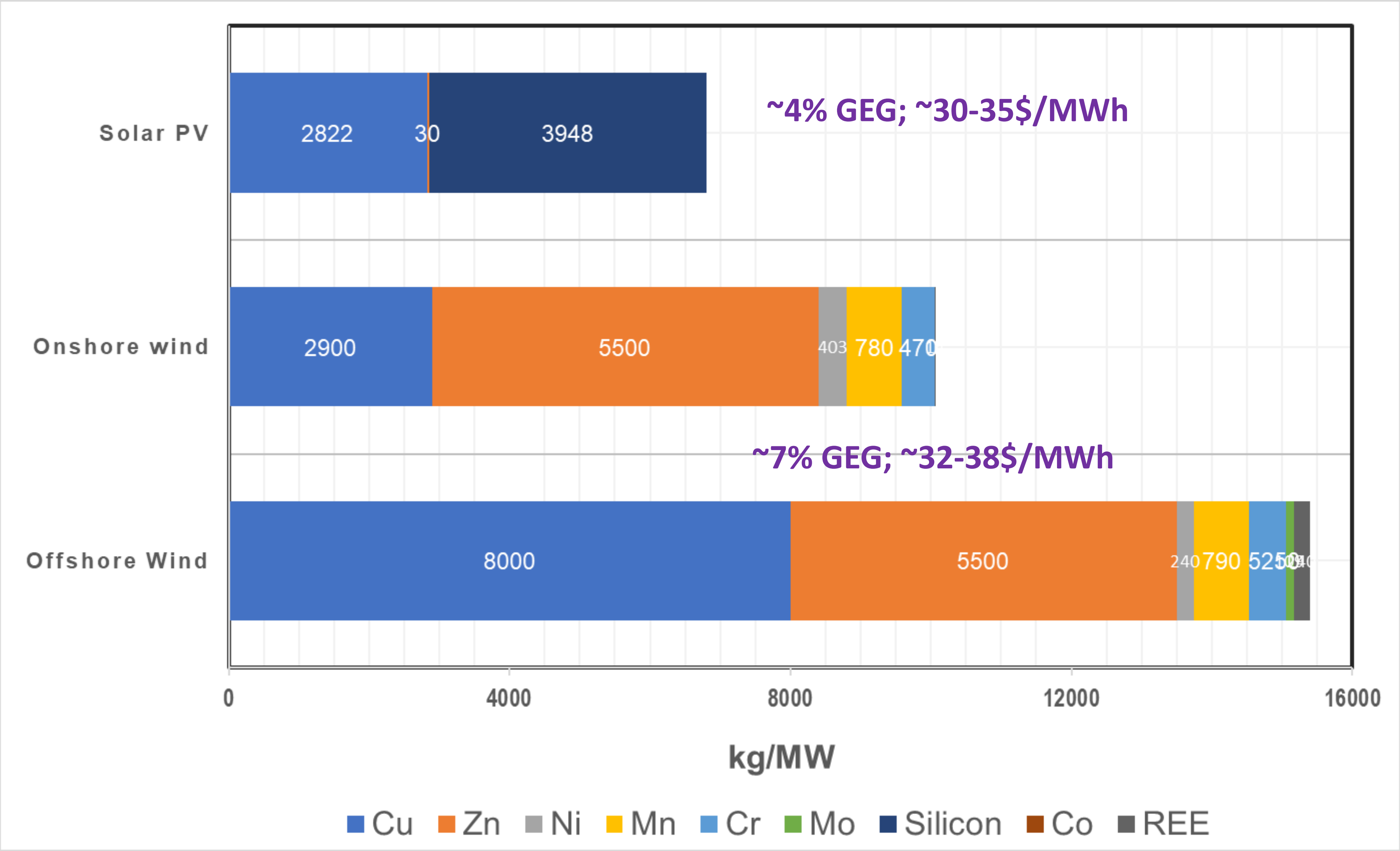
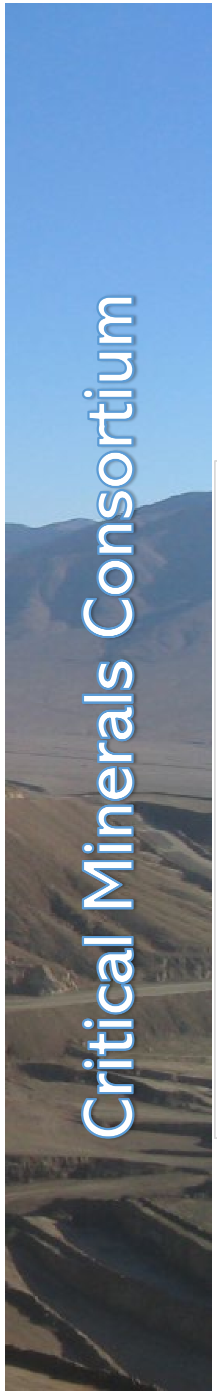
[1] Borate (boron-oxygen compound) is listed as critical to the EU.
[2] Natural graphite and coking coal are listed as critical to the EU.
[3] Fluorspar (CaF_2) is listed as critical to the EU.
[4] Bauxite is listed as critical to the EU.
[5] Phosphate rock is listed as critical to the EU.
[6] Baryte ($BaSO_4$) is listed as critical to the EU.
[7] Non-stable isotopes / human synthesis. Source: Johnson, J. (2017). "Origin of the Elements in the Solar System." Science Blog from the Sloan Digital Sky Surveys http://blog.sdss.org/2017/01/09/origin-of-the-elements-in-the-solar-system/ Accessed 2 Jul 2021 2021.
[8] Source: European Commission (2020). Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability. Brussels.



Renewable Energy & Demand for CMs

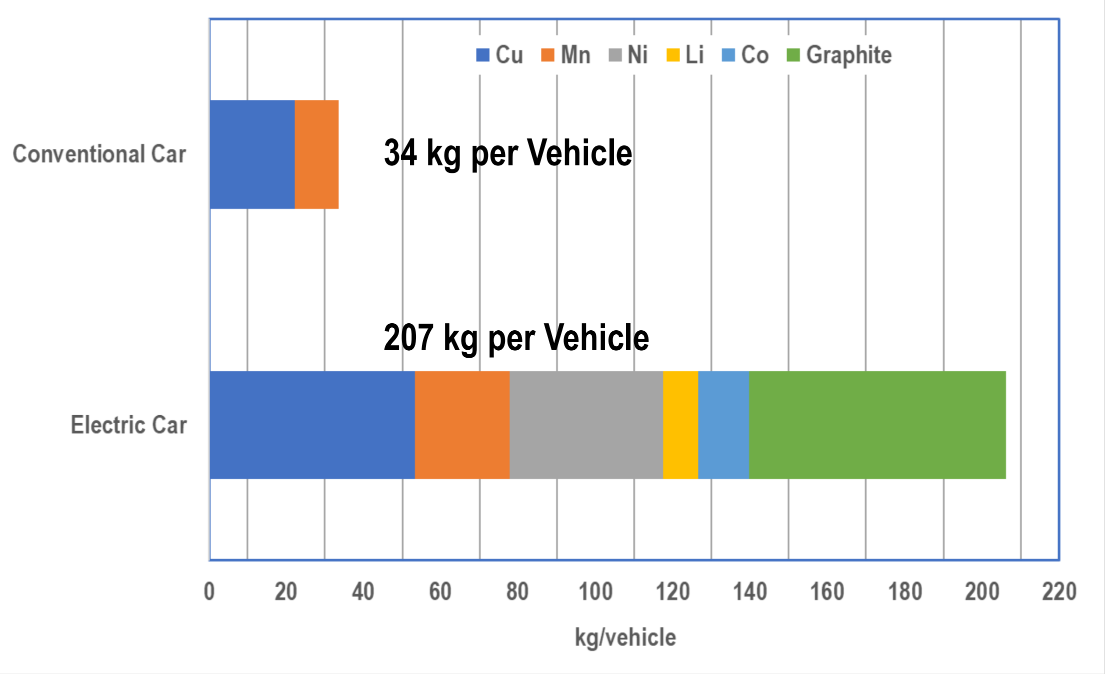


Data Source: IEA (2021), The Role of Critical Minerals in Clean Energy Transitions, IEA,

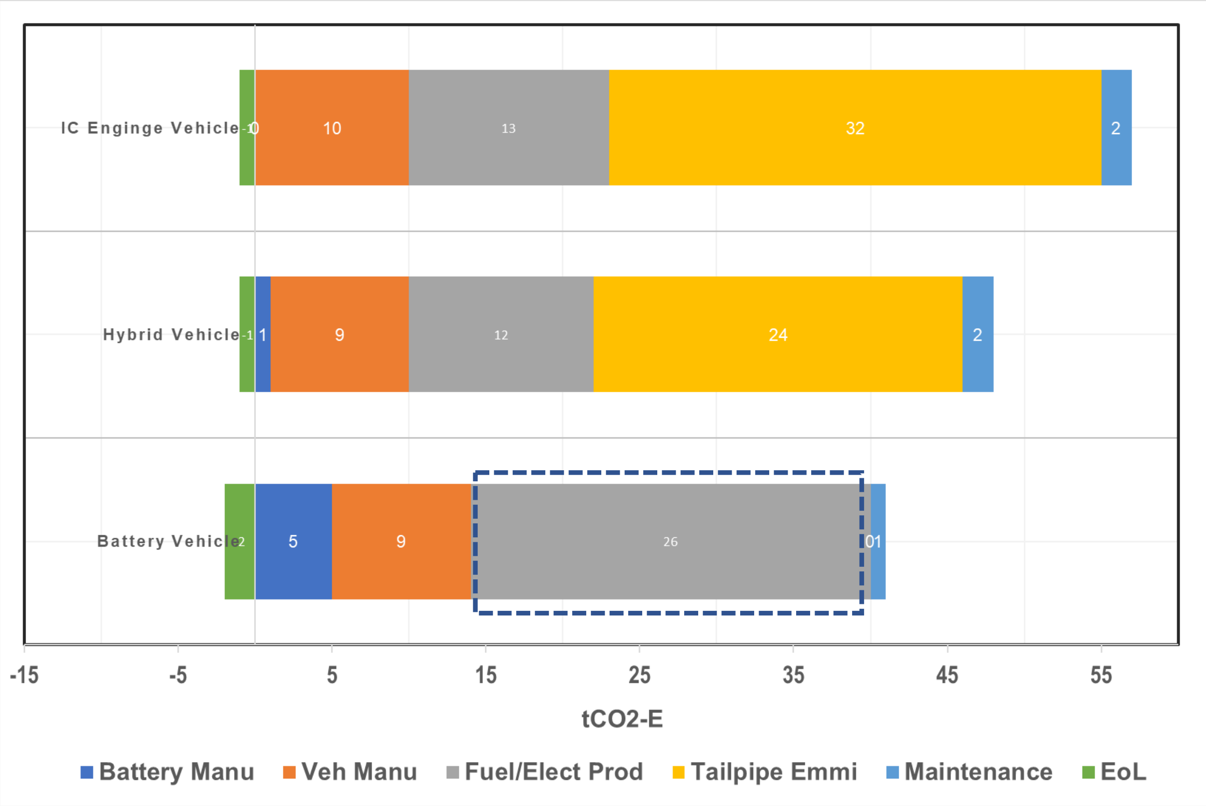


EVs vs their Conventional Cousins: a Driver of Critical Mineral Demand

A typical electric car requires 6x the mineral inputs of a conventional internal combustion engine car.



Conventional and Electric Vehicles

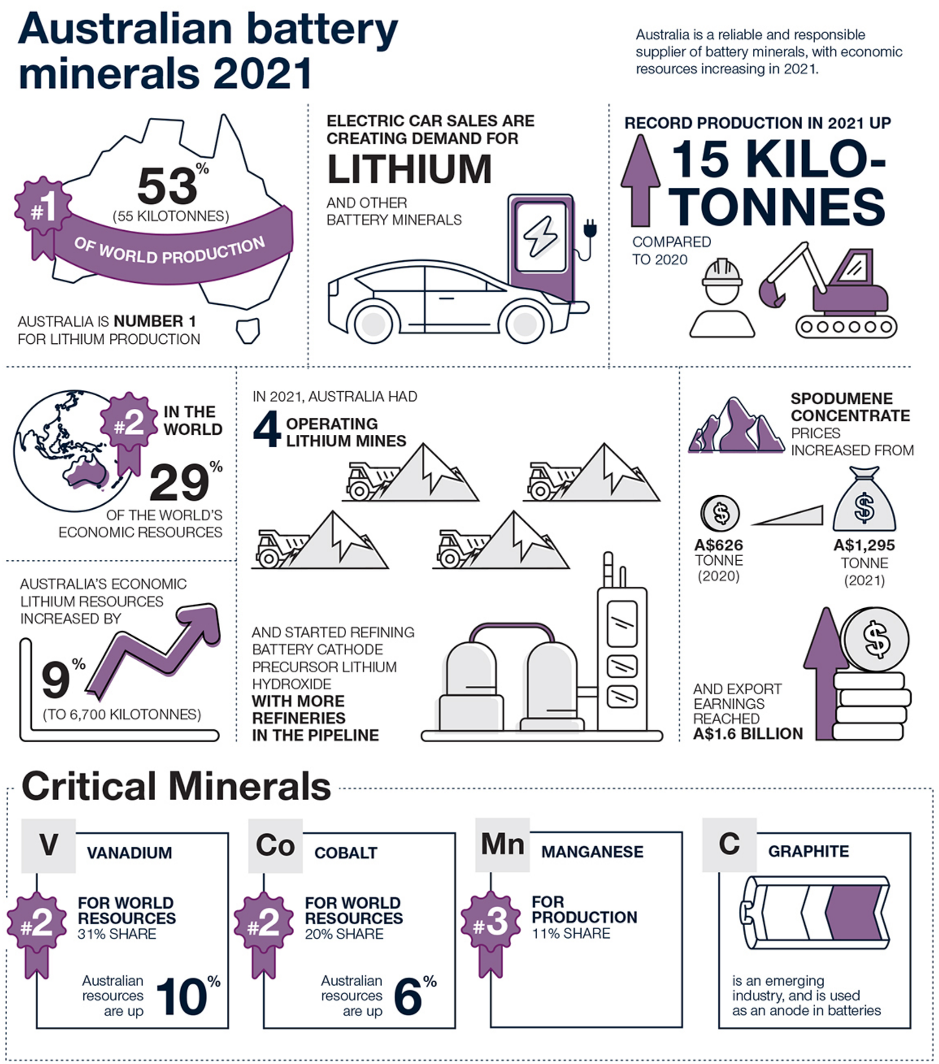


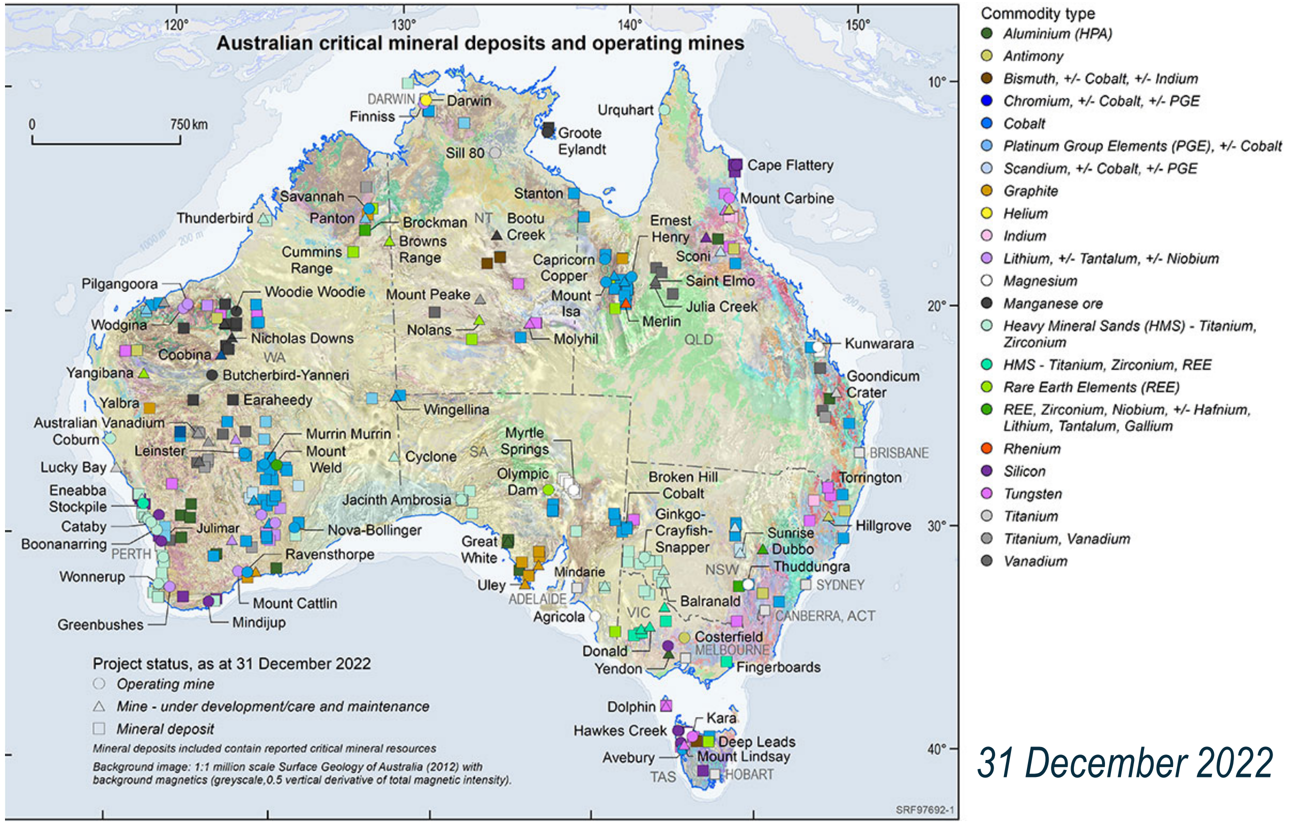
Life Cycle Emissions of Vehicles

Data Source: IEA (2021), The Role of Critical Minerals in Clean Energy Transitions

Data Source: Polestar and Rivian Pathway Report (2023)

Australia Critical Mineral Deposits and Operating Mines



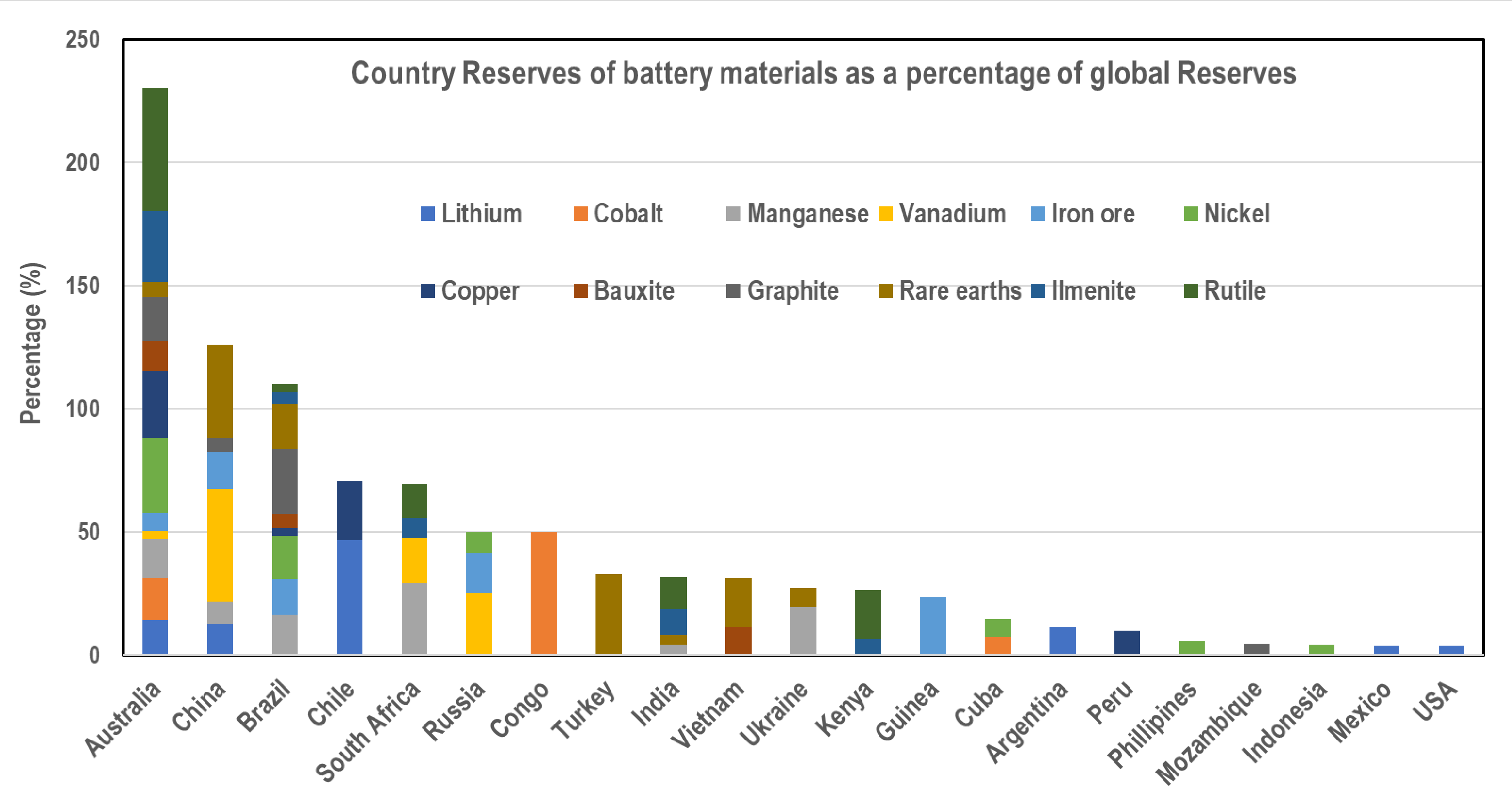


31 December 2022

Critical Minerals Consortium

Fig Source: https://www.ga.gov.au/scientific-topics/minerals/critical-minerals

Clean Energy Metals: What we have?



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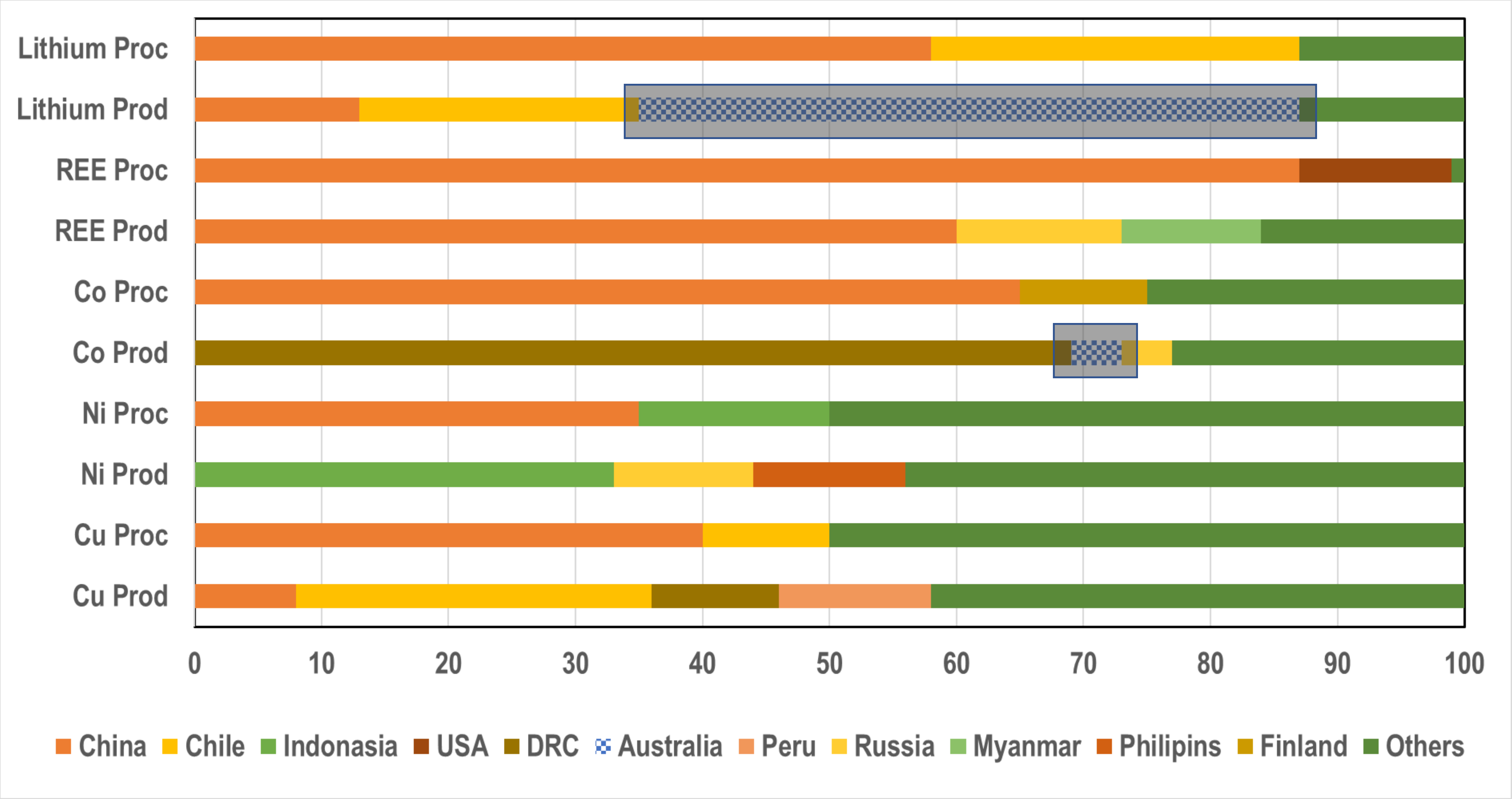
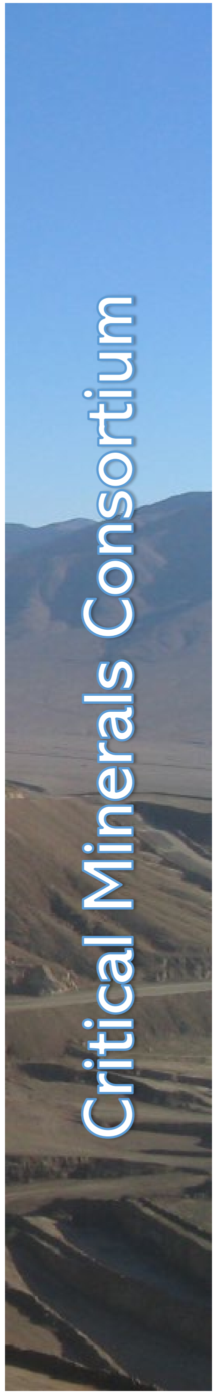
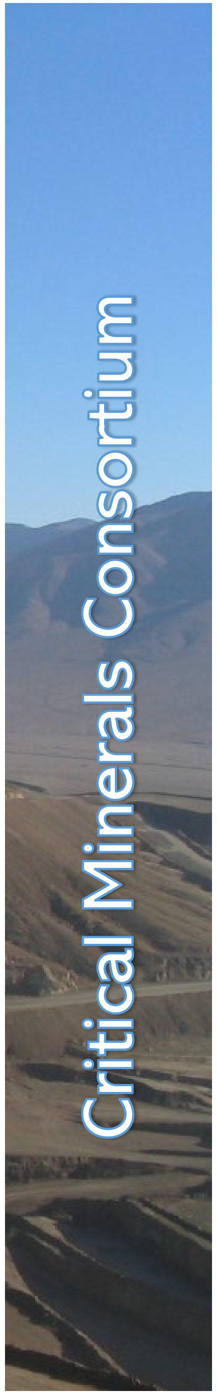
Clean Energy Metals: Production Vs Processing



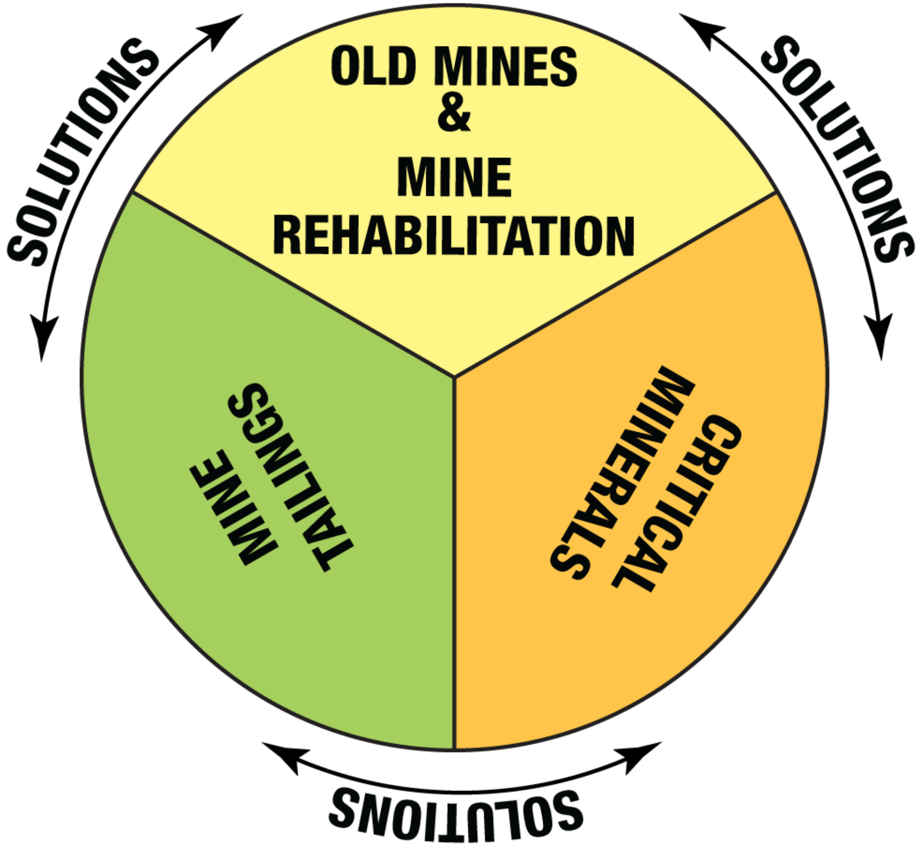
Data Source: IEA (2021), The Role of Critical Minerals in Clean Energy Transitions





Recovering CRMs from Legacy Mines and Tailings

How we take advantage of growing opportunities while fulfilling rehabilitation obligations?



minerals

MDPI

Article

A Geospatial Database for Effective Mine Rehabilitation in Australia

Tim T. Werner [1], Peter M. Bach [2,3,4], Mohan Yellishetty [4,*], Fatemeh Amirpoorsaeed [4,5], Stuart Walsh [4], Alec Miller [4], Matthew Roach [4], Andrew Schnapp [4], Philippa Solly [4], Youming Tan [4], Chloe Lewis [4], Ehren Hudson [4], Kim Heberling [4], Thomas Richards [4], Han Chung Chia [4], Melissa Truong [4], Tushar Gupta [6] and Xiaoling Wu [4]

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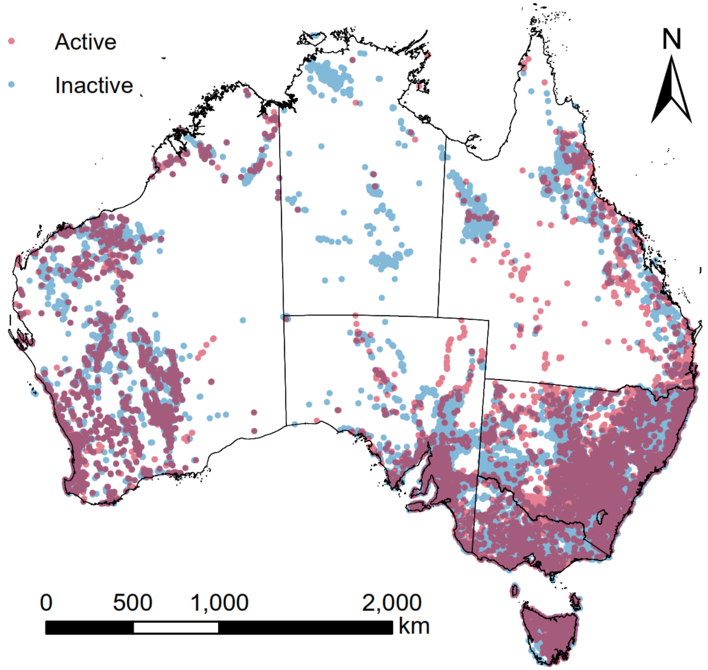
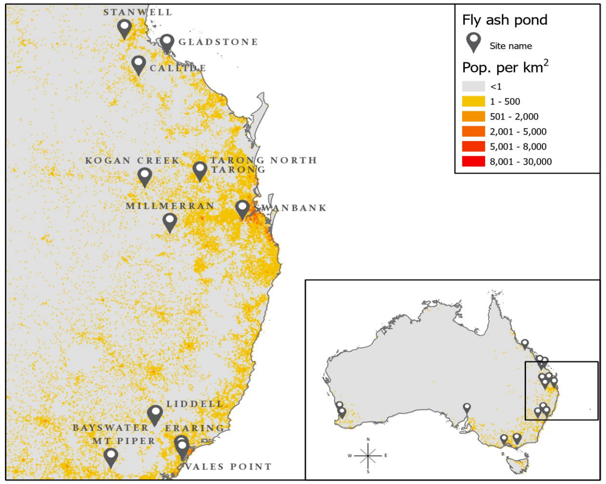
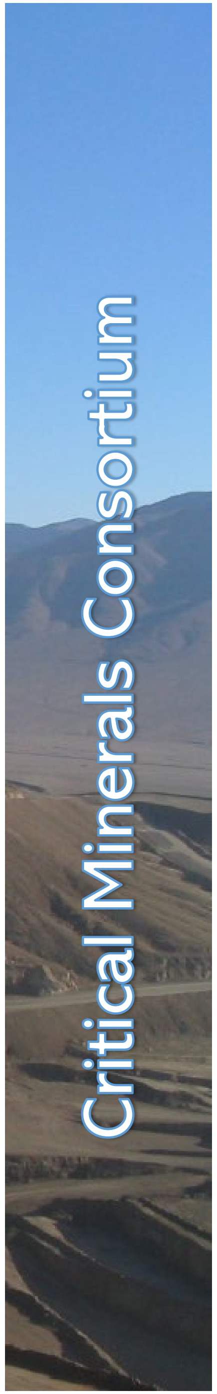
2 Swiss Federal Institute of Aquatic Science & Technology (Eawag), 8600 ZH Dübendorf, Switzerland; peter.bach@monash.edu

3 Institute of Environmental Engineering, ETH Zürich, 8093 Zürich, Switzerland



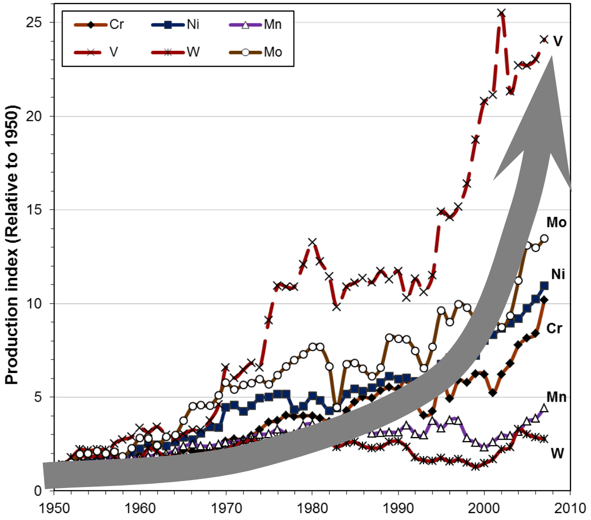




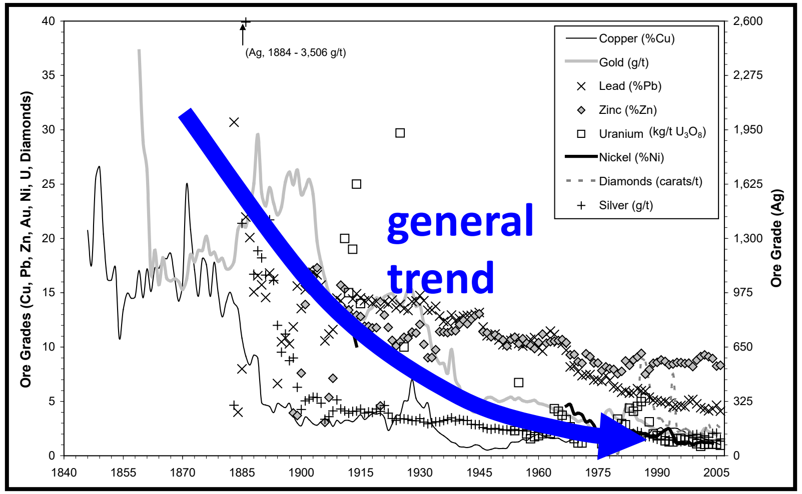
Mineral Industry – Transitions

Metals	Crustal Concentration	Ore deposit	Enrichment Factor
Aluminium	8%	30%	x 4
Iron	5.8%	60%	x 10
Copper	55 ppm	1%	x 180
Nickel	72 ppm	1%	x 140
Zinc	82 ppm	1%	x 121
Uranium	1.6 ppm	3.4%	x 21250
Lead	10 ppm	1%	x 1000
Platinum	5 ppb	5 g/t	x 1000
Gold	4 ppb	5 g/t	x 1250

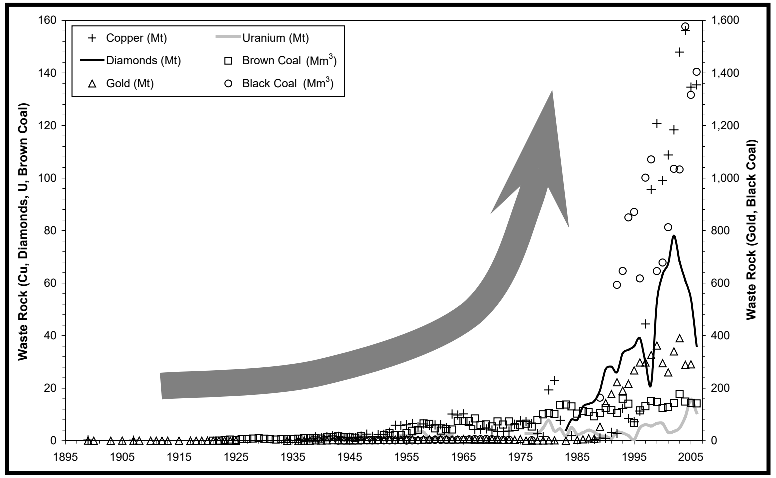
	Grade	Minerology	Depth	Cost	Wastes	Efficiency
	High	Simple	Shallow	Low	Low	Low
	Low	Complex	Deep Deposits	High	High	High



Production Trends (Mudd, Var)



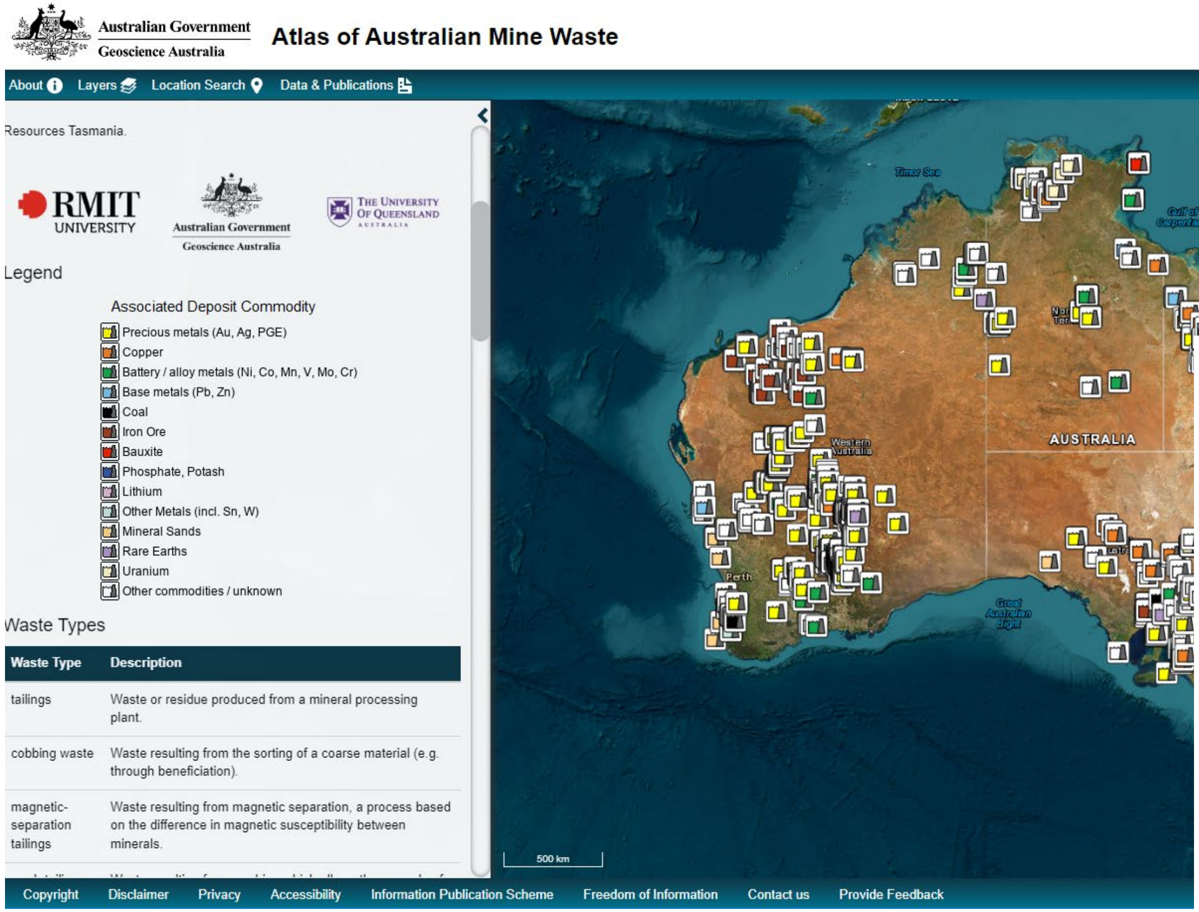
Declining Ore Grades



Waste Rock Generation

Atlas of Australian Mine Waste – secondary perspectivity

Critical Minerals Consortium



https://portal.ga.gov.au/persona/minewaste

NEW WAYS TO PRODUCE CRITICAL MINERALS

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ABSTRACT

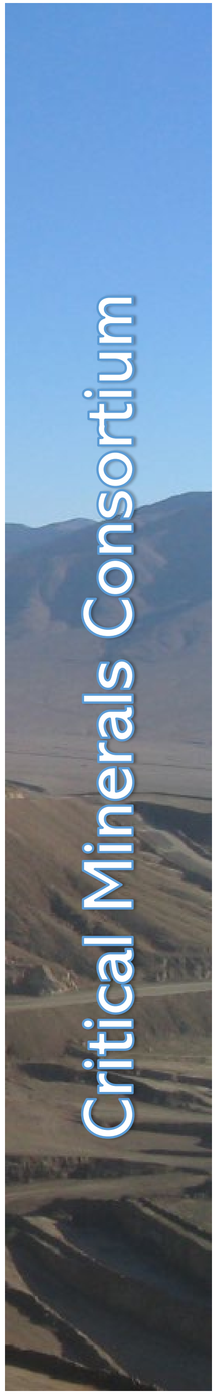
Ongoing geopolitical challenges and the acceleration of the world energy transition makes the supply and production of critical minerals ever more urgent. Given the critical role of copper we would add this to the more than 70 minerals identified as “critical”.

The paper reviews some of the recent advances in leaching which are applicable to many of the common critical minerals. We build on this to propose a novel method of sustainable mining and production that could obviate the classic downsides of conventional mining and mineral processing, viz the production of large quantities of solid waste. Copper alone currently produces over 2000 M t/y of tailings.

Our proposal is to target in-situ leaching with the novelty being a new way to break rock in place not using commonly used water fracking. One of the authors has developed and patented a “Slow Releasing Material Agent (SREMA) that could be injected from boreholes to target zones to break the rock to the required size. This has been tested in the laboratory at temperatures and pressures equivalent to those found deep underground.

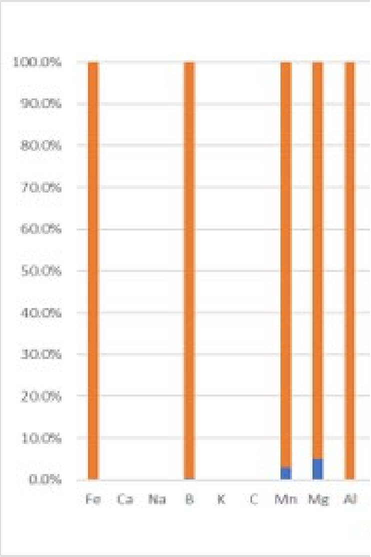
The approach may also be applicable to heap leaching and the recovery of critical minerals from waste piles and tailings storage facilities.

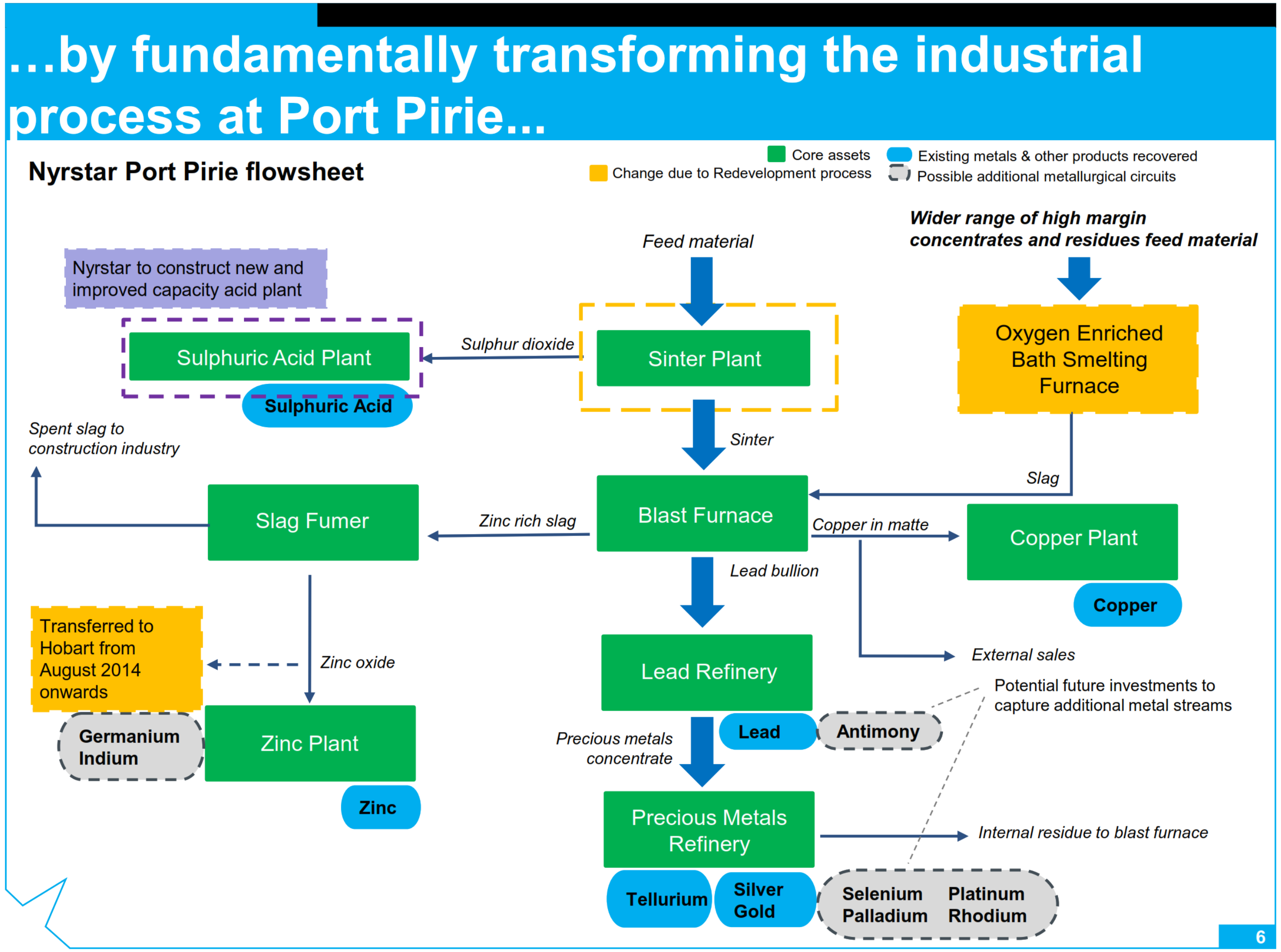
Key words: critical minerals, in situ leaching, in situ rock breakage

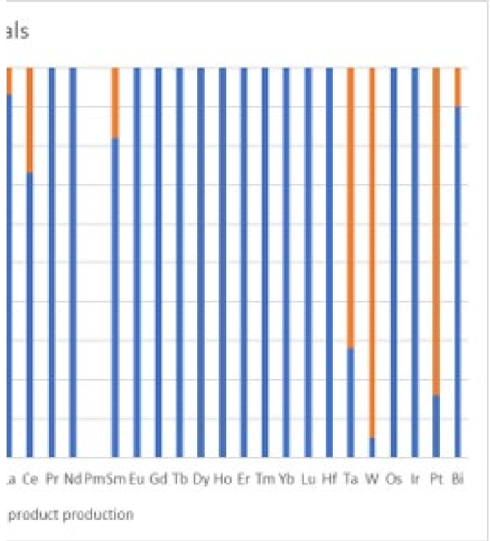


Coproduction

The production of many critical minerals is dominated by co-production. This sets up what is known as “cross-elasticity of supply”, making markets less efficient.

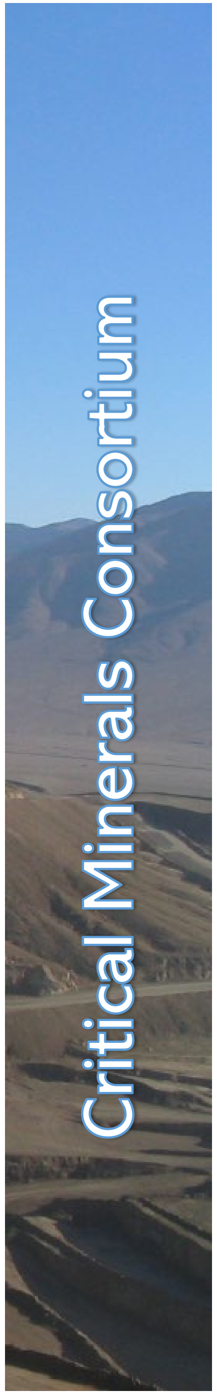






Nyrstar, 2014

16 MAY 2014



Substitution & Recycling

‘Ideal’ markets need short-term substitutability. This is difficult.
In the long term – substitutability can be disruptive (but will contribute to efficient markets).

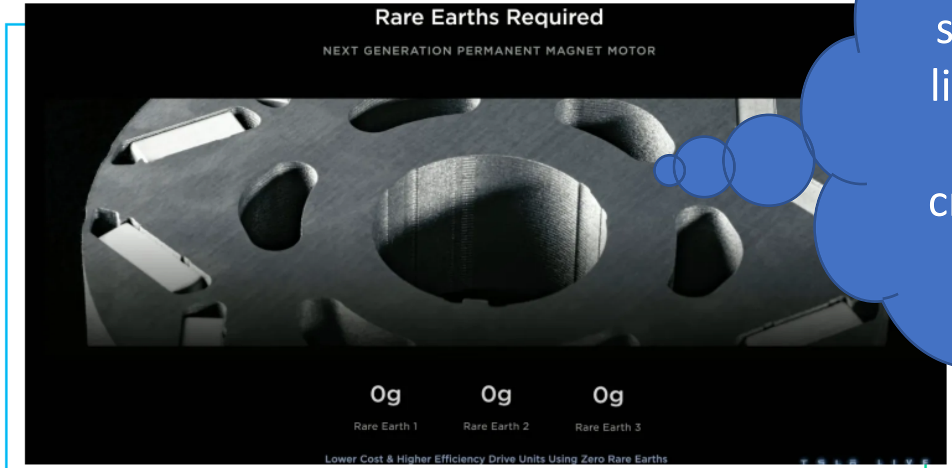
Hina Battery Becomes 1st Battery Maker to Put Sodium-ion Batteries in Evs in China

February 23, 2023 · Add comment · 5 min read

Source: [Hina Battery Becomes 1st Battery Maker to Put Sodium-ion Batteries in Evs in China - Batteries News]

Tesla is going (back) to EV motors with no rare earth elements

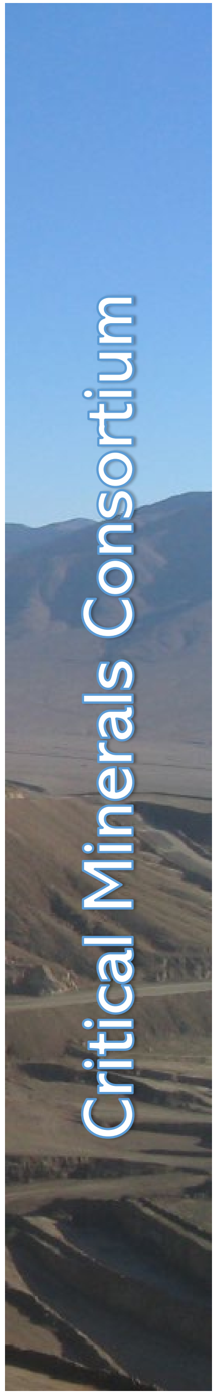
Jameson Dow | Mar 1 2023 - 3:23 pm PT | 25 Comments



Tesla will create a permanent magnet electric vehicle motor with zero rare earth elements in it, the company announced at its Investor Day today.

Don’t forget that substitutes will likely come one day to your critical minerals market.

Source: [Tesla is going (back) to EV motors with no rare earth elements (electrek.co)]



What China did well besides building industry capability?

“**The Chinese Society of Rare Earths (CSRE)** founded in 1980:

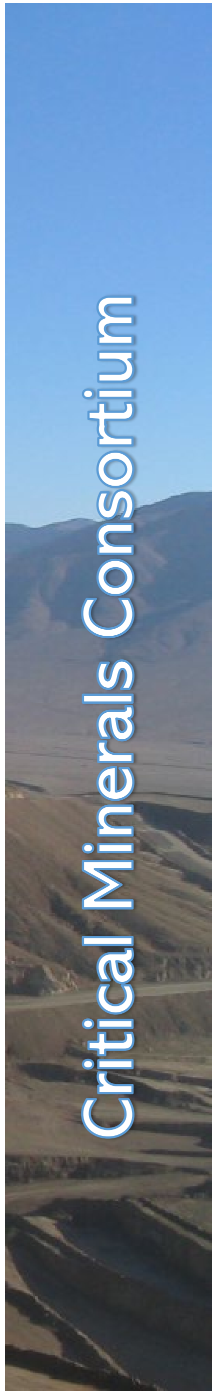
“The CSRE is a **scientific and technological researchers’ organization** There are more than 100,000 registered experts in CSRE, which is the biggest **academic community on rare earth in the world**.

Besides serving for the government and researchers on the science and technology of rare earths, CSRE provide a stage for rare earth scientists to exchange their research ideas, propose scientific and technical plans on fundamental and applied fields on rare earths, as well as rare earth R&D plans for the industry. CSRE is, therefore, the most important social force in developing the rare earth science and technology in China. It organizes the International Conference on Rare Earth Development and Application once every four years, and Annual Meeting once every two years periodically. There are 15 subcommittees in CSRE, which cover almost every R&D field on rare earth.”

Source: http://metalpedia.asianmetal.com/metal/rare_earth/organization.shtml

“When you think that **between 2015 and 2019**, China filed more than **11,000 patents in critical minerals extraction and processing**, five times more than the second largest filer, 10 times more than Australia” - The Hon Dr Jim Chalmers MP

https://ministers.treasury.gov.au/ministers/jim-chalmers-2022/speeches/address-australian-critical-minerals-summit-sydney



Critical Minerals International Alliance (CMIA)

Govt dept members – Aus, India, US, Japan, UK, Korea – Fund and Appoint

Board members industry and research reps – Aus, India, US, Japan, UK, Korea

CEO and management team

Exploration and technology
priority minerals and the projects that will support their production

Markets andinvestment
supply/demand ratios and pricing supply guarantee and offtake agreements and joint partnerships

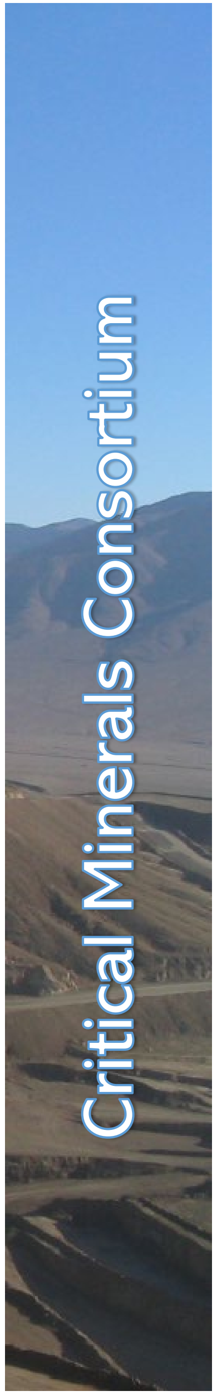
Government and regulation
royalties, intellectual property (IP), foreign investment and tariffs review and reform

Advisory members
Business Advisors, Research Institutes and Government Departments

Member organisations
Australia India Chamber of Commerce; American Chamber of Commerce in Australia; Australia Japan Business Cooperation Committee; Confederation of India Industry; Minerals Council of Australia, and Australasian Institute of Mining and Metallurgy

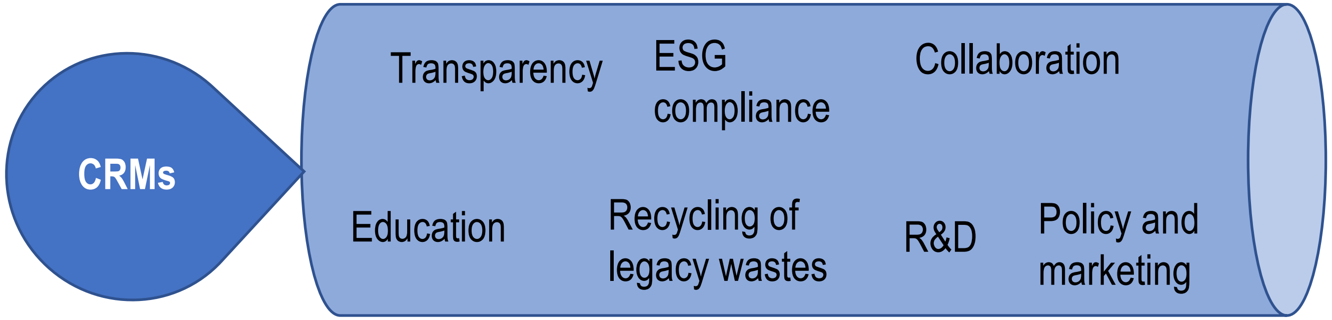
Beneficiaries:

- Critical Mining and Rare Earth mining companies
- Other Mining companies yet to mine critical minerals in Australia and India
- Advanced manufacturing companies
- Scientists and Research bodies in mining including universities and government funded departments, eg. Monash, Geoscience Australia, CSIRO and counterparts in India and Japan
- Technology and automation developers for mining and manufacturing
- Mining industry bodies in regions eg.Ministry of Mines in India,
- Member bodies eg. International Chambers
- Consultants and advisors in setting up partnerships, project and funding access advice, IP sharing etc



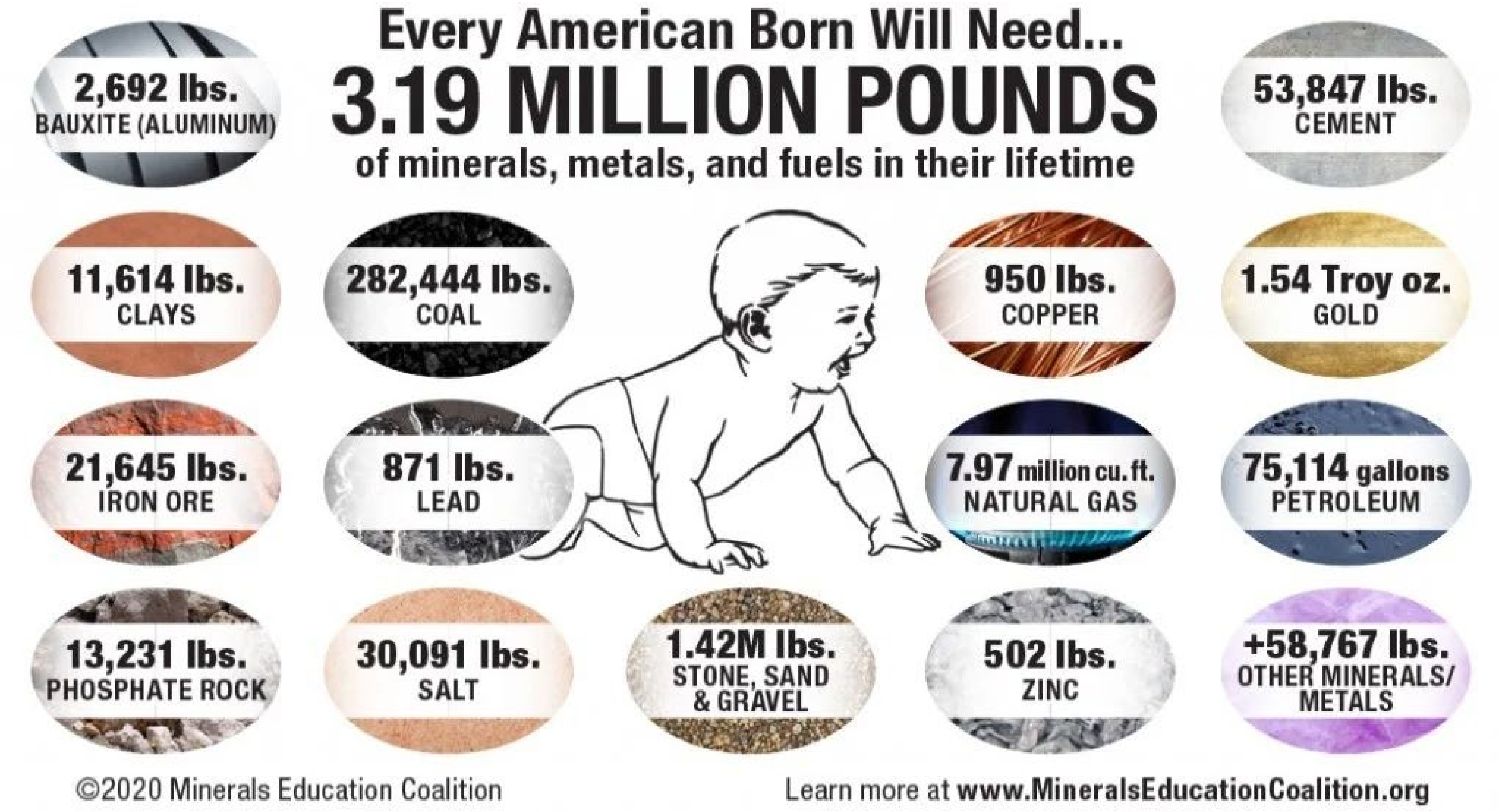
Summary & Recommendations

- Dynamic criticality assessment of minerals for Australia and its trading partners and be open to work with partners
- Sovereign interference remains a significant risk.
- Implementation of collaborative framework, both national and international for evaluation and recoveries of CRMs from legacy waste streams.
- Incentivize smelters and refineries to recover CMs that are needed for energy transition and catch before they end up in tailings dam
- Training and upskilling of workforce to promote large-scale operation to high ESG standards.
- Targeted support from governments and stakeholders for a CMIA, including research and development, IP libraries, and technology transfer and planning.

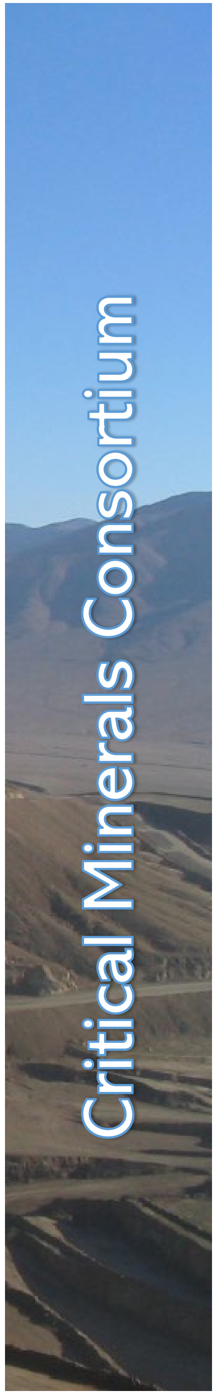


***'Ancora Imparo'* = 'I am still learning'**

Thank YOU!



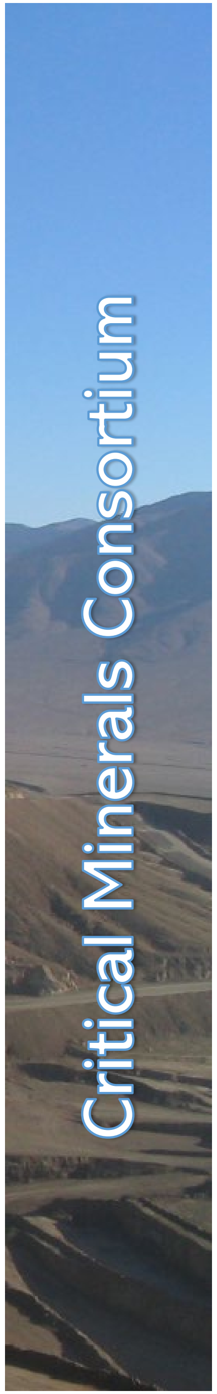
MONASH University



Some Good News

Furthermore, in the October 2022-2023 budget, the government announced it will invest in research and development, build our mid/downstream processing capabilities and diversify Australia's existing critical minerals supply chains through:

- up to $1 billion under the National Reconstruction Fund for a Value-Adding in Resources Fund
- $50.5 million for the Australian Critical Minerals Research and Development Hub to build valuable intellectual property in critical minerals processing
- $50 million for the Strategic Critical Minerals Development Program (CMDP) to assist critical minerals' producers progress strategically significant projects. The CMDP will provide competitive grants over three years to support early and mid-stage critical minerals projects. The program builds on the A$49.7 million already committed to six projects under the CMDP in mid-2022



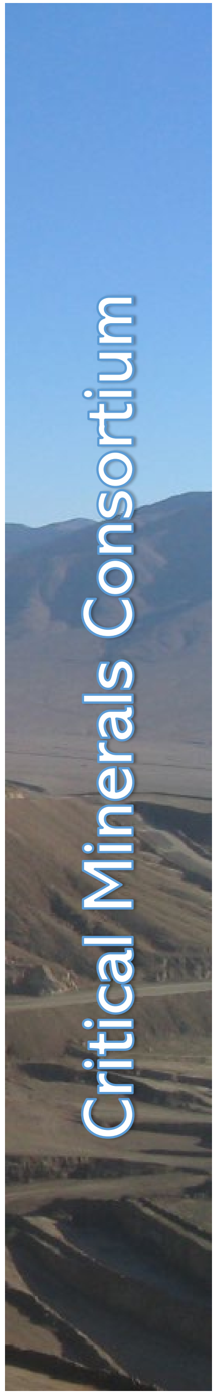
Market size

Most critical minerals markets are relatively small

Mineral commodity	Australian critical minerals prospectus	EU critical	US critical	Estimated market size ($bn)	Notes
Iron ore				296	Useable ore
Coal (export)		2017[1]		238	Global coal export value
Aluminium		2020[2]	2018[2]	228	Smelted aluminium
Copper				199	Copper metal
Gold				179	Gold metal
Nickel			2021	83	Nickel metal
Potassium Oxide			2018[3]	68	KO2 equivalent
Lithium	Y	2011	2008	22	Lithium carbonate
PGMs	Y	2011	2008	20	Platinum and palladium only
Phosphorus		2017		20	Marketable phosphate rock
Manganese	Y	2023	2008	18	Manganese metal
Magnesium	Y	2011	2018	17	Magnesium metal
Chromium	Y	2014	2018	14	Chromite ore
Cobalt	Y	2011	2008	13	Cobalt cathode
Rare earth elements	Y	2011	2008	3	REE revenue
Antimony	Y	2011	2015	2	Antimony metal
Niobium	Y	2011	2008	<2	Niobium metal
Tantalum	Y	2011	2008	<0.3	Tantalum
Graphite	Y	2011	2011	0.2	Graphite
Hafnium	Y	2017	2011	<0.2	78 tonnes

Global market size for ‘prospectus’ minerals is ~$110bn

1. Coking coal
2. Bauxite/Aluminium
3. Not included in subsequent years



Barriers to Entry ☒

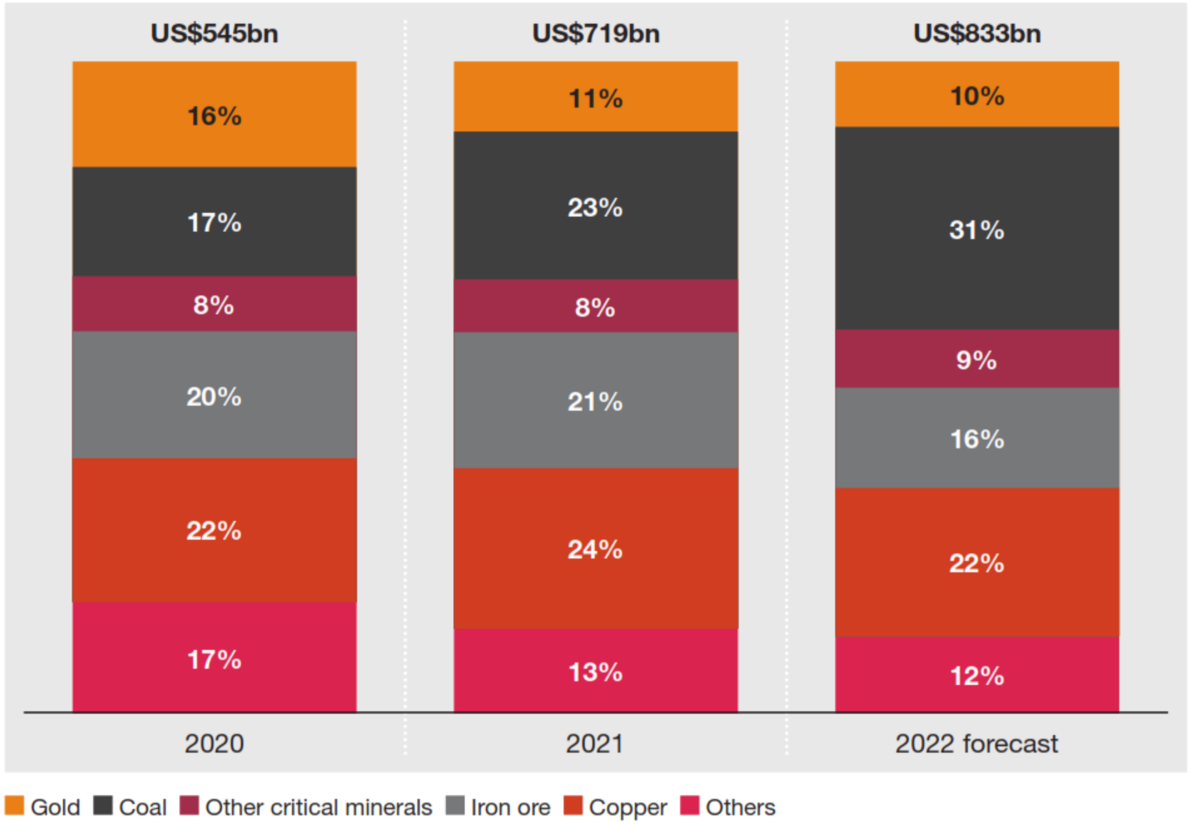
Major mining companies remain focused on other markets

Major mining companies remain focused on the much larger and mature markets for coal, iron ore, copper and gold.

This implies critical minerals industries will need to be able to thrive with small and mid-sized companies on the supply side.

Lack of price discovery complicates financing.

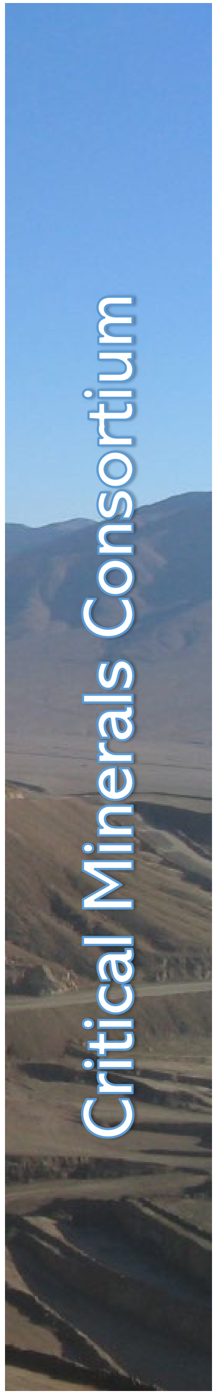
Top 40 revenue-based commodity mix



Note: *Other critical minerals* of 9% includes nickel, aluminium, palladium, platinum, lithium and cobalt. *Others* of 12% includes a variety of commodities, such as diamonds, rhodium, potash and zinc.

Source: Company annual reports, PwC analysis

Source: PWC (2022). Mine 2022

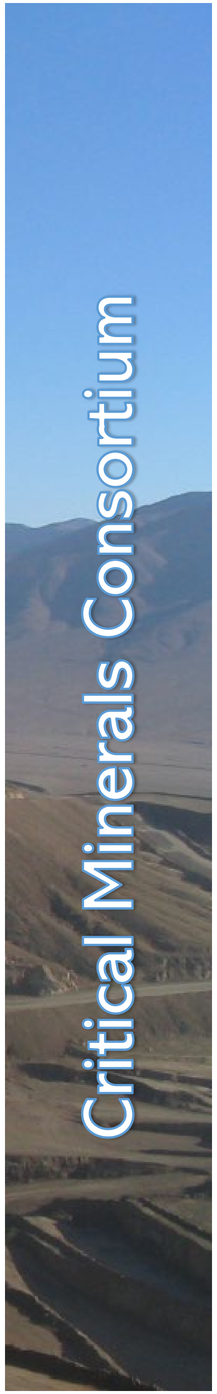


Complexities in supply chains - neodymium

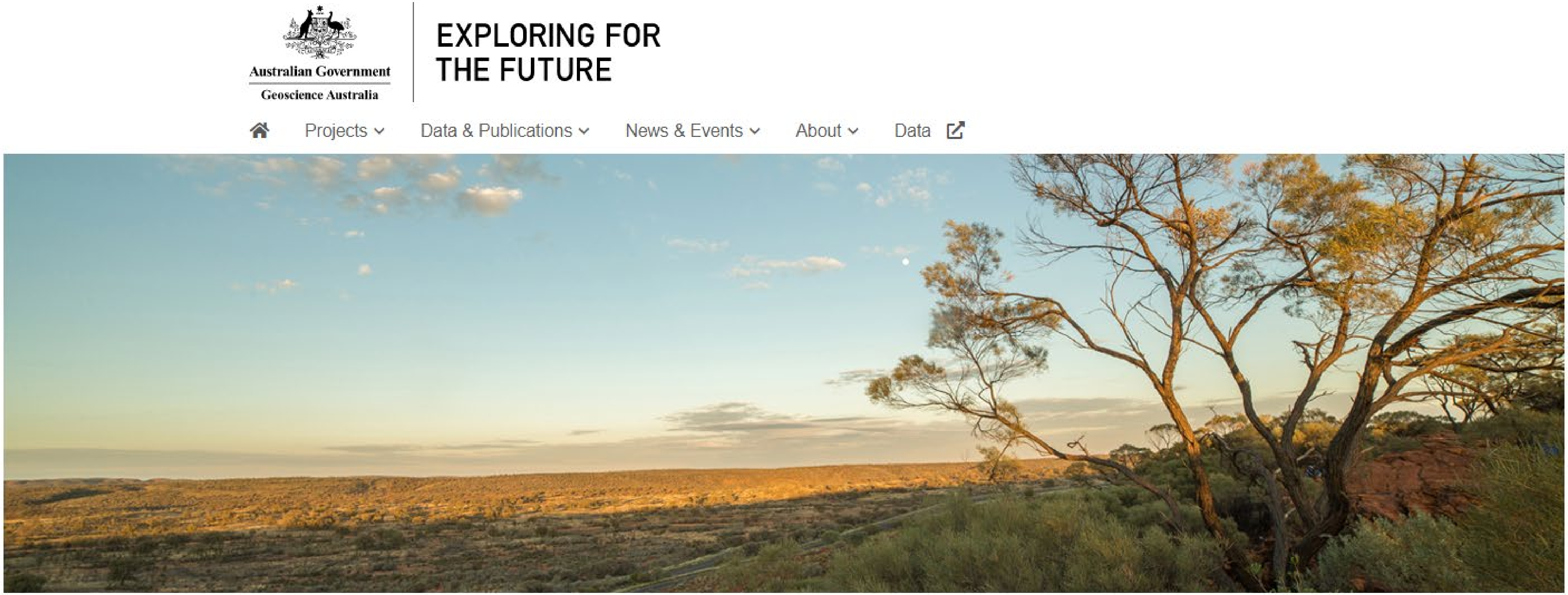
Country	Mining	Mixed chemical compounds	Separation to REO		Oxide to metal	Magnet alloys	NeFeB sintered magnets
			LREE	HREE			
Australia	✓	Pilot					
Myanmar	✓	✓					
Burundi	✓						
China	✓	✓	✓	✓	✓	✓	✓
Estonia			✓				
Germany							✓
France			✓	✓			
Malaysia		✓	✓				
Russia	✓	✓	✓				
India	✓	✓	✓				
Japan				✓	✓	✓	✓
Kazakhstan			Idle				
United States	✓	**	**	**	Idle	Idle	**
United Kingdom					✓	✓	
Vietnam					✓	✓	✓
Other	✓	✓	✓		✓	✓	✓

What is 'critical' here? Referring to critical minerals by elemental names can be misleading

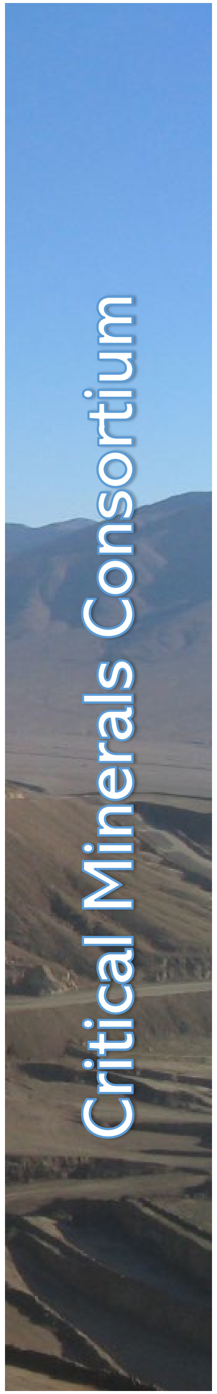
Global locations for NeFeB magnets supply chain tiers (The White House 2021).



Exploring for the Future program



https://www.ga.gov.au/eftf



Critical Cooperation: How Australia, Canada and the United States are Working Together to Support Critical Mineral Discovery

https://www.usgs.gov/news/critical-cooperation-how-australia-canada-and-united-states-are-working-together-support

Use of Energy Transition Minerals

	NMC811 Nickel (80%) Manganese (10%) Cobalt (10%)	NMC523 Nickel (50%) Manganese (20%) Cobalt (30%)	NMC622 Nickel (60%) Manganese (20%) Cobalt (20%)	NCA+ Nickel Cobalt Aluminum Oxide	LFP Lithium iron phosphate
LITHIUM	5KG	7KG	6KG	6KG	6KG
COBALT	5KG	11KG	11KG	2KG	0KG
NICKEL	39KG	28KG	32KG	43KG	0KG
MANGANESE	5KG	16KG	10KG	0KG	0KG
GRAPHITE	45KG	53KG	50KG	44KG	66KG
ALUMINUM	30KG	35KG	33KG	30KG	44KG
COPPER	20KG	20KG	19KG	17KG	26KG
STEEL	20KG	20KG	19KG	17KG	26KG
IRON	0KG	0KG	0KG	0KG	41KG

ELEMENTS

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