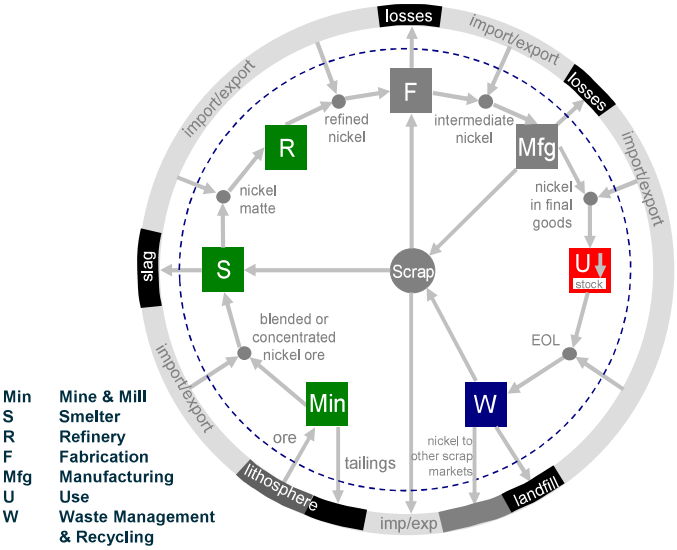
Dr. Gavin M. Mudd

The Critical Minerals Space

UK Critical Minerals Intelligence Centre

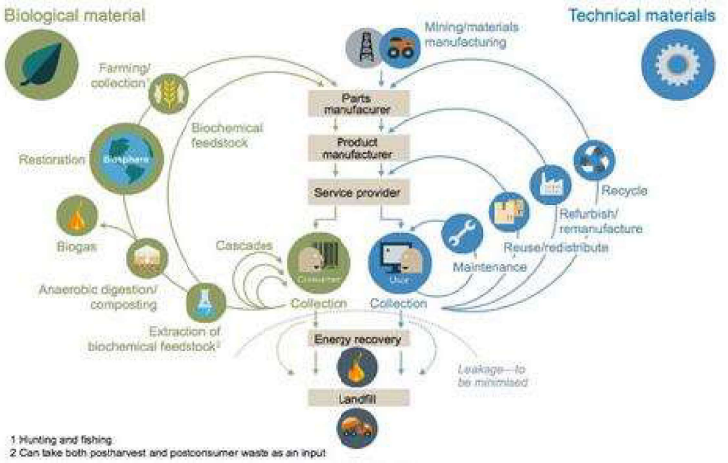
British Geological Survey

The Intellectual Foundation of Critical Minerals: Industrial Ecology, aka the Circular Economy



Min	Mine & Mill
S	Smelter
R	Refinery
F	Fabrication
Mfg	Manufacturing
U	Use
W	Waste Management & Recycling
EOL	End-of-Life flows

© Yale University

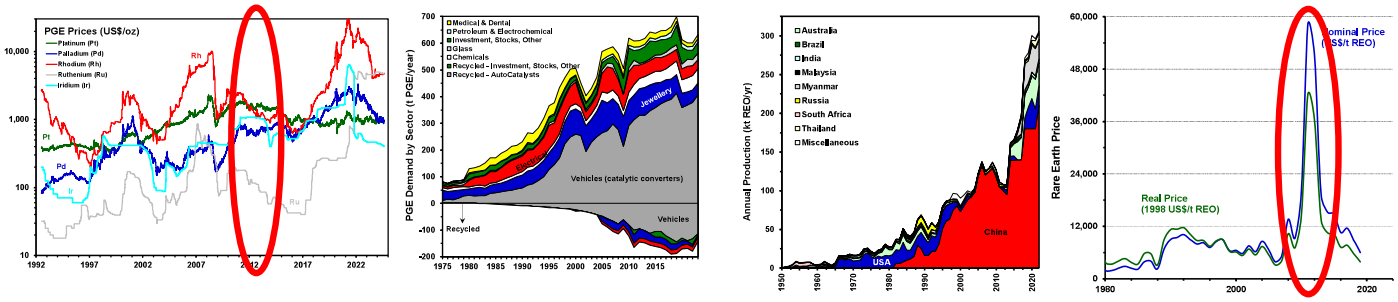


© Ellen Macarthur Foundation

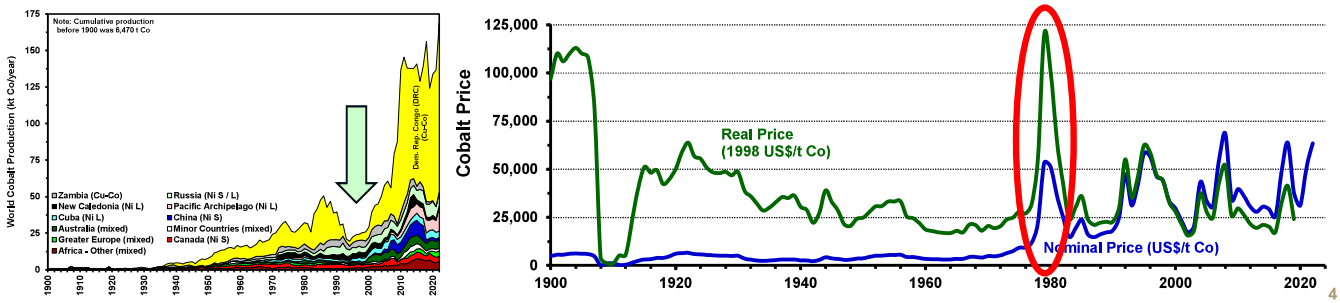
Critical Minerals: Key Issues

- Supply reliability of critical minerals is one of the fundamental parts of determining criticality and links to key societal goals (climate, energy, …)
- Various examples exist historically which demonstrate supply issues such as black swan events (e.g., civil unrest) to export controls or bans
- Responses can vary but none are easy:
  - substitution (e.g., Co) – takes time, but not always possible / preferable
  - change trading partners / sources – not easy in case of dominant supplier
  - support development of alternative supplies – takes time, possible but not easy
  - stockpiling – tried and true method, conceptually easy, quick but limited scale(?)
  - legislate to 'redirect' market, fund incentives (e.g., EU Critical Raw Materials Act, US Inflation Reduction Act) – can be transformative, but takes time
  - trade tariffs & market interventions – difficult to target but can help
- Overall, many examples and responses but always a long, winding road!

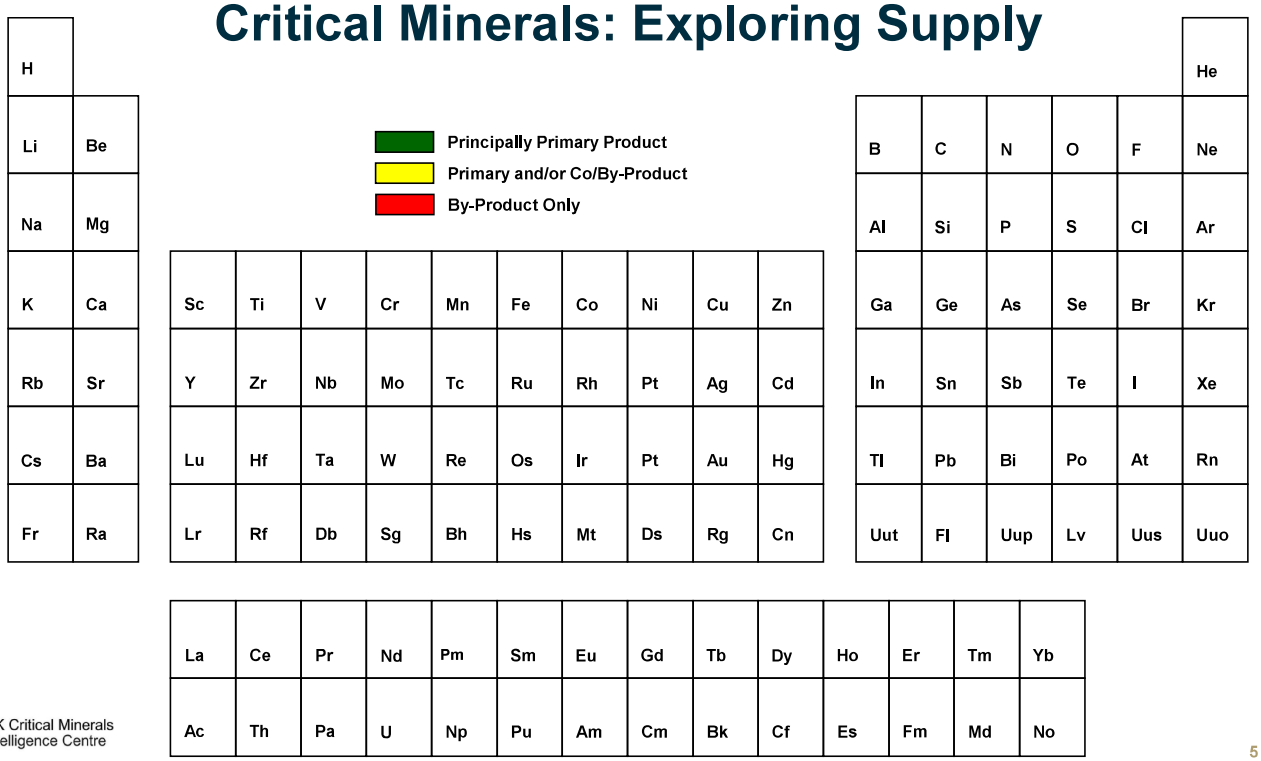
Critical Minerals: Examples of Risks



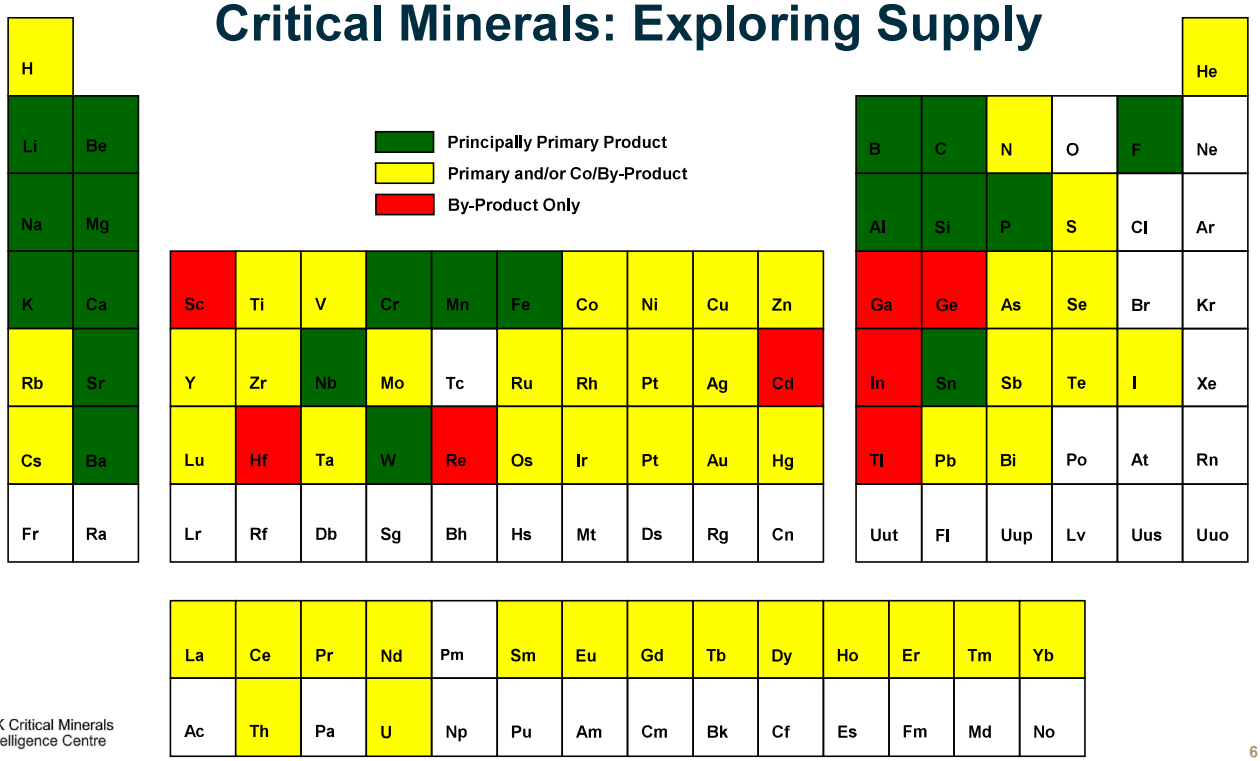
all BGS, USGS, Mudd synthesized data



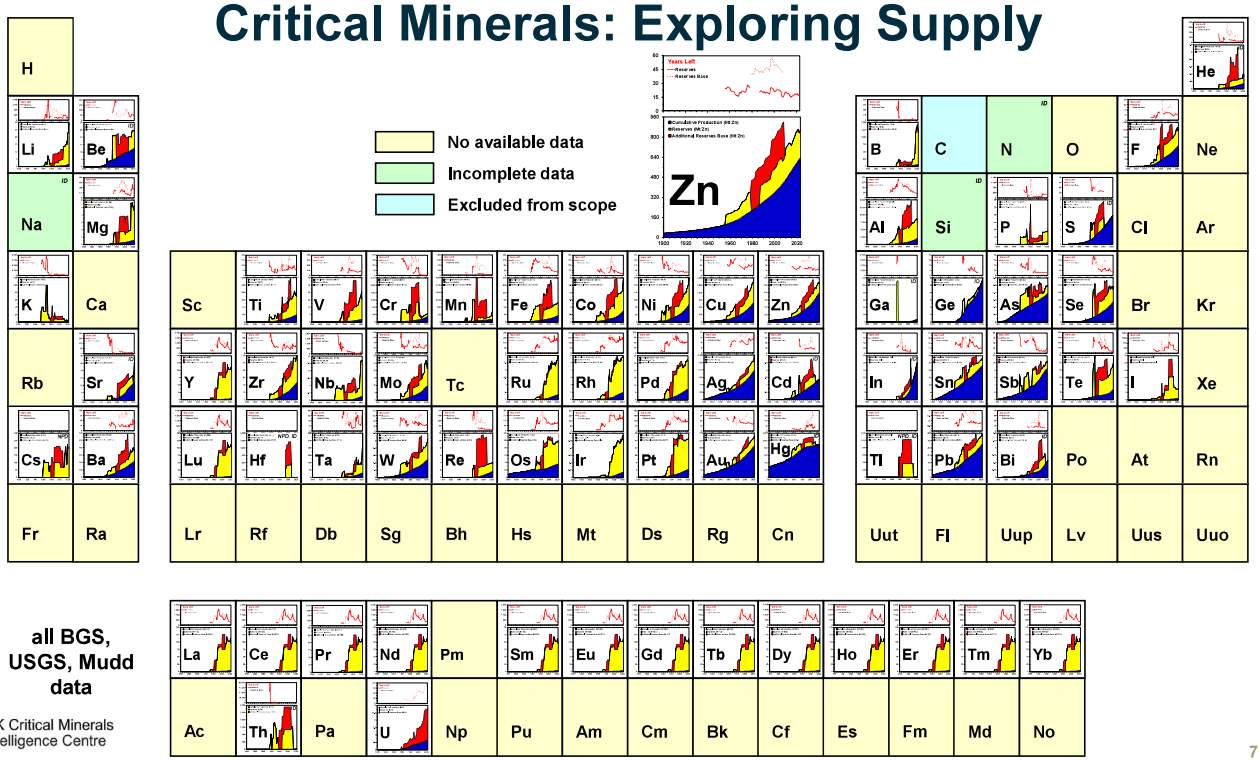
Critical Minerals: Exploring Supply



Critical Minerals: Exploring Supply

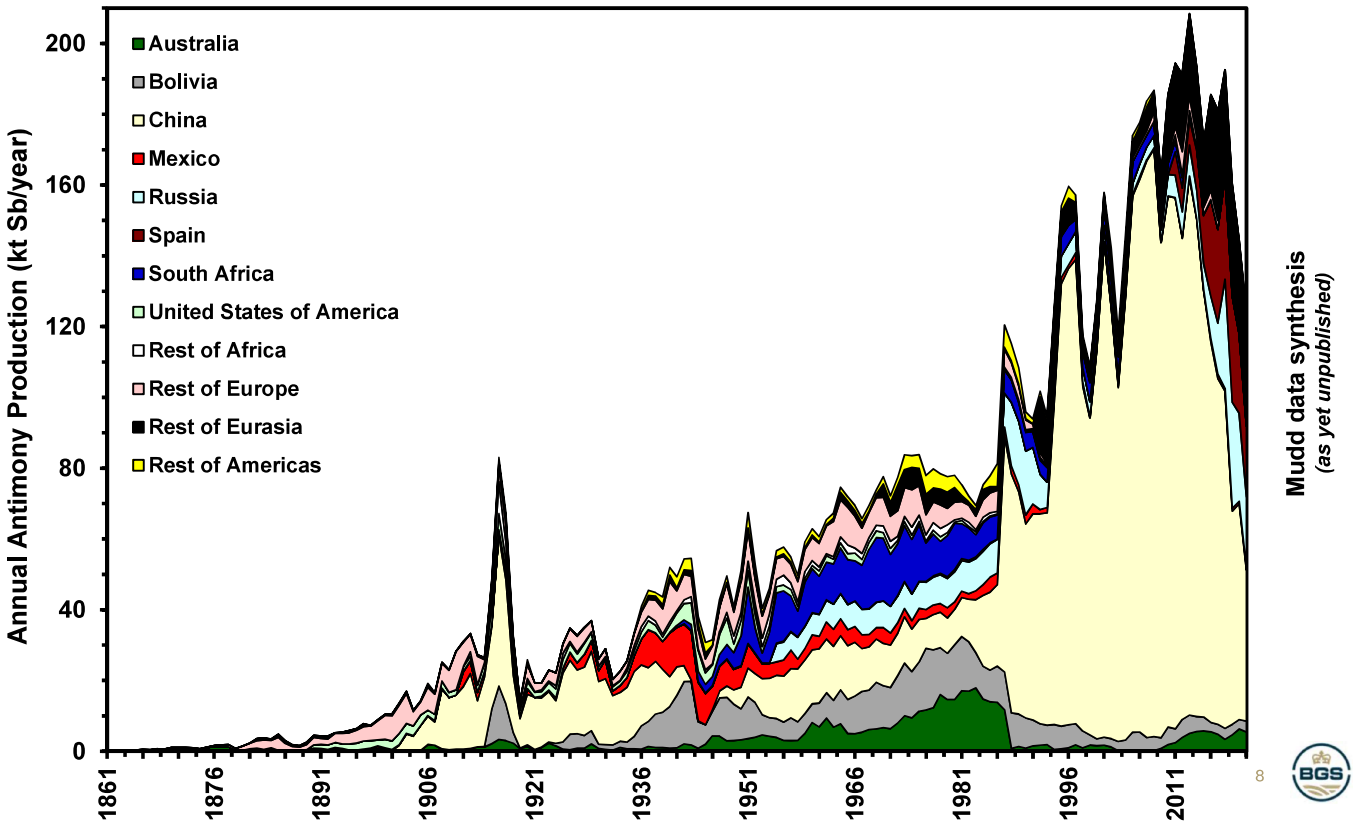


Critical Minerals: Exploring Supply



all BGS, USGS, Mudd data

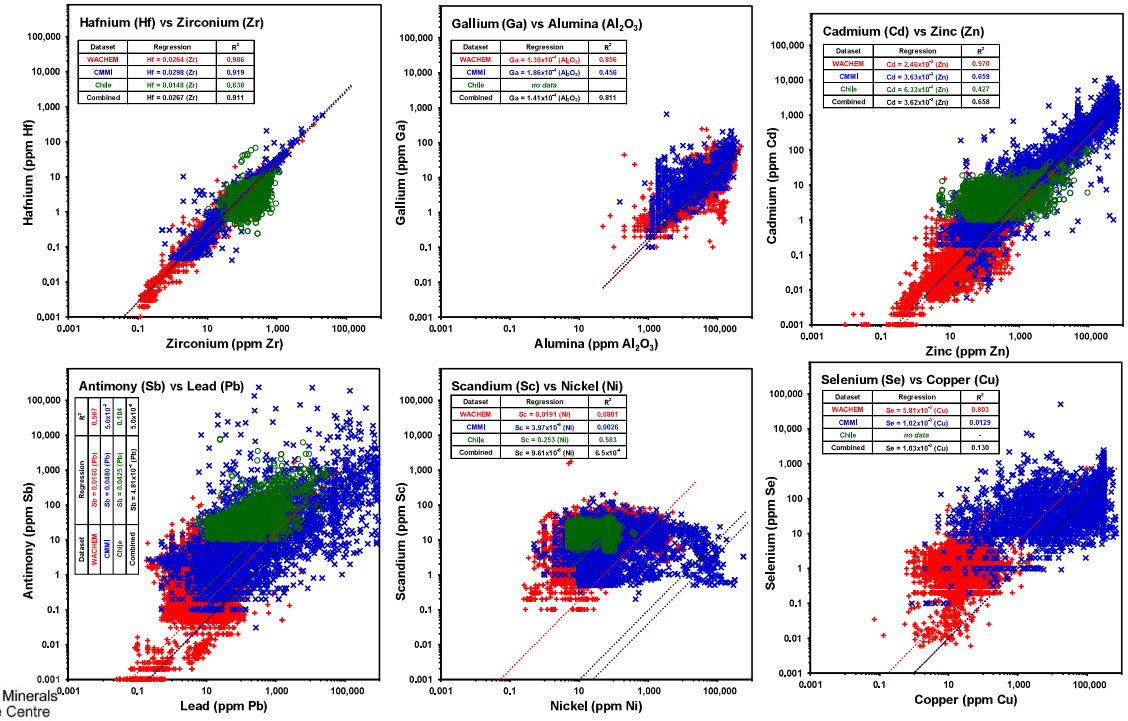
UK Critical Minerals Intelligence Centre



UK Critical Minerals Intelligence Centre

Critical Minerals: A Way Forward?

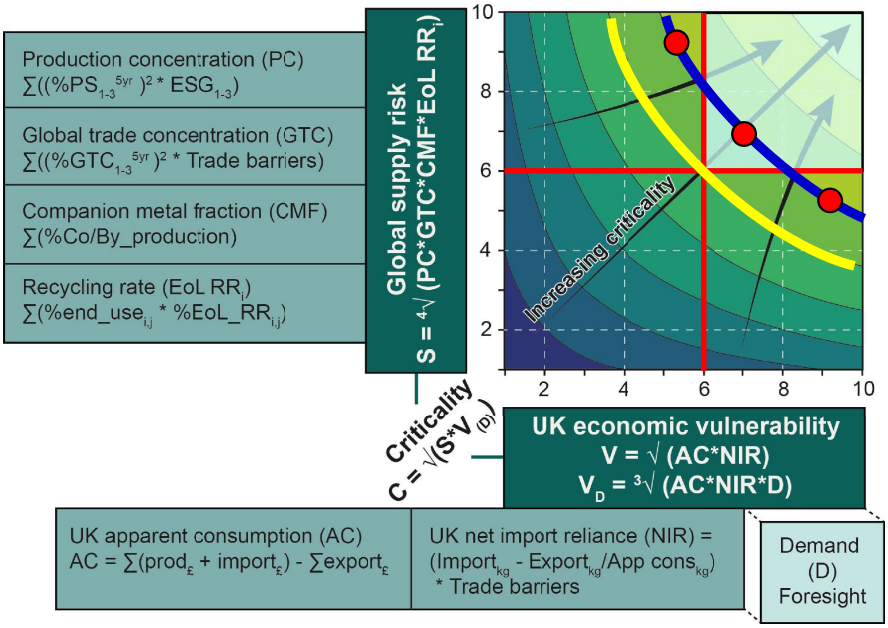
Can we use a commonly reported element to approximate a CM?



Mudd et al, 2024 (just accepted!)

UK Mineral Prospectivity

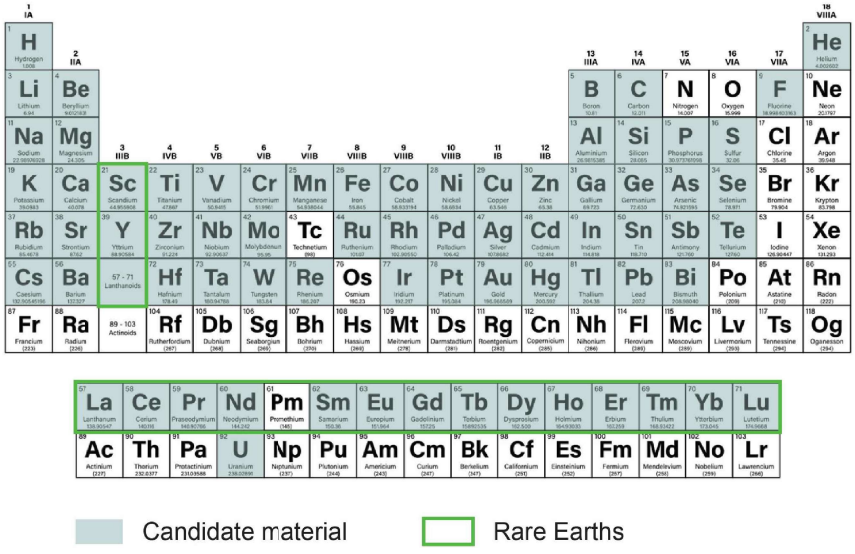
The Revised UK Criticality Assessment Methodology



The Revised UK Criticality Assessment: Candidate Materials

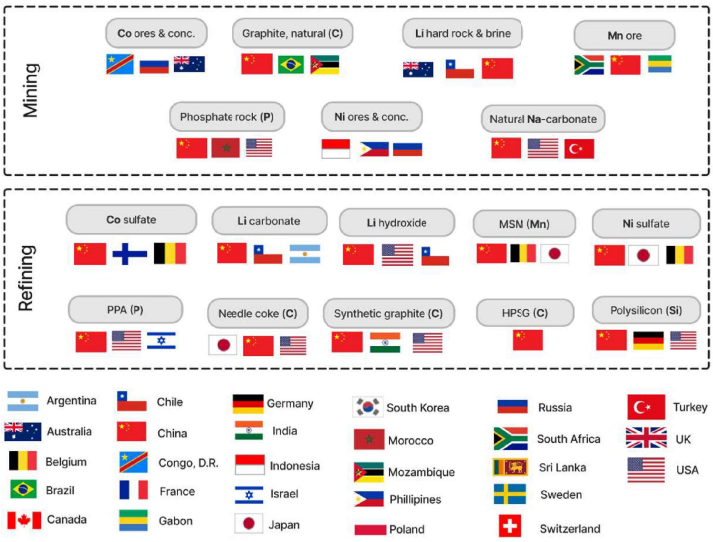
- 56 individual elements
- Rare Earths (n = 17)
- 25 industrial minerals

Barytes	Kaolin clay	Pyrophyllite
Bentonite	Kyanite	Rock salt (NaCl)
Borates	Limestone	Silica sand
Diamonds	Magnesite	Talc
Diatomite	Natural graphite	Vermiculite
Feldspar	Perlite	Wollastonite
Fluorspar	Phosphate rock	Zeolite
Garnet	Pumice	
Gypsum	Pyrites	



CA Supply: Production Concentration (Mined/Refined)

- Many CRMs are 'critical' due to their supply concentration
  - *often China but not always*
  - *supply disruption risks vary enormously across different countries / regions*
- Need to consider mining / smelter / refinery stages
  - *but how far downstream do you go?*
- Based primarily on data from BGS World Mineral Statistics, plus others as needed
- Use past 5-year averages and fraction of top 3 producers

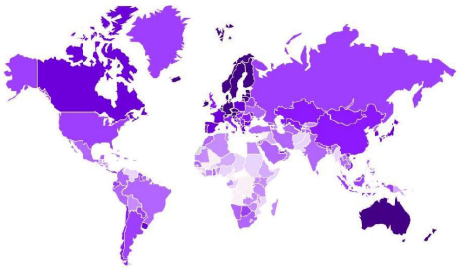


Production concentration (PC)

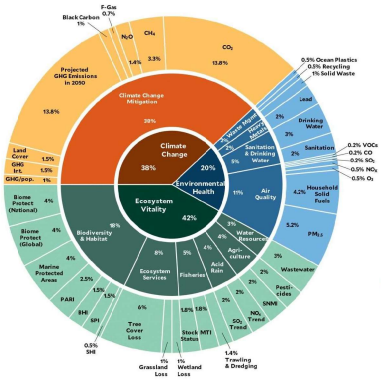
$$\sum((\%PS_{1\text{-}3}{}^{5yr})^2 * ESG_{1\text{-}3})$$

CA Supply: Production Concentration – ESG Ratings

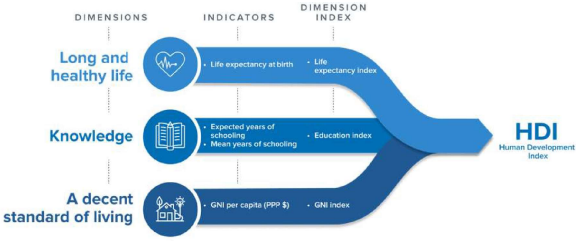
World Governance Index
WGI



Environmental Performance Index
EPI



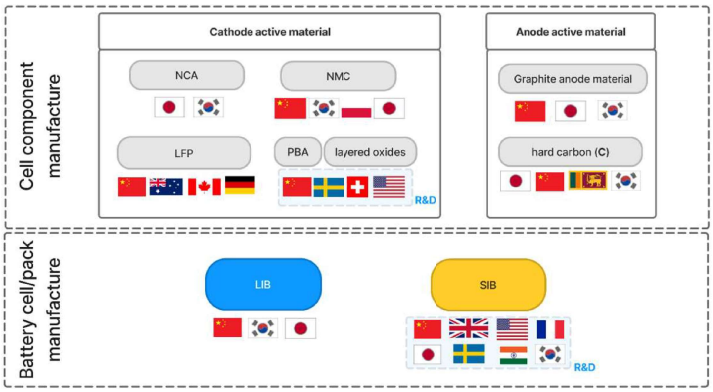
Human Development Index
HDI



$$ESG = \sqrt[3]{(WGI * EPI * HDI)}$$

CA Supply: Global Trade Concentration

- Similar to production concentration, but looks at global trade data instead of mine production
  - *dominance of China, Japan manufacturing and trace very clear in batteries, solar PV, etc …*
- Based primarily on UK Trade and UN CommTrade data, plus others as needed
- Use past 5-year averages and fraction of top 3 traders



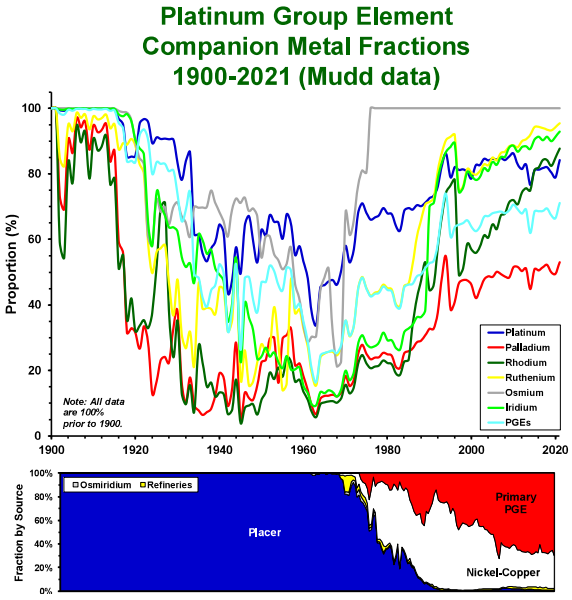
Global trade concentration (GTC)
$\sum((\%GTC_{1\text{-}3}{}^{5yr})^2 * \text{Trade barriers})$

CA Supply: Companion Metal Fraction

- Previous work by Nedal Nassar at Yale Uni (now USGS) in 2015, variable data quality
- Recent work by EU as part of CRMs research

CMIC proposed work to review:

- EU & Nassar (et al) work, extract to spreadsheets
- Use of global mineral resources studies to establish companion metal fractions
- Use country production data to establish companion metal fractions (where possible)



Companion metal fraction (CMF)
$\sum(\%Co/By\_production)$

CA Supply: UK Recycling Rates

- Given the differences between UK midstream & manufacturing, we ideally need UK-specific recycling data and rates
- Recent review by Beta Technology for CMIC / DBT is most recent UK study, e.g.:
  - still a lack of suitable data, in general, to facilitate estimation of recycling metrics
  - DEFRA collect waste electrical & electronic equipment ('WEEE') data by main type & quantity – but no material composition allocated or analysed
  - UK has no secondary copper smelter
  - considerable R&D into battery chemistry & recycling technologies
  - extent of initiatives to develop recycling capabilities varies widely

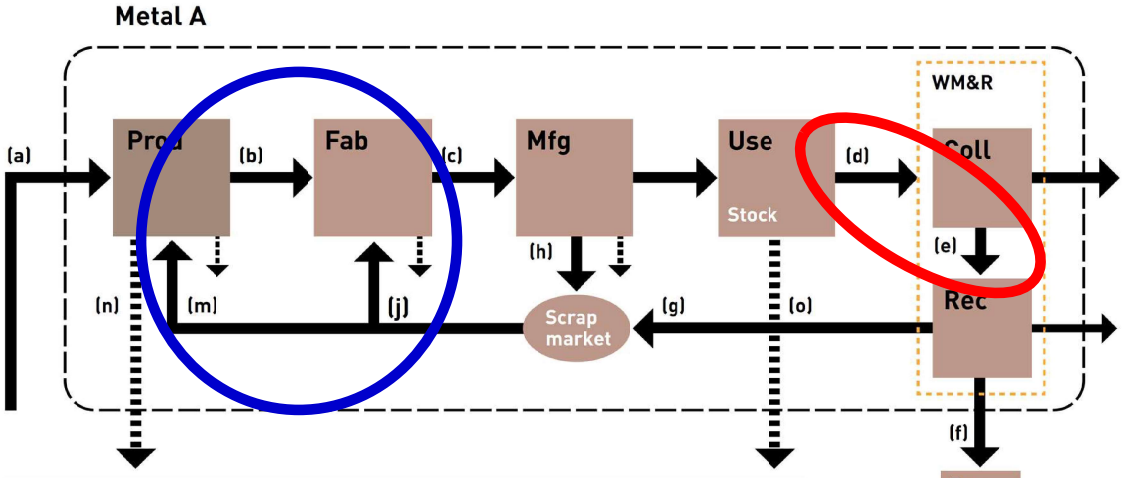
Product Type	UK Data Coverage				Circular Economy Stages		CRM Present
	PoM*	Collection	RiR	EoL CR	Recycle	CRM Reuse	
Batteries	✓	✓	×	×			Antimony
							Cobalt
							Lithium
							Nickel
							Graphite
							Tin
							Silicon
							Graphite
PEM Electrolysers	✓	×	×	×			Iridium
Electric Vehicle Motors	✓	✓	×	×			REE
Solar Panels	✓	✓	×	×			Gallium
							Silicon
							Tellurium
Catalytic Convertors	✓	✓	×	×			Palladium
							Platinum
WEEE							
- LCD Displays	✓	✓	×	×			Indium
- LEDs	✓	✓	×	×			Gallium
- Circuit Boards	✓	✓	×	×			Palladium
	✓	✓	×	×			Tantalum

Circular Economy Status

Product Type	UK Data Coverage				Circular Economy Stages		CRM Present
	PoM*	Collection	RiR	EoL CR	Recycle	CRM Reuse	
	✓	✓	×	×			Silicon
	✓	✓	×	×			Tin
	✓	✓	×	×			Aluminium
- Mobile Phones	✓	✓	×	×			Tantalum
LAS Glass-Ceramics	×	×	×	×			Lithium
Aluminium	✓	✓	×	×			Manganese
Steel	✓	✓	×	×			Niobium
	✓	✓	×	×			Vanadium
Stainless Steel	✓	✓	×	×			Nickel
Aluminium	✓	✓	×	×			Silicon
	✓	✓	×	×			Manganese
Manure	×	×	×	×			Phosphates

Recycle	CRM Reuse
Multiple UK Manufacturers	CRMs Extracted
Limited UK Manufacturers	Waste Reduced To Major Compounds
No UK Manufacturer	No Recycling/Recovery

CA Supply: UK Recycling Rates



a: primary metal input
b: refined metal
c: intermediate products (e.g. alloys, semis)
d: end-of-life (EOL) products (metal content)
e: EOL metal collected for recycling
f: EOL metal separated for non-functional recycling
g: recycled EOL metal (old scrap)
h: scrap from Manufacturing (new scrap)
j: scrap used in Fabrication (new &old)
m: scrap used in Production (new & old)
n: tailings and slag
o: in-use dissipation

Recycling rate (EoL RR_i)
$\sum(\%end\_use_{i,j} * \%EoL\_RR_{i,j})$

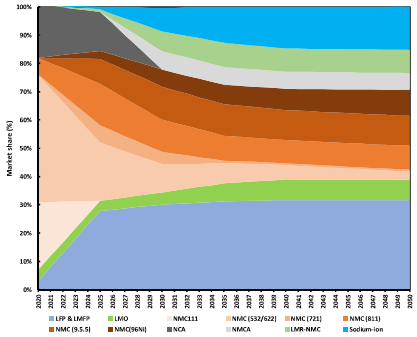
EoL RR: (e) / (d)

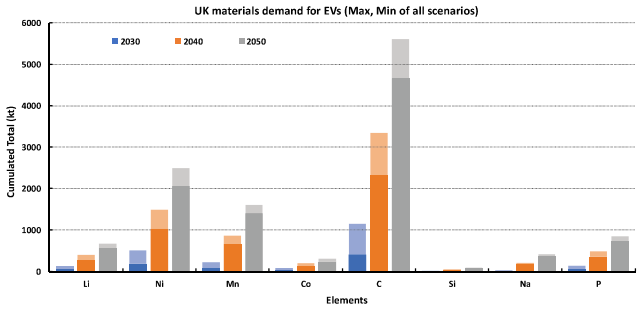
RiR: (m+j) / (b)

CA Demand: Foresight Studies

Confidential until reports released

Demand (D) Foresight





Batteries

Fuel cells & Electrolysers

Wind turbines

Heat pumps

Traction motors

Nuclear technologies

Photovoltaics

National Grid Infrastructures

CA Demand: Apparent Consumption, Net Import Reliance

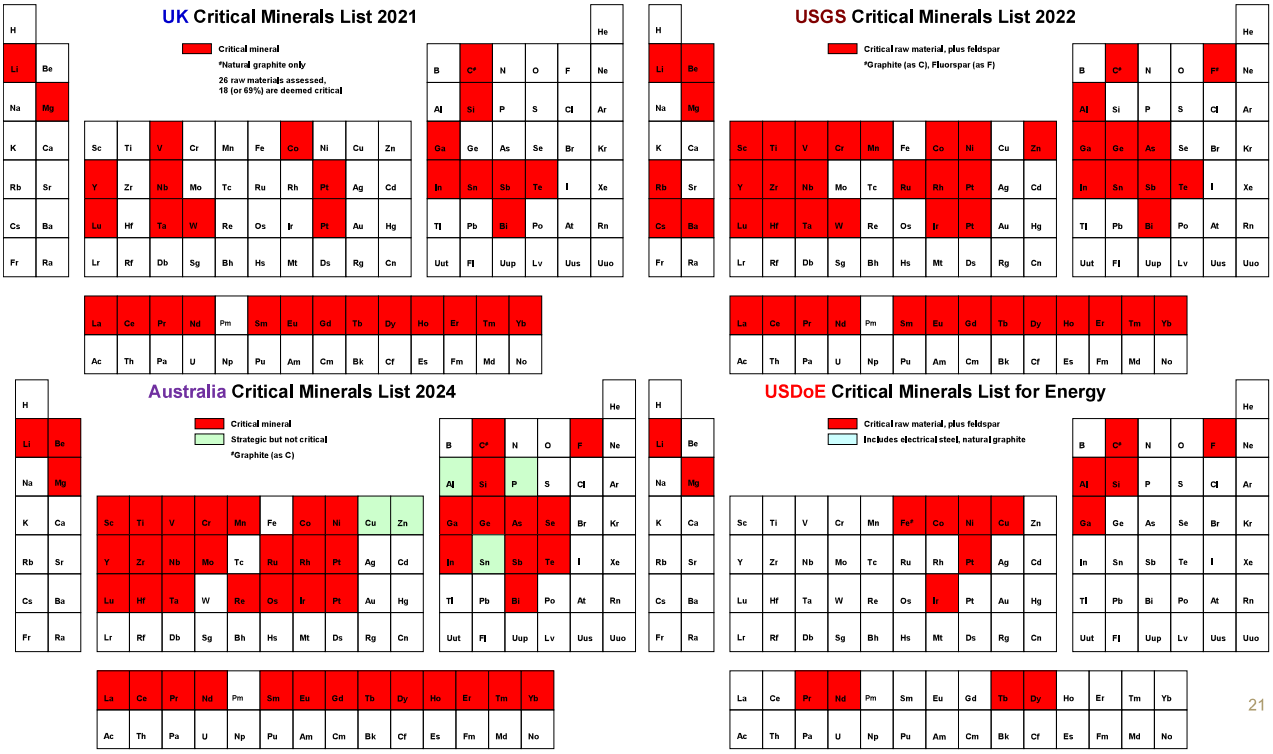
• TRADE DATA

- Imports, Exports, Apparent Consumption, Net Import Reliance
  - use BGS World Mineral Statistics, CommTrade, UK Trade, ITC
- Need to align HS trade codes, establish standardised template before getting going
  - make clear decisions on HS codes included for analysis, material basis & composition, justify those excluded – even if possibly significant with respect to material flows
- Trade Barriers – difficult to apply consistently across all countries & trade codes, using case study approach instead

UK apparent consumption (AC)
$AC = \sum(prod_{£} + import_{£}) - \sum export_{£}$

UK net import reliance (NIR) =
$(Import_{kg} - Export_{kg}/App\ cons_{kg})$
* Trade barriers

Comparing the Some of the Lists!!



Concluding Thoughts

- Critical minerals needs to be approached with a supply chains and circular economy framework, including key links to economic geology and mining
- 2024 Criticality Assessment is most comprehensive ever undertaken for the UK to date – there is LOTS to get stuck into!
  - data synthesis work ranges from straight forward and ‘quick’ to others which take extensive work to prepare final data for use
- We are schedule for public release in late November 2024
- Fundamentally, this project will deliver the basis for the UK’s approach to critical raw materials for years to come –funding, policy, investment, etc
- The approach mirrors many of our cousin centres in the EU, USA et al