NATURAL HISTORY MUSEUM

Professor Richard Herrington

The Resource Challenge of Going Green

Surrey IET January 18th 2023

NHM Mineral Collection

Ga-rich sphalerite ZnS

- Meteorites
- Minerals
- Ore and rock collections

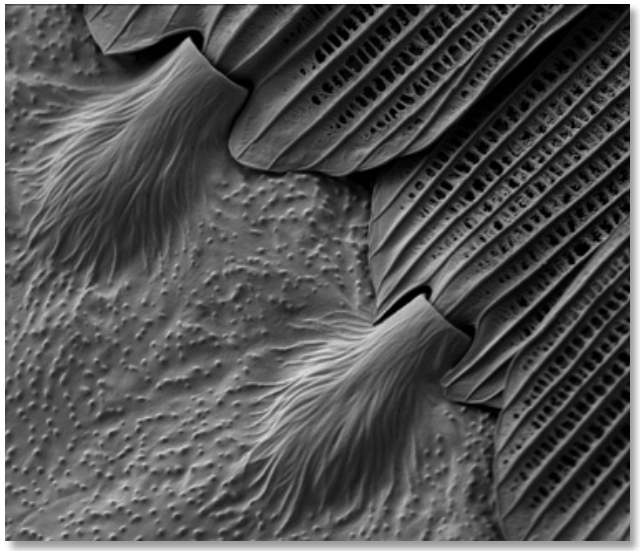
Kunzite $LiAl(SiO_3)_2$

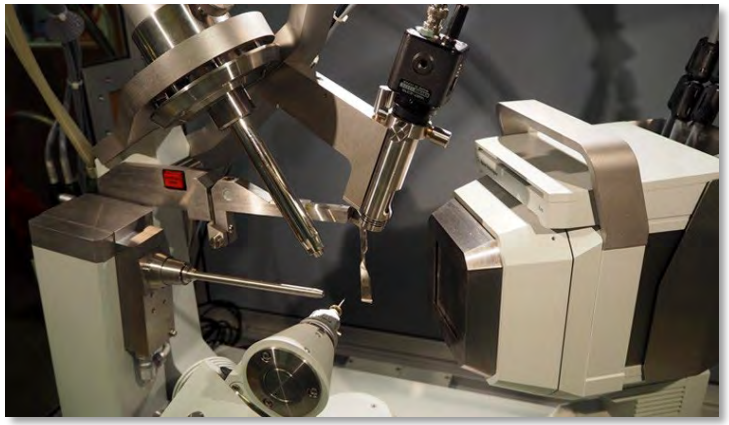
Gem form of the Li ore mineral spodumene

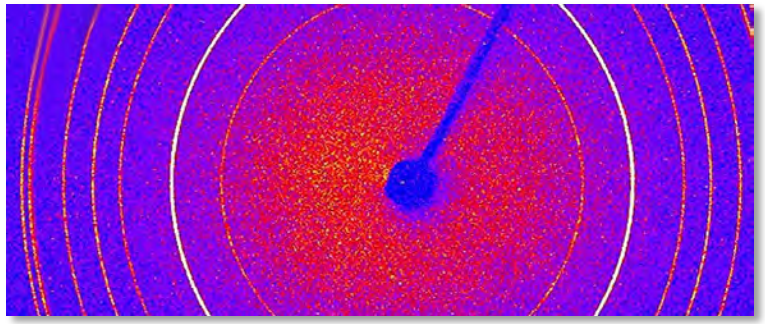
- 80 million specimens in the NHM collections
- Includes >185,00 mineral specimens – many types
- Systematically collected
- Library of natural materials with variable chemistries and properties
- Actively studied and used as a reference collection

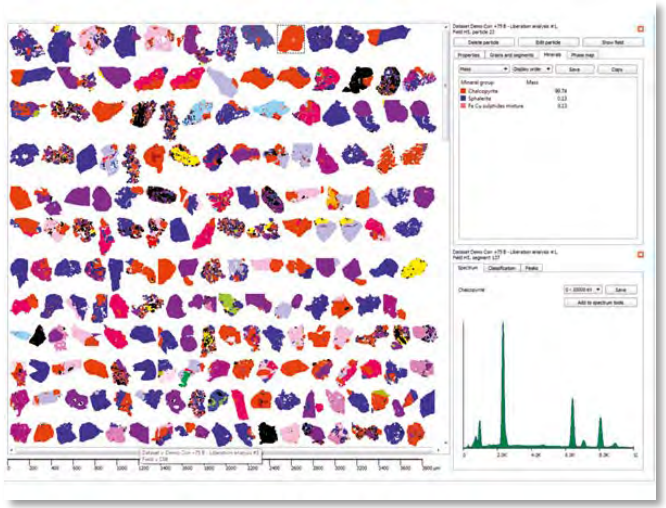
NATURAL HISTORY MUSEUM

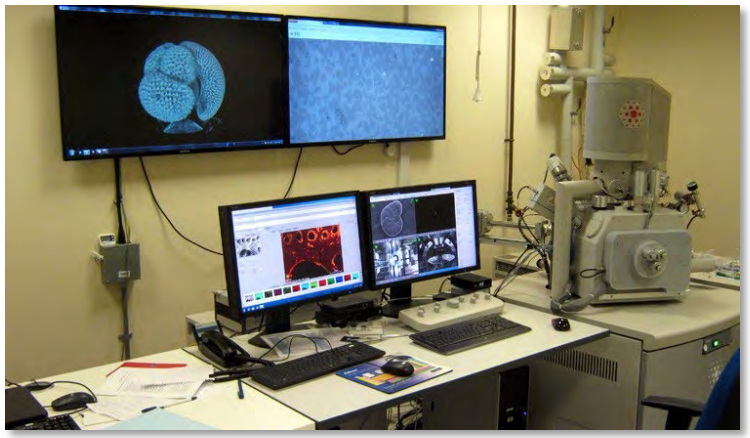
Advanced Mineralogical Analysis Infrastructure











IET January 2023

NHM Unlocked Programme

PRESS RELEASE

Natural History Museum to open major new research centre with the University of Reading

First published 20 May 2022

- NHM to be on 3 sites by 2026
- £182 million government support for Science and Digitisation Centre
- New facility to be delivered at the Thames Valley Science Park, Reading
- Opportunities to build closer science links with external partners (existing and new)
- Development of next generation analytical facilities

Committee on Climate Change Challenge in 2019

+

Theresa May announces legislation for zero emissions by 2050

June 12, 2019

© Ojen

=

- **Electric vehicles.** By 2035 at the latest all new cars and vans should be electric (or use a low-carbon alternative such as hydrogen). If possible, an earlier switchover (e.g. 2030) would be desirable, reducing costs for motorists and improving air quality. This could help position the UK to take advantage of shifts in global markets. The Government must continue to support strengthening of the charging infrastructure, including for drivers without access to off-street parking.

=

NATURAL HISTORY MUSEUM

Visit Discover Take part Join

Specimen of the mineral coboltite - a cobalt iron arsenic sulphide

PRESS RELEASE

Leading scientists set out resource challenge of meeting net zero emissions in the UK by 2050

First published 5 June 2019

A letter authored by Natural History Museum Head of Earth Sciences Prof Richard Herrington and fellow expert members of SoS MinErals (an interdisciplinary programme of NERC-EPSRC-Newton-FAPESP funded research) has today been delivered to the Committee on Climate Change

The metal resource needed to make all cars and vans electric by 2050 and all sales to be purely battery electric by 2035. To replace all UK-based vehicles today with electric vehicles (not including the LGV and HGV fleets), assuming they use the most resource-frugal next-generation NMC 811 batteries, would take 207,900 tonnes cobalt, 264,600 tonnes of lithium carbonate (LCE), at least 7,200 tonnes of neodymium and dysprosium, in addition to 2,362,500 tonnes copper**.** This represents, just under two times the total annual world cobalt production, nearly the entire world production of neodymium, three quarters the world's lithium production and 12% of the world's copper production during 2018. Even ensuring the annual supply of electric vehicles only, from 2035 as pledged, will require the UK to annually import the equivalent of the entire annual cobalt needs of European industry.

IET January 2023

But it is bigger than that!

- Net Zero pledges worldwide are committed to ‘decarbonising’ all sectors of the economy

Press release

Plans unveiled to decarbonise UK power system by 2035

The plans will focus on building a secure, home-grown energy sector that reduces reliance on fossil fuels and exposure to volatile global wholesale energy prices.

From: Department for Business, Energy & Industrial Strategy and The Rt Hon Kwasi Kwarteng MP

Published 7 October 2021

GOV.UK

Policy paper

Net Zero Strategy: Build Back Greener

This strategy sets out policies and proposals for decarbonising all sectors of the UK economy to meet our net zero target by 2050.

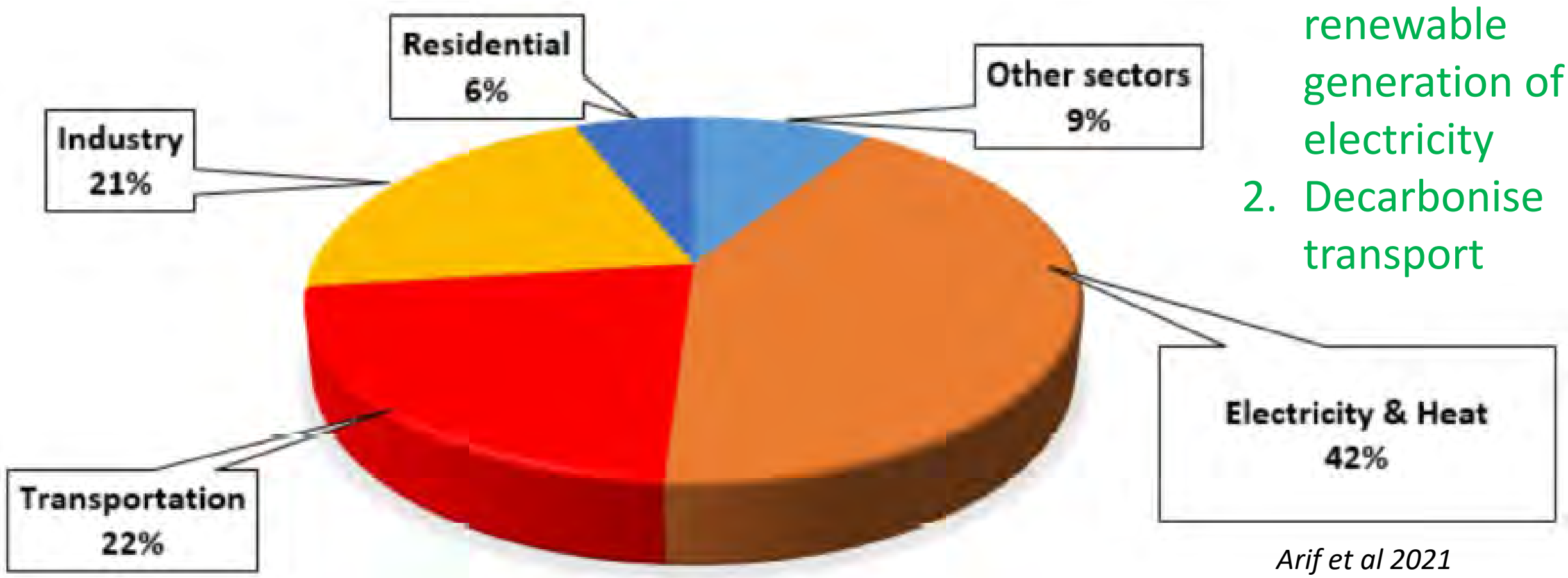
From: Department for Business, Energy & Industrial Strategy

Published 19 October 2021

Last updated 14 December 2021 — See all updates

Decarbonising – what do we need to change?

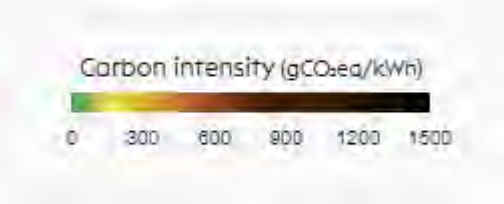
Sources of anthropogenic CO_2

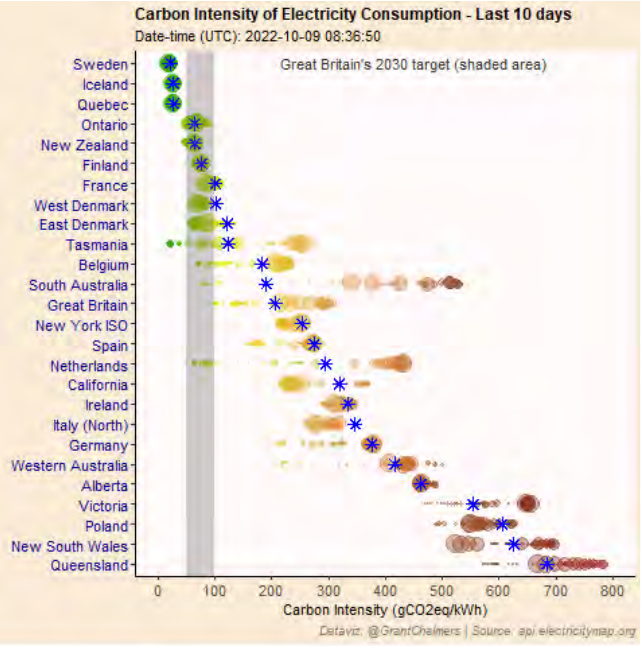


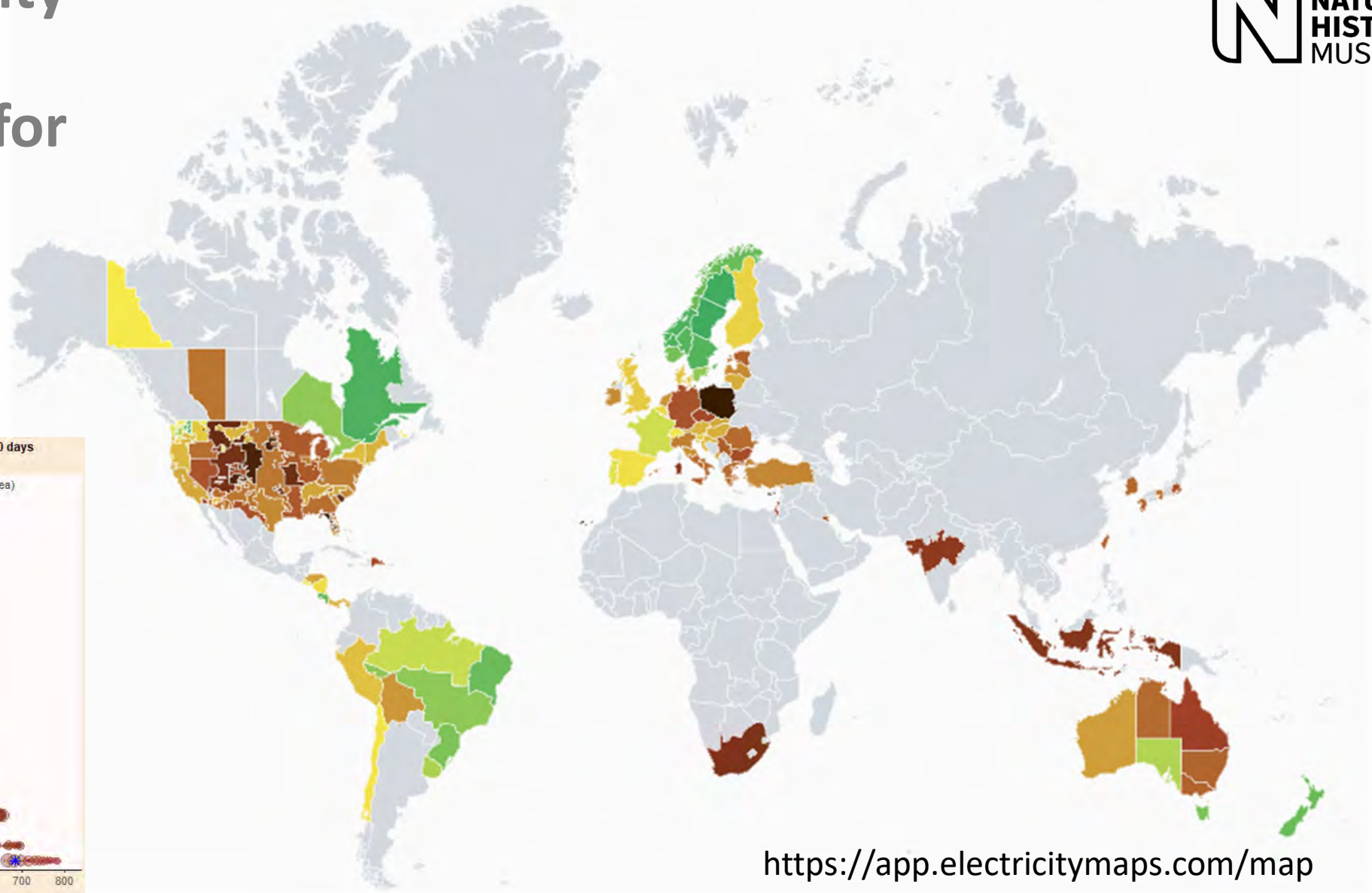
1. Switch to renewable generation of electricity
2. Decarbonise transport

Arif et al 2021

Carbon intensity of energy consumption for 2022

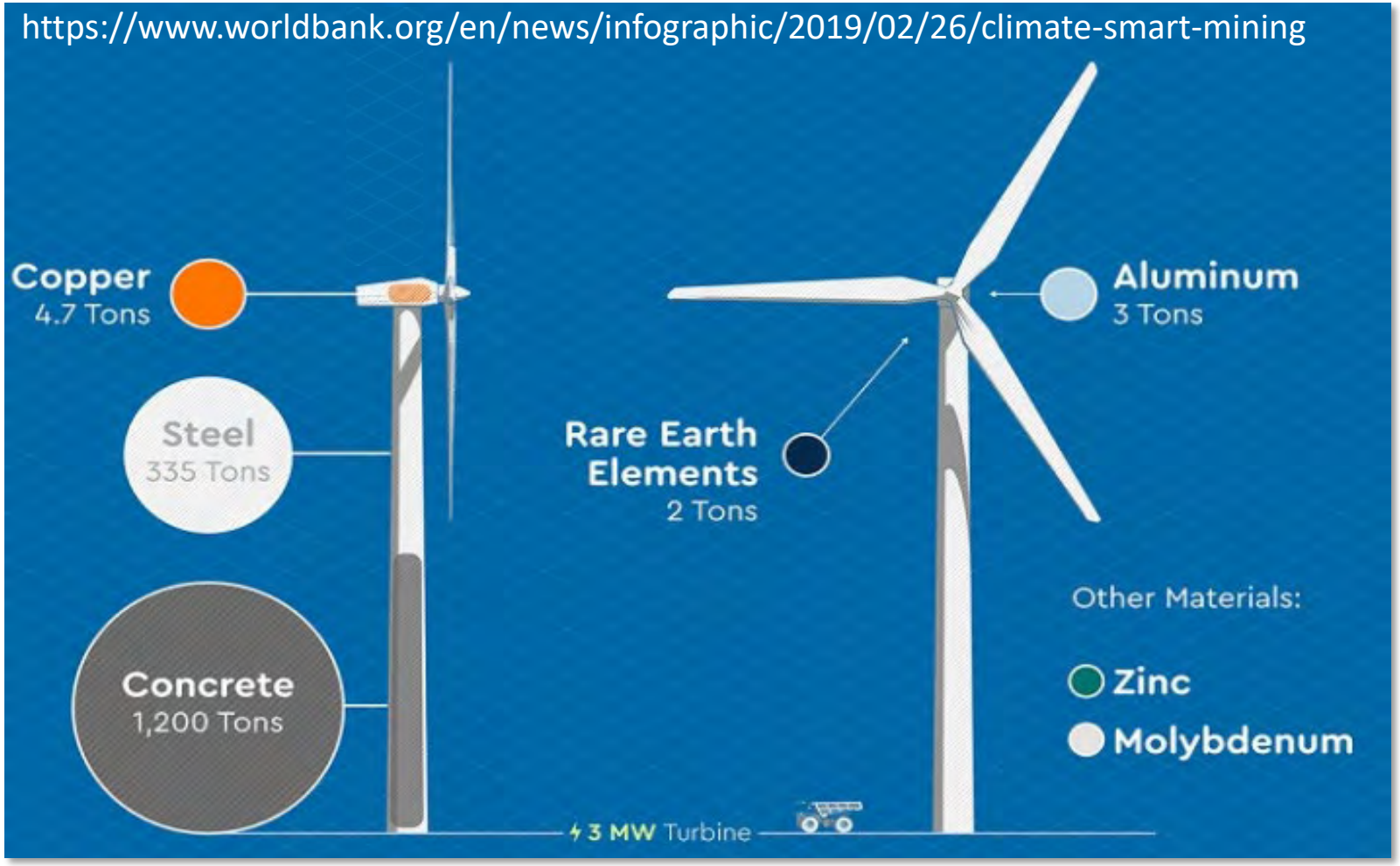






https://app.electricitymaps.com/map

Electricity needs to become renewable

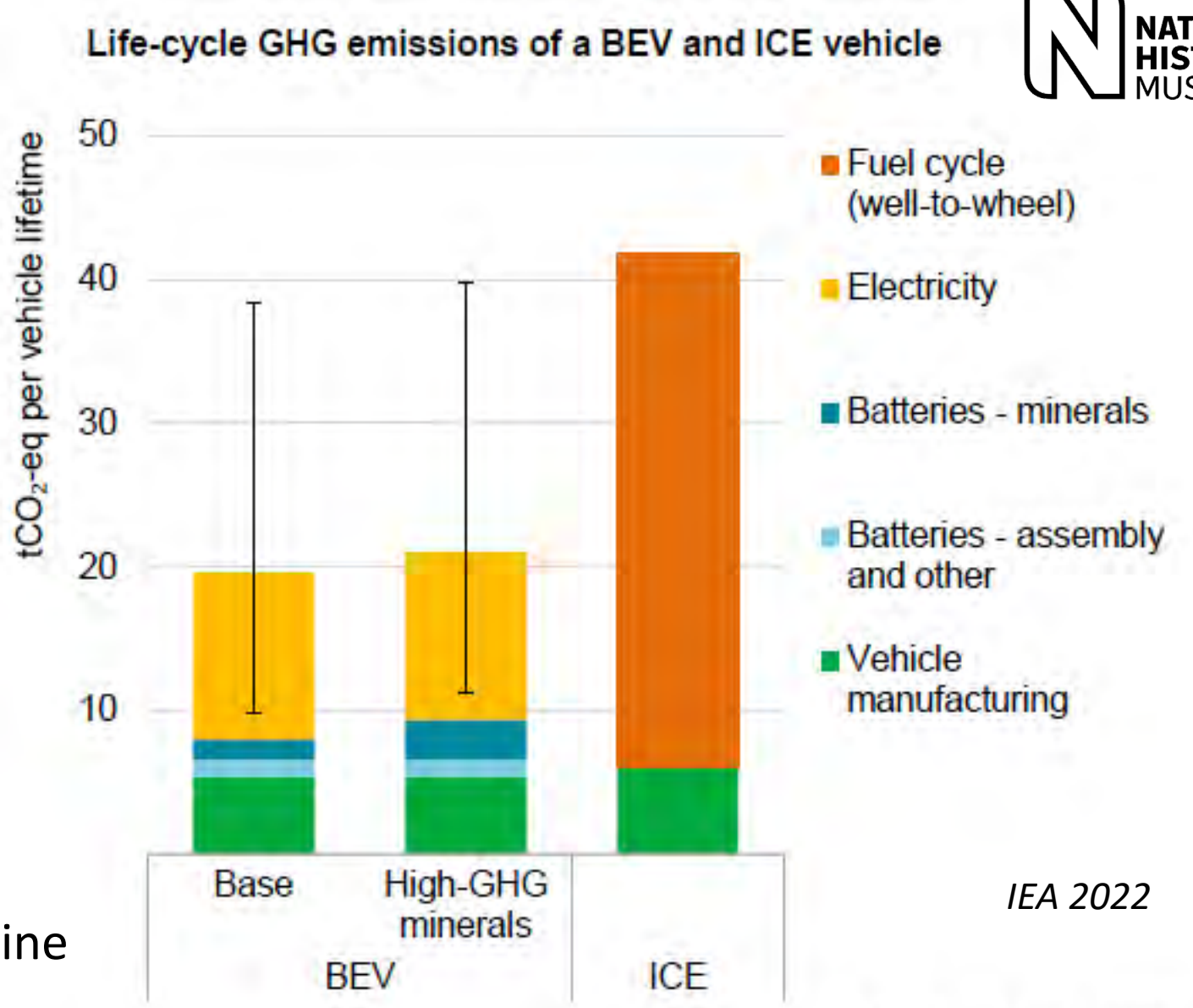


However, all renewable technologies use significant mineral sourced materials….

IET January 2023

Transport needs to move from fossil fuels

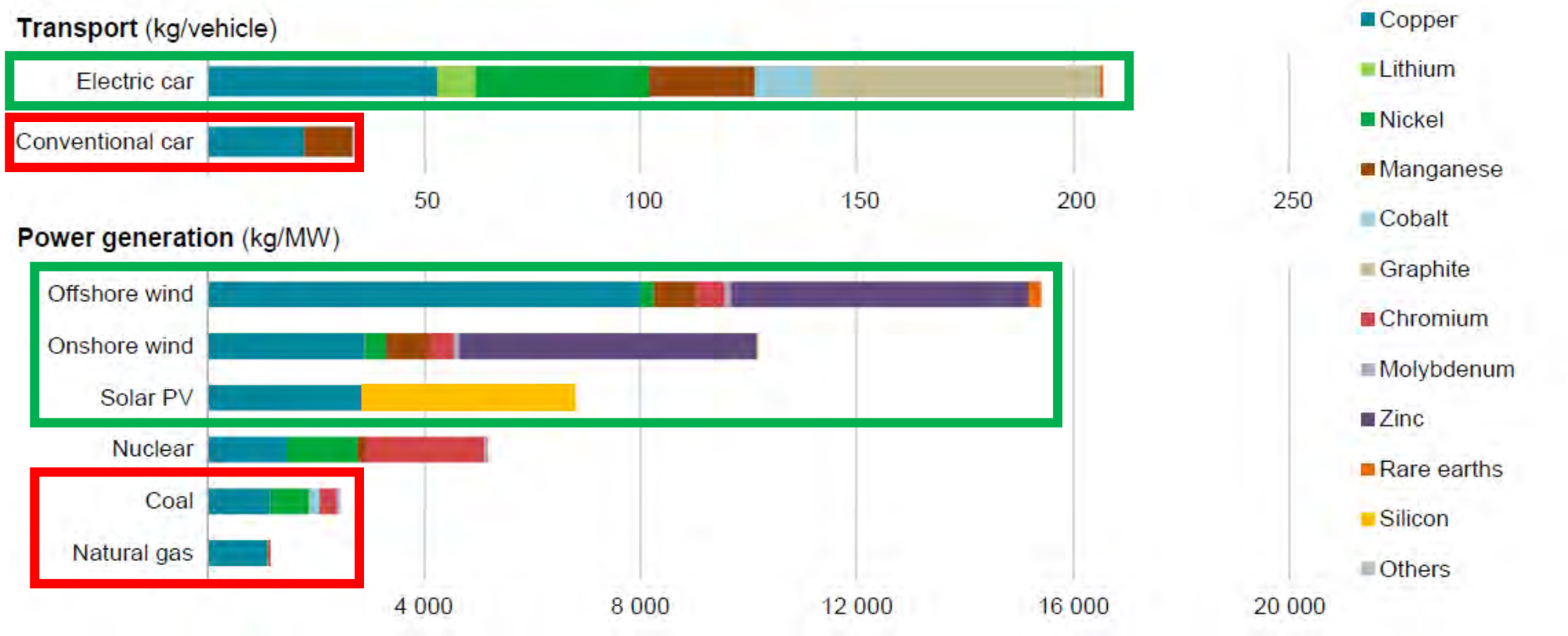
Electric vehicles really do make sense if recharged with low-CO_2 electricity



IEA 2022

ICE = internal combustion engine
BEV = battery electric vehicle

But going completely green is a mineral hungry business

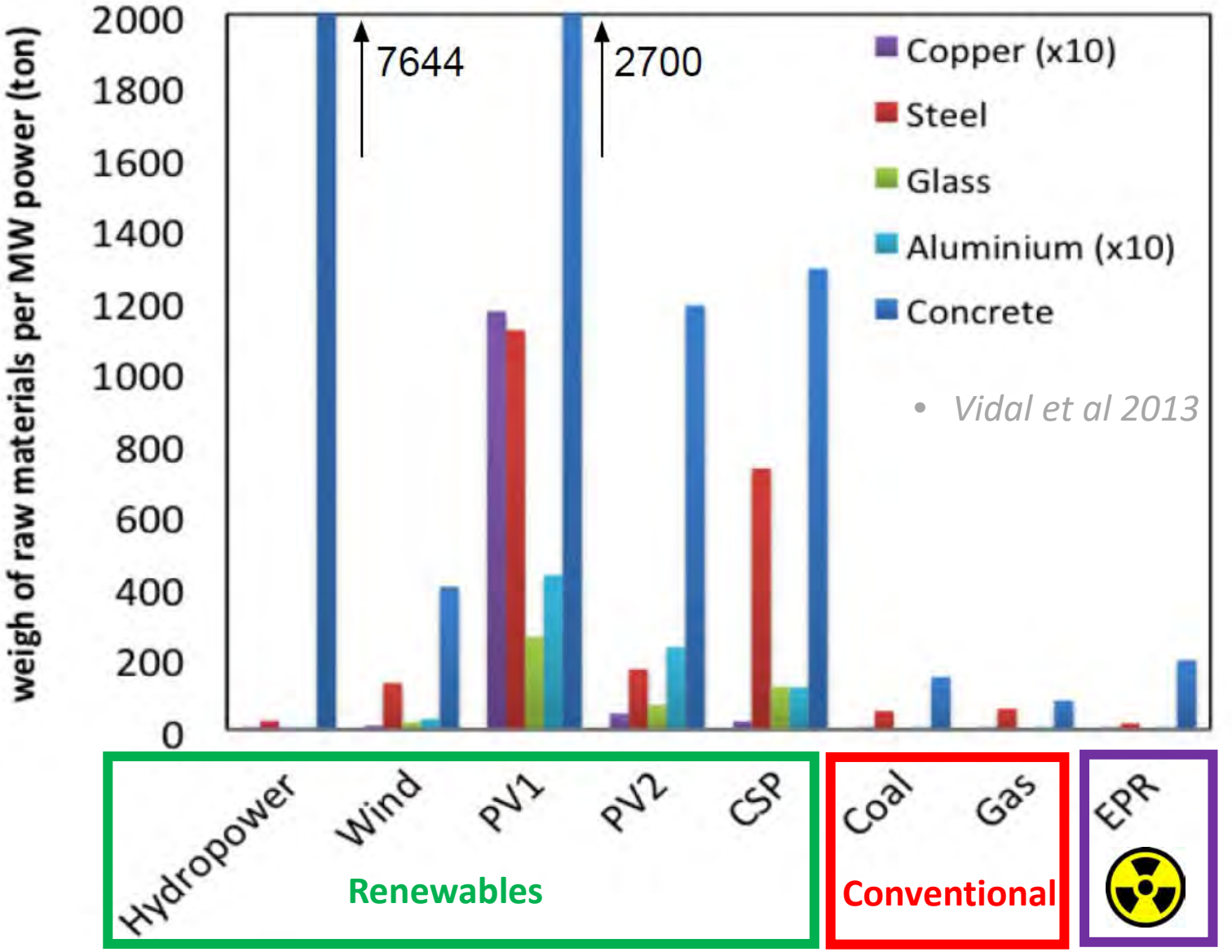


- *IEA 2021*

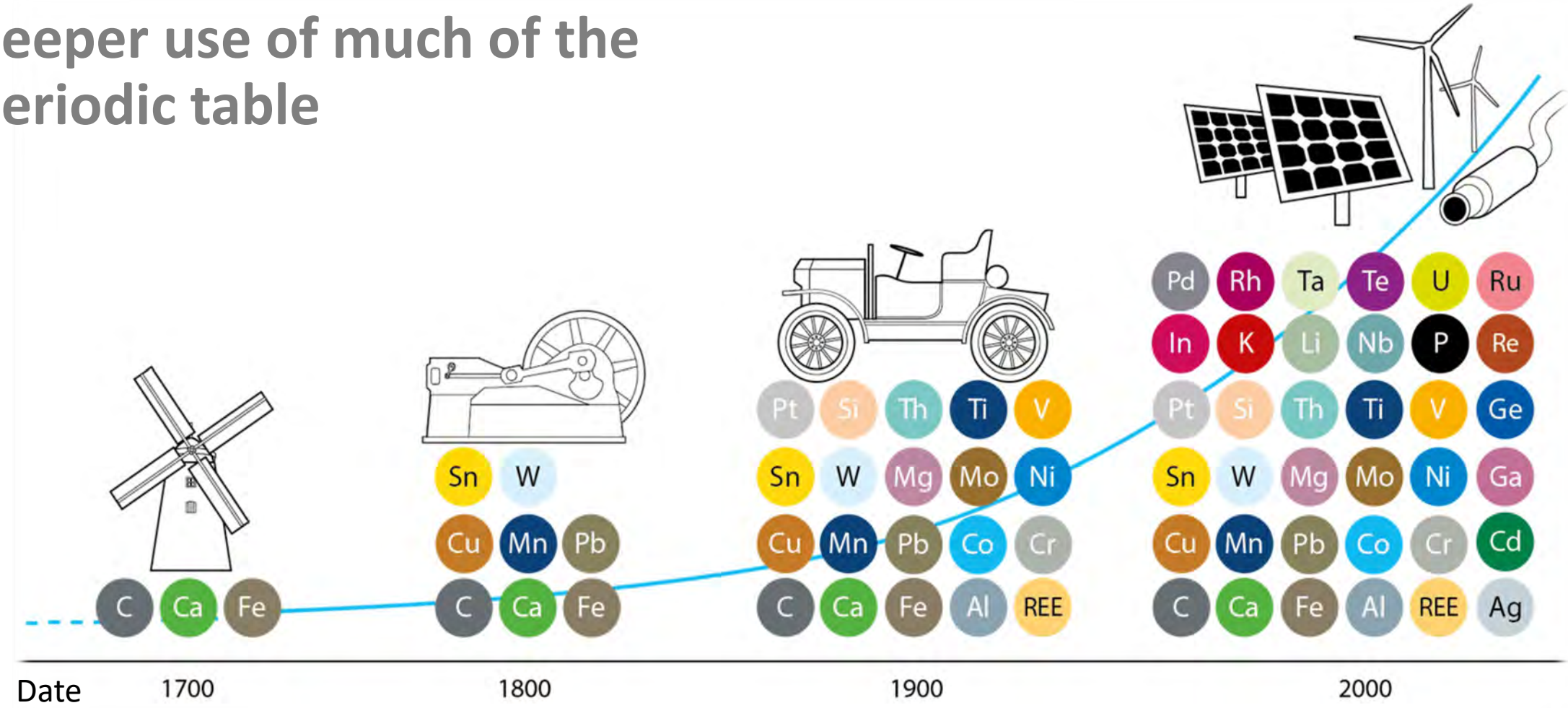
NATURAL HISTORY MUSEUM

Renewable energy needs more infrastructure

Increased demand for common bulk commodities as well as critical metals



Human development generally has meant a much broader and deeper use of much of the periodic table



Zepf et al. (2014)

A long list of ‘critical’ elements are needed for the energy transition

Magnets in motors
- Neodymium
- Dysprosium
- Praseodymium

} REE

Alloys
- Aluminium
- Niobium
- Magnesium
- Titanium
- Scandium?

Not just rare earths

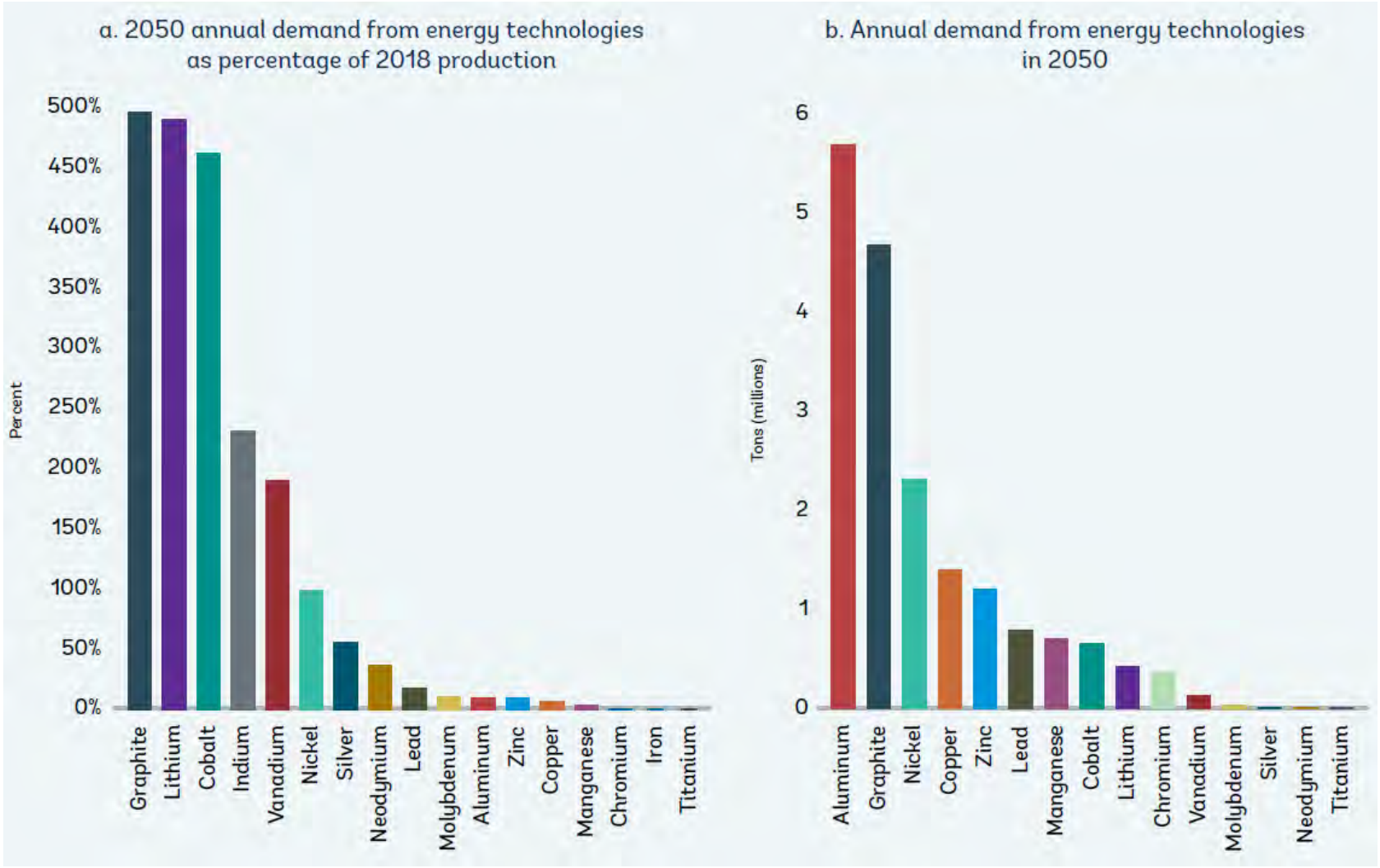
Batteries
- Lithium
- Cobalt
- Graphite
- Nickel
- Manganese
- Vanadium

Hydrogen
- Platinum Group Metals

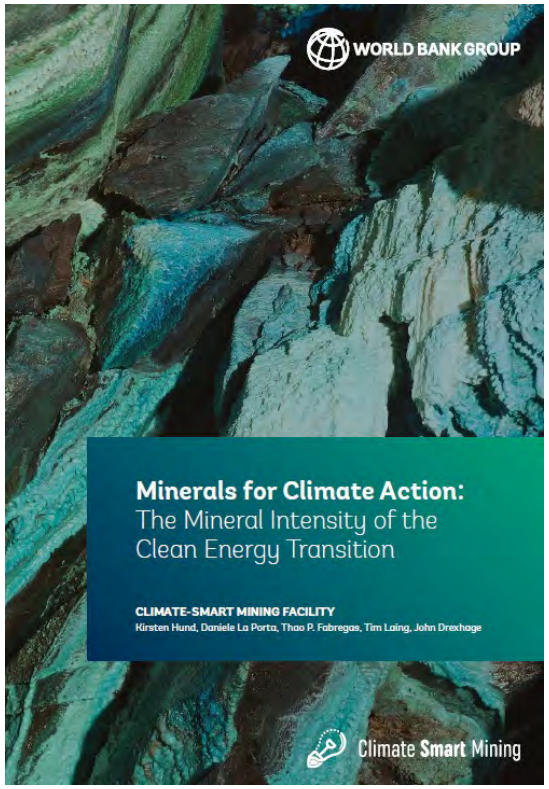
Solar panels
- Gallium
- Indium
- Tellurium
- Selenium

Various uses
- Copper
- Zinc
- Silver
- Chromium
- Steel alloys etc.

Increasing demands very strong for a range of metals



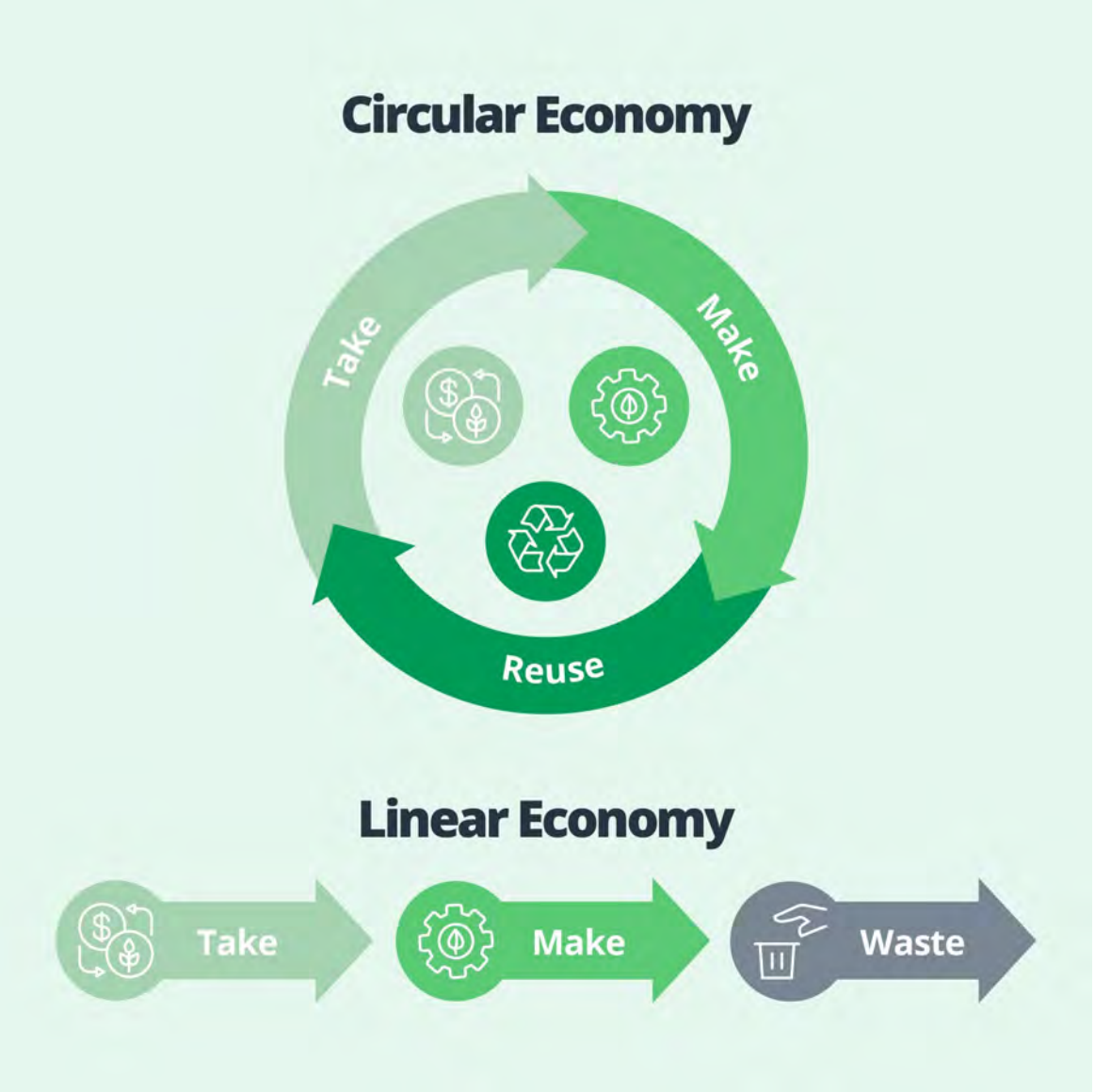
IET January 2023



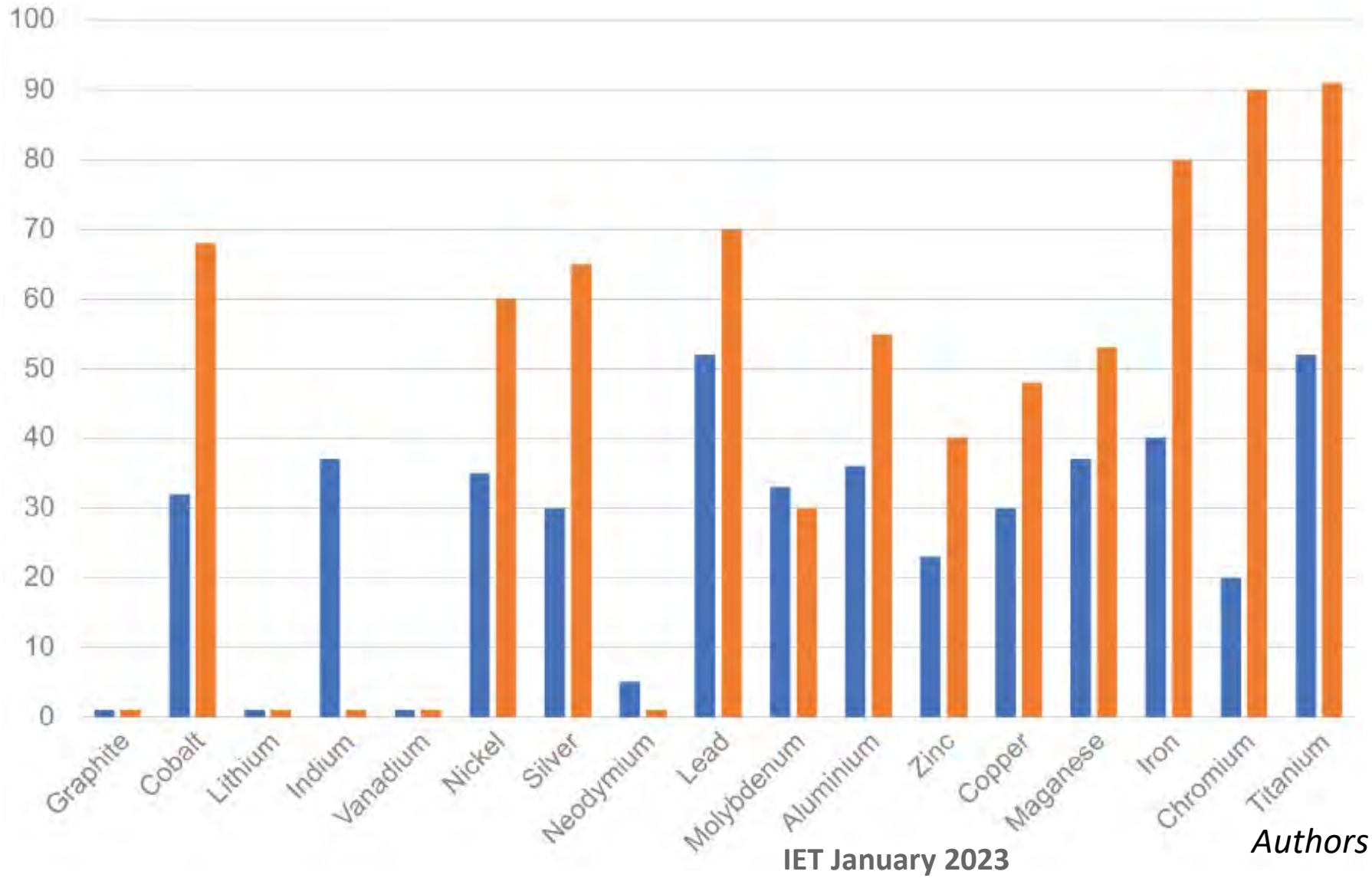
https://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf

Circular economy

What we need from recycling?



Can’t we just recycle? – no, there isn’t enough ‘stock’

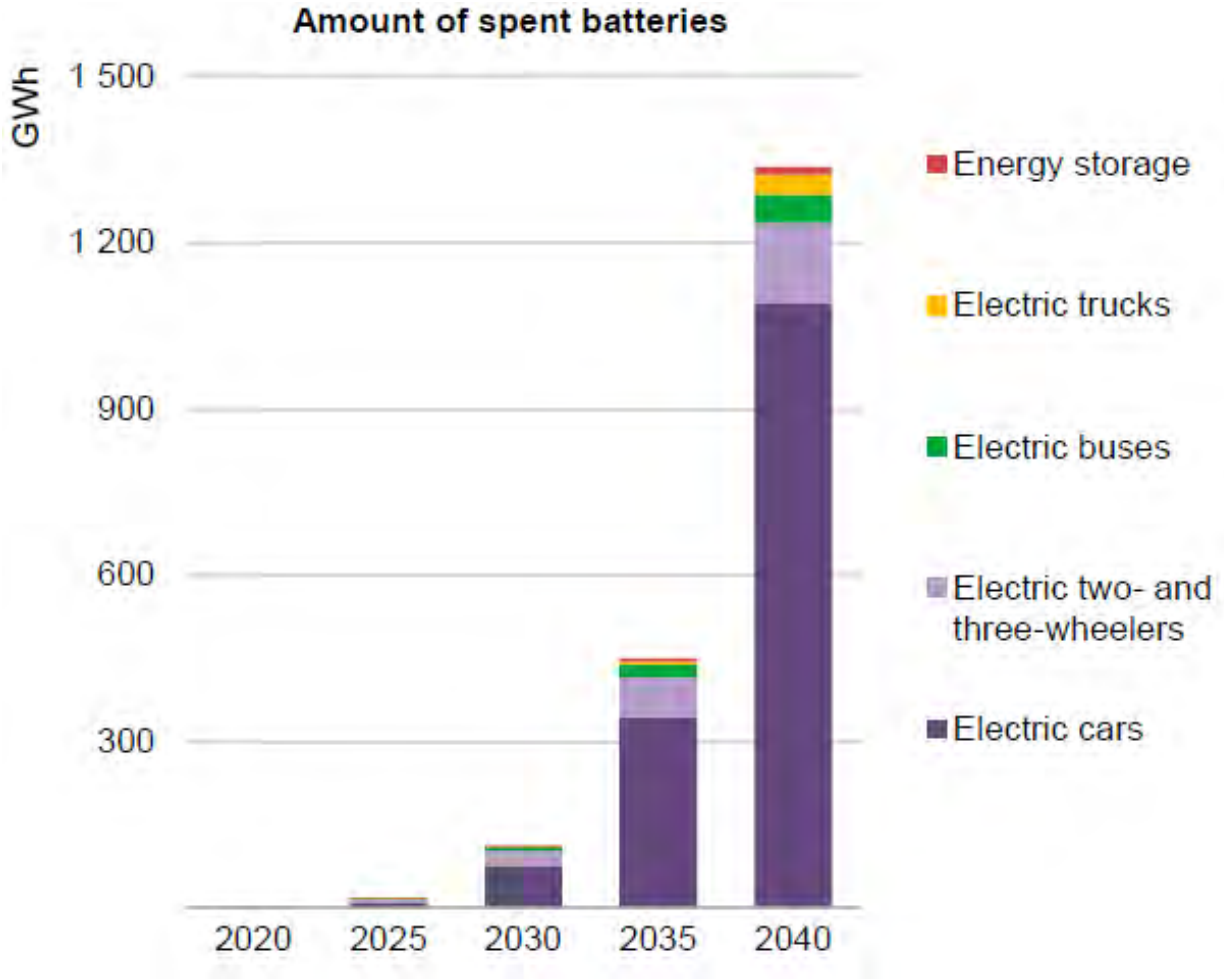


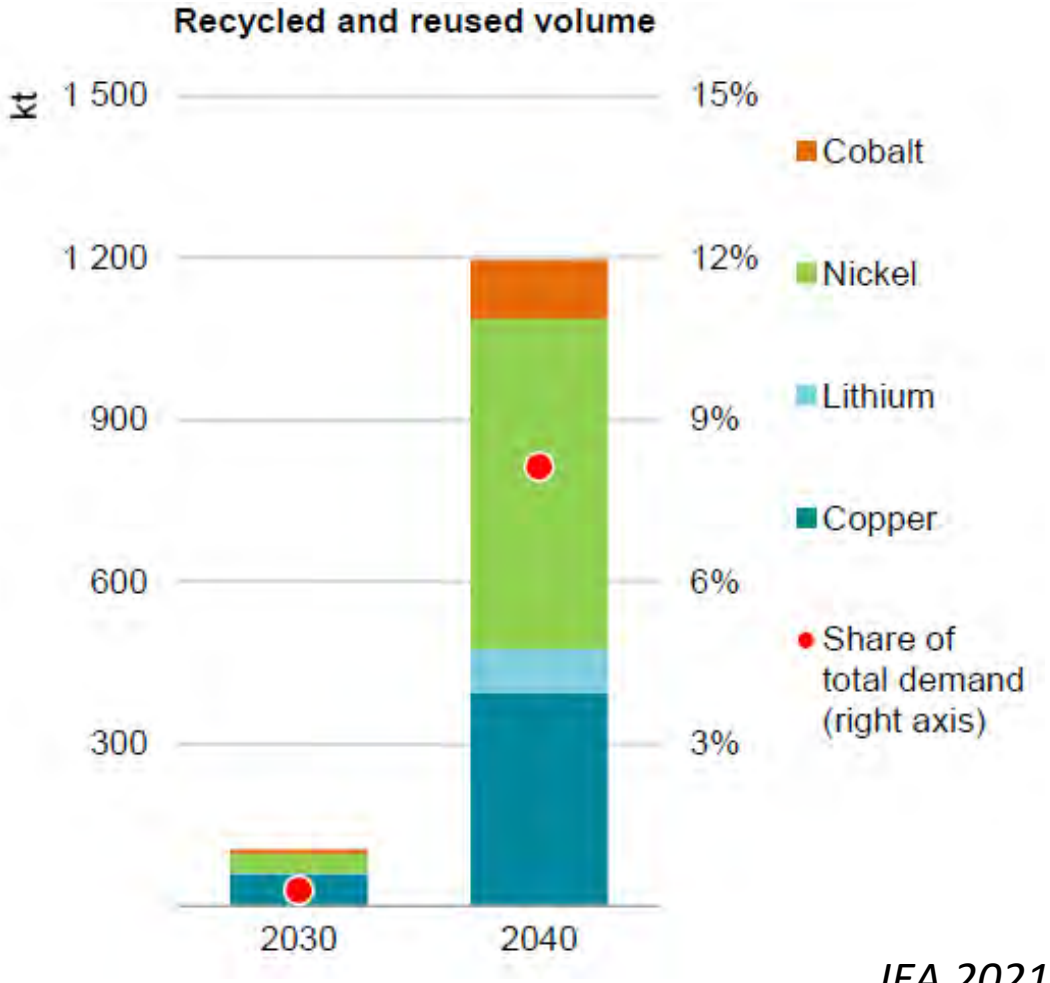
Orange = percentage of commodity recycled at end-of-life

Blue = percentage of current demand satisfied by recycling

Authors figure from published data

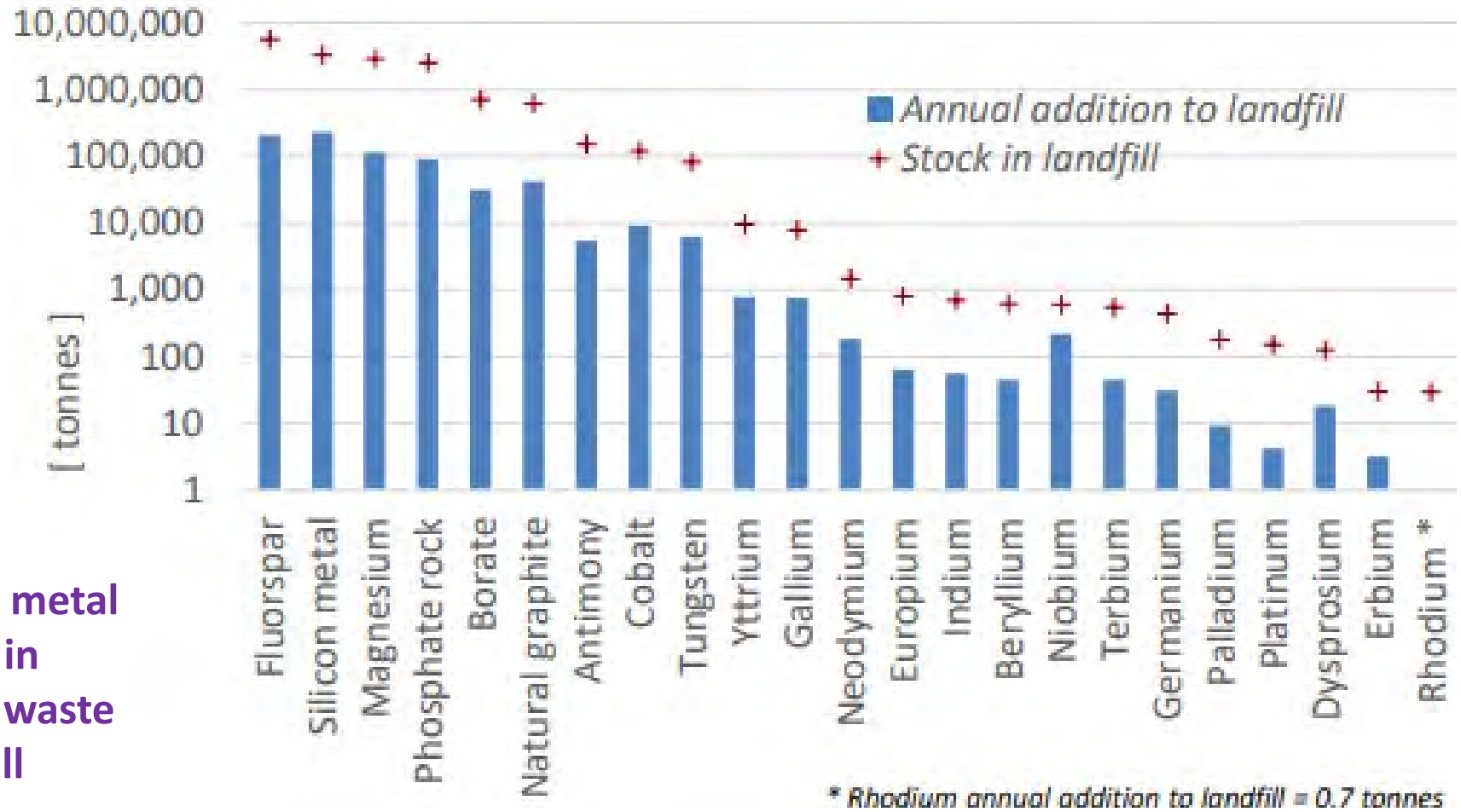
Only by 2040 will recycling become significant for many of these materials





IEA 2021

Wastes should be looked at as a source for metals - but waste alone cannot feed the need

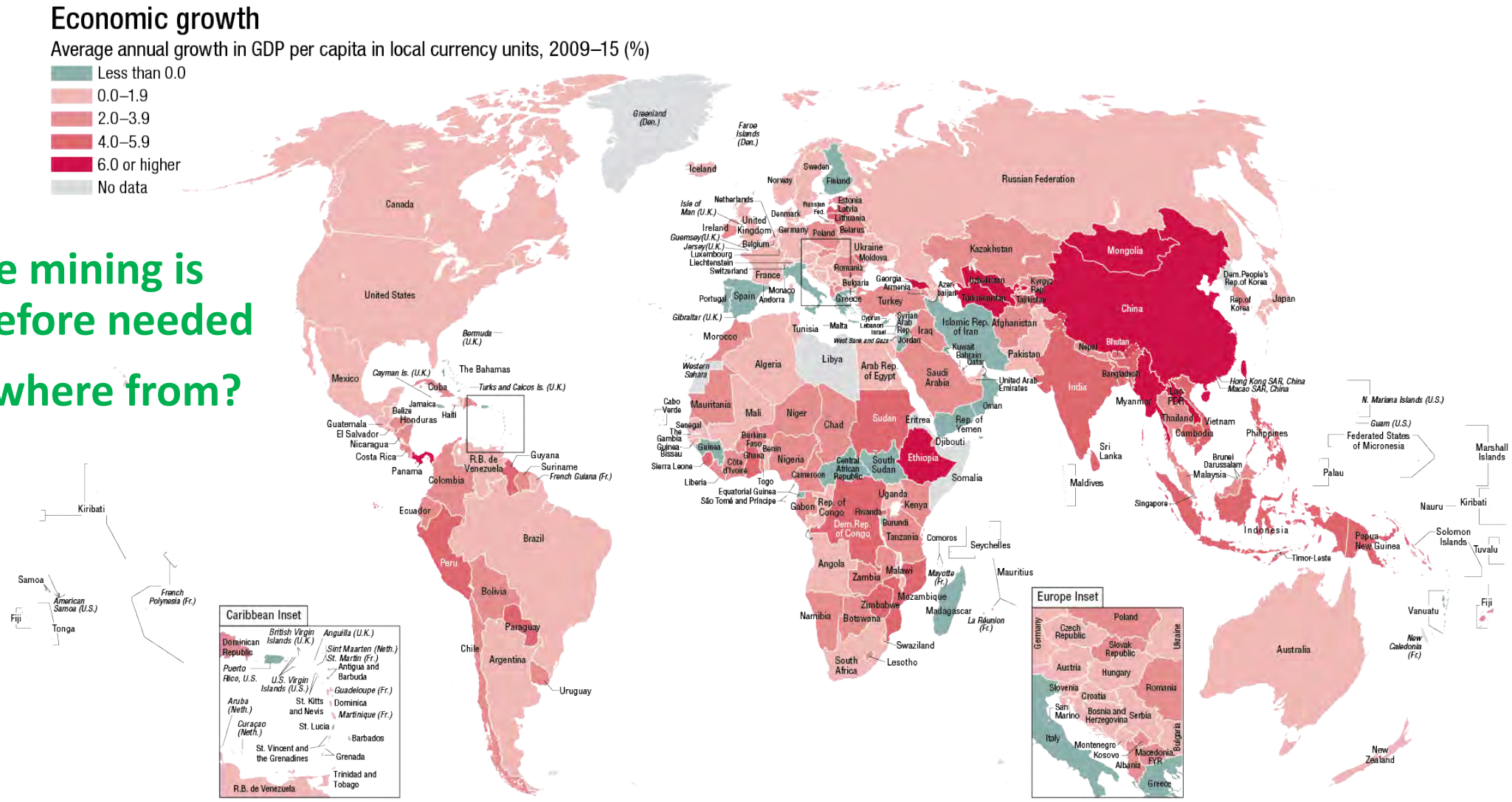


Estimated metal resources in European waste and landfill

JRC EU Report 2019

World economic growth drives increased demand

- More mining is therefore needed
- But where from?

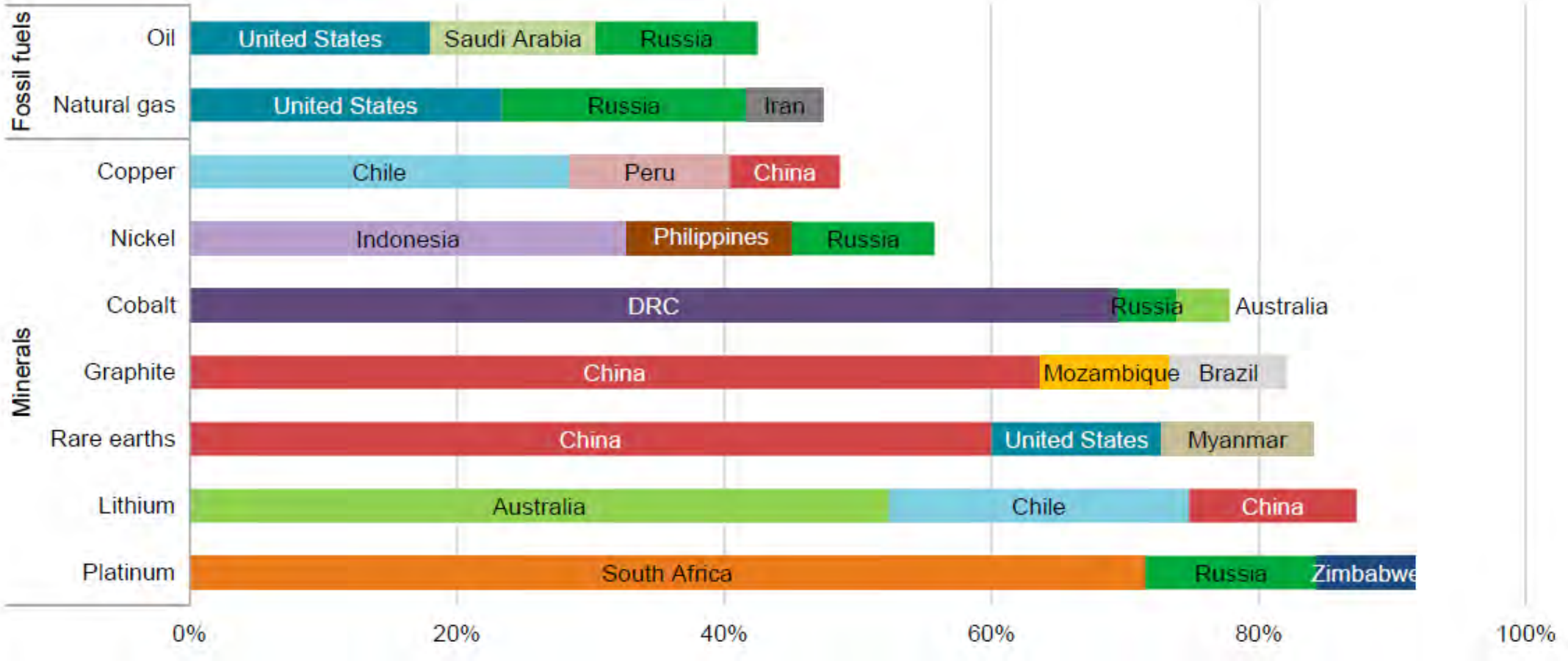


World Bank 2019

NATURAL HISTORY MUSEUM

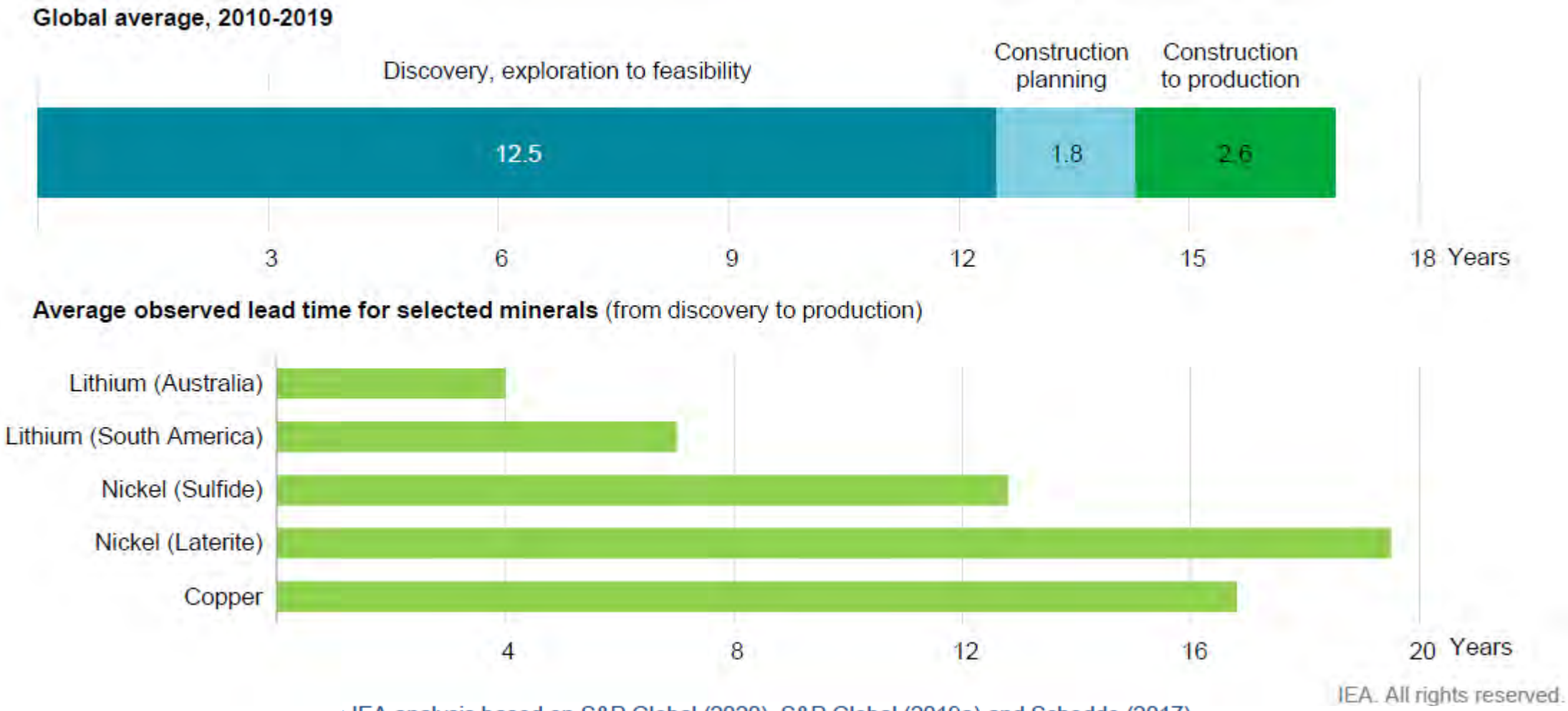
Growth demands more new materials to feed the circle

Problem 1- geographic monopolies are stronger for minerals than they are for oil

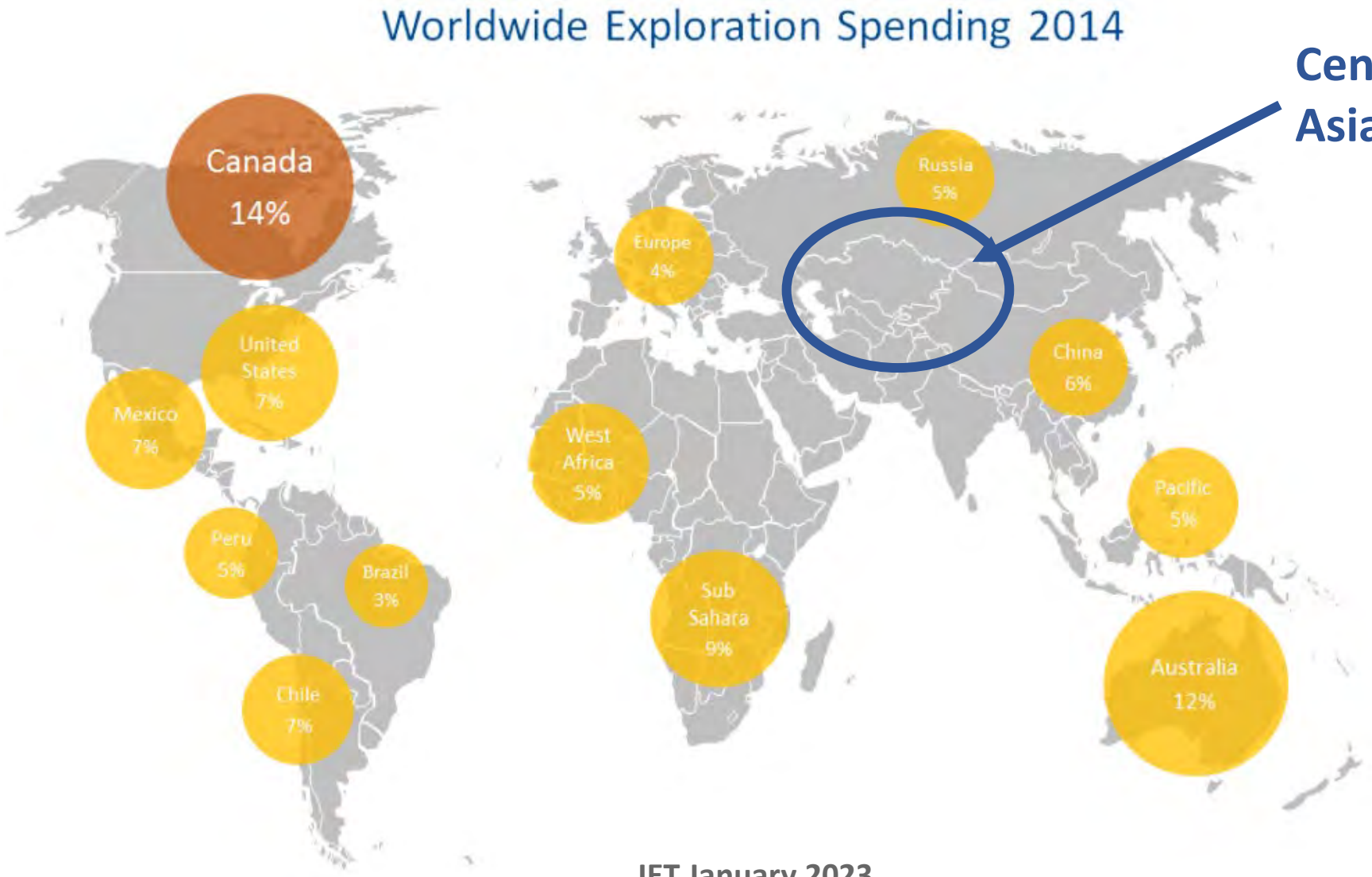


Top three producers for each commodity shown – data as for 2020 (IEA 2021)

Problem 2 – Opening a new mine often has a long lead time



We need to expand the places we look for new minerals

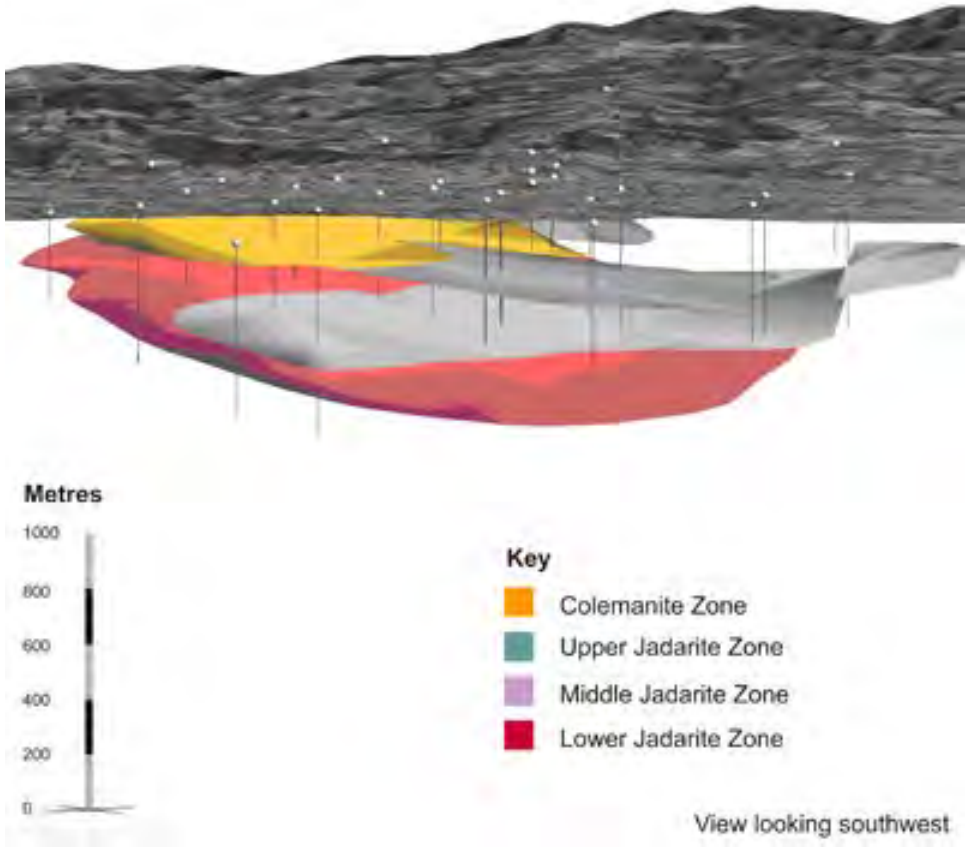


Mining Association of Canada Facts and Figures 2015

It is still possible to find new deposit types

Jadar Li-B Deposit, Serbia

RioTinto



IET January 2023

Inferred Resource

- > 110 Million tonnes

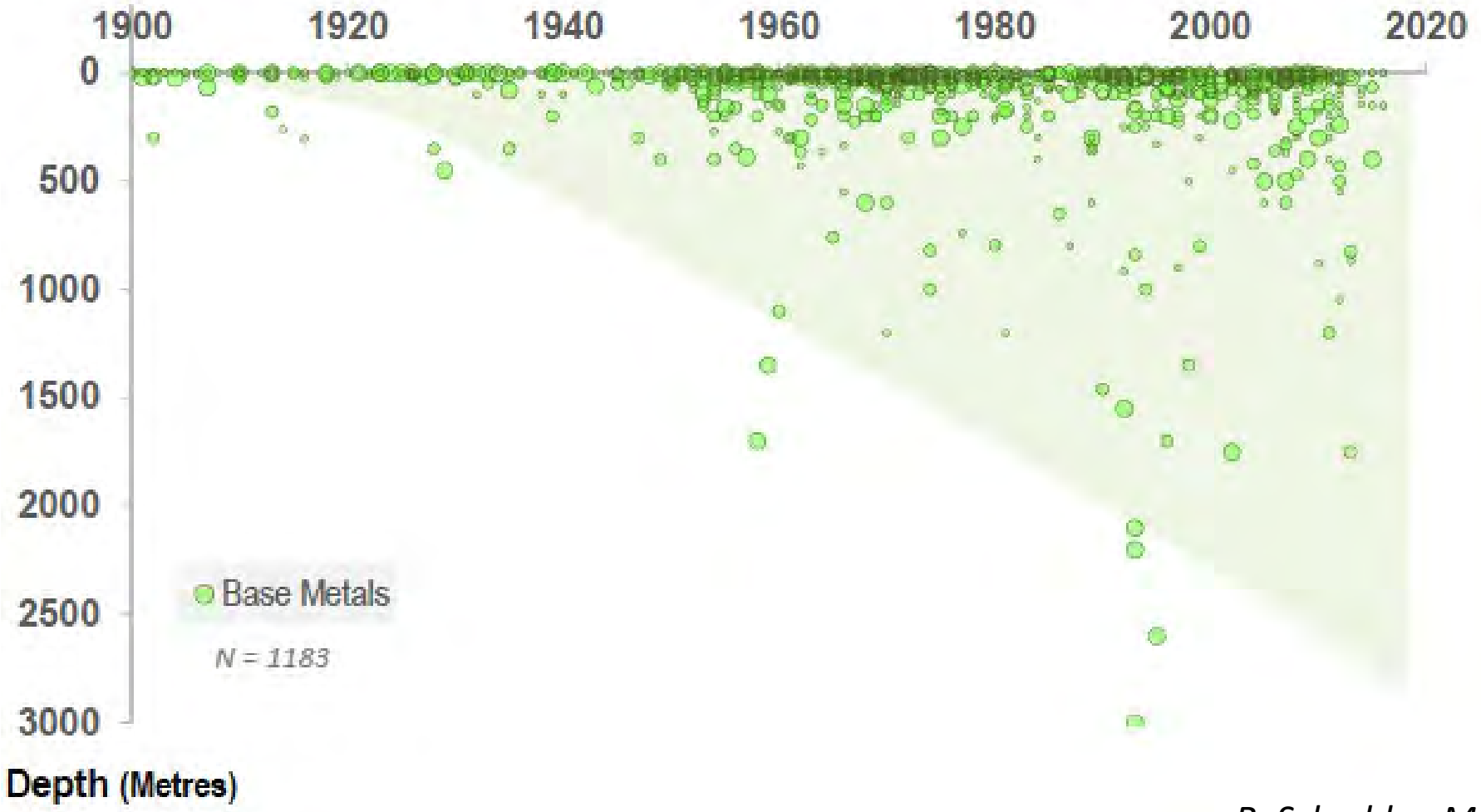
@ 1.8% Li_2O 13.1% B_2O_3

- 100Mt of an entirely new mineral discovered in 1994

Jadarite $LiNaSiB_3O_7(OH)$

We can look deeper in the earth

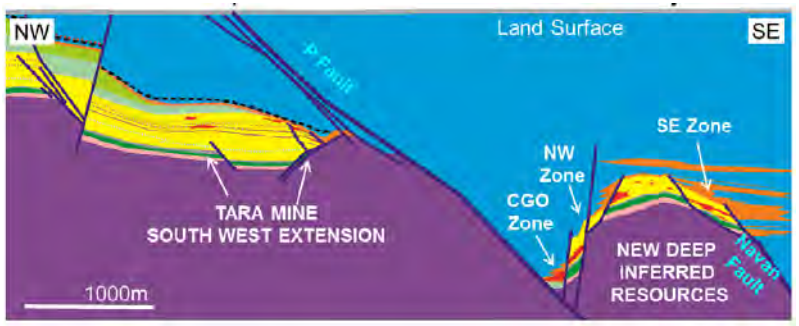
Plot of depth of discovery for newly reported exploration finds – base metals

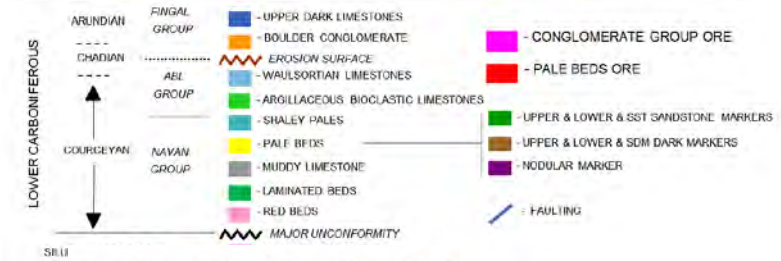


- We are learning to find deposits under cover..
- But, since 2000, only 9 out of 239 discoveries are deeper than 500m and 7 of those are 'brownfields'

R. Schodde - Minex consulting March 2016

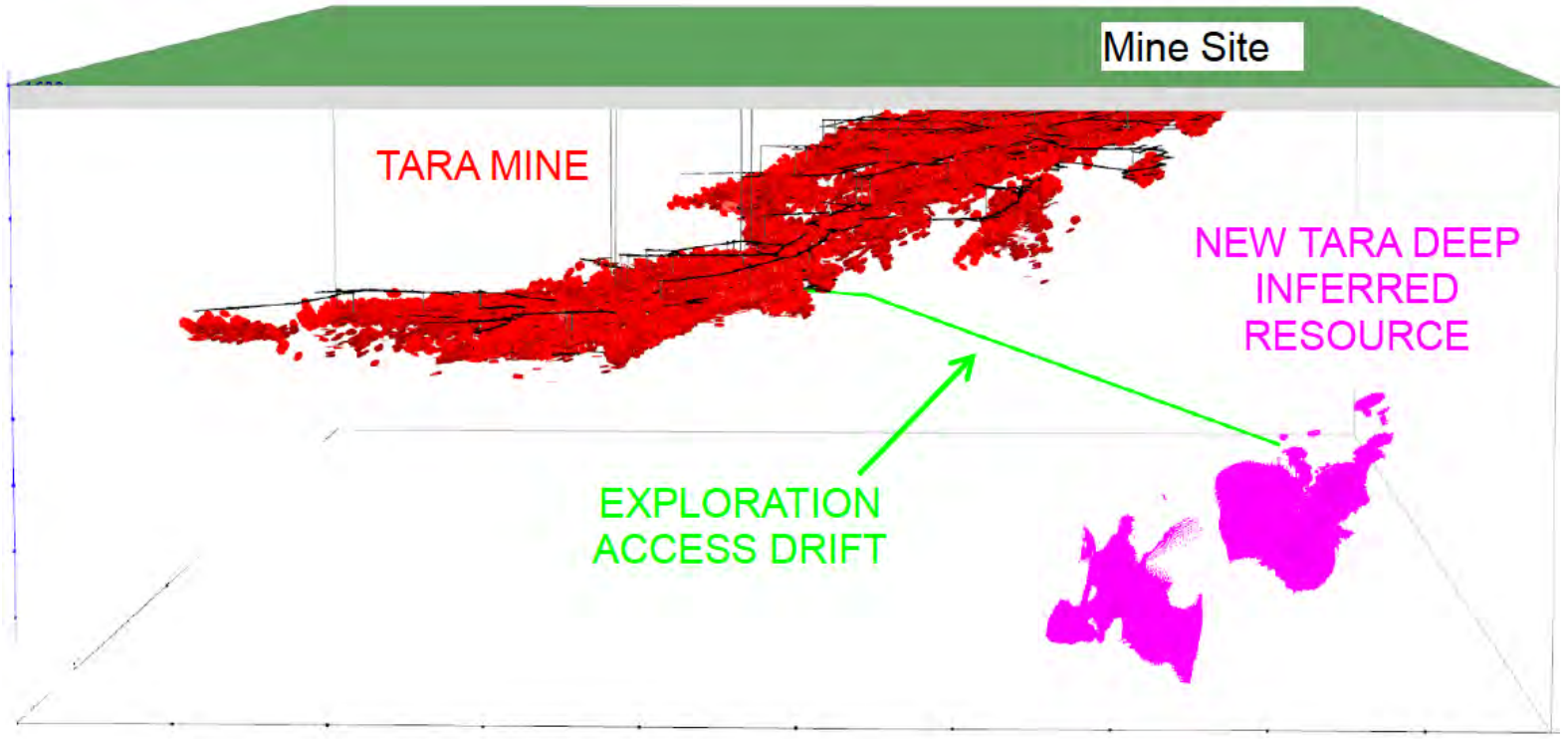
So we can go deeper at existing mines to find more





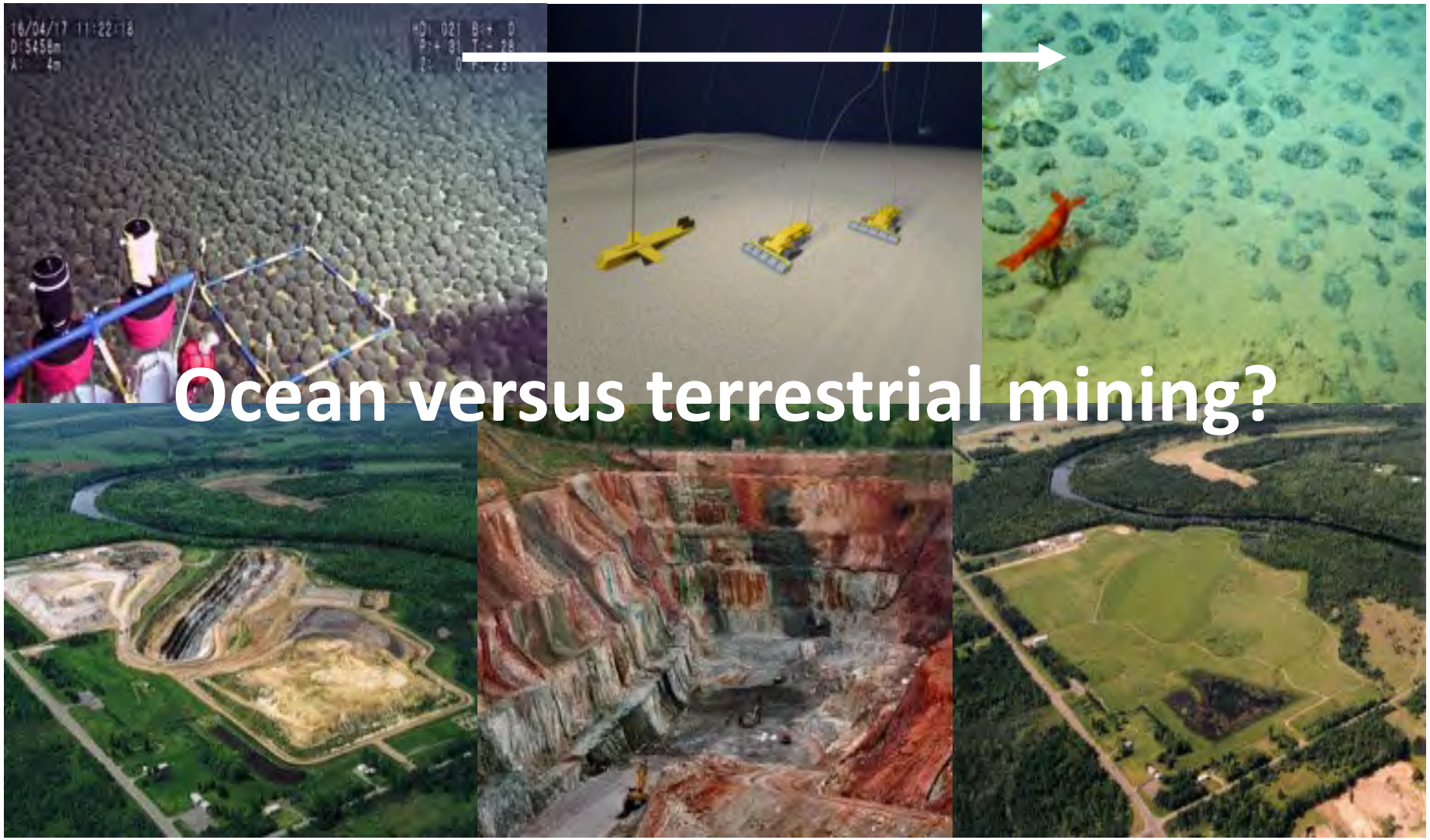
NEW BOLIDEN

- Novel deep seismic exploration Navan Mine, Ireland



New technologies
Brownfields exploration

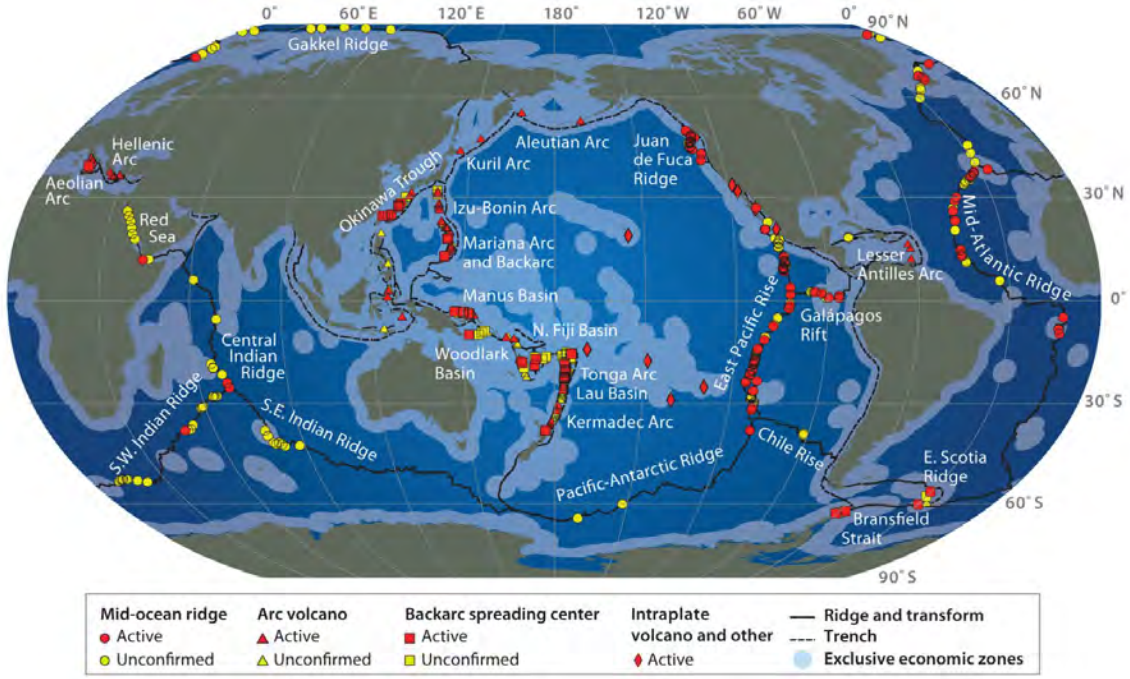
Mining could move onto the ocean floor?



Deep oceans

Seafloor sulfides

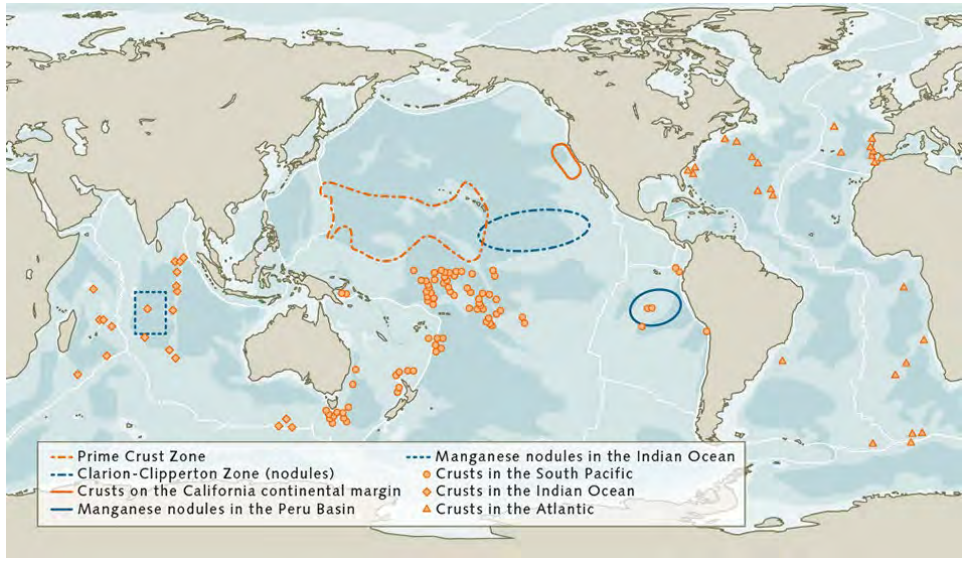
- Global resource at least 6x 10^8 tonnes sulfides
- Solwara 1 - 1.3 x 10^6 tonnes 7% Cu, 6g/t Au



Hannington et al. 2011

Polymetallic nodules

- CCZ alone hosts 21x 10^9 tonnes nodules
- 27% Mn, 1.3% Ni, 1.05% Cu, 0.2% Co
- This amounts to:
  - 10 years global Cu production
  - 300 years global Mn production
  - 450 years global Co production

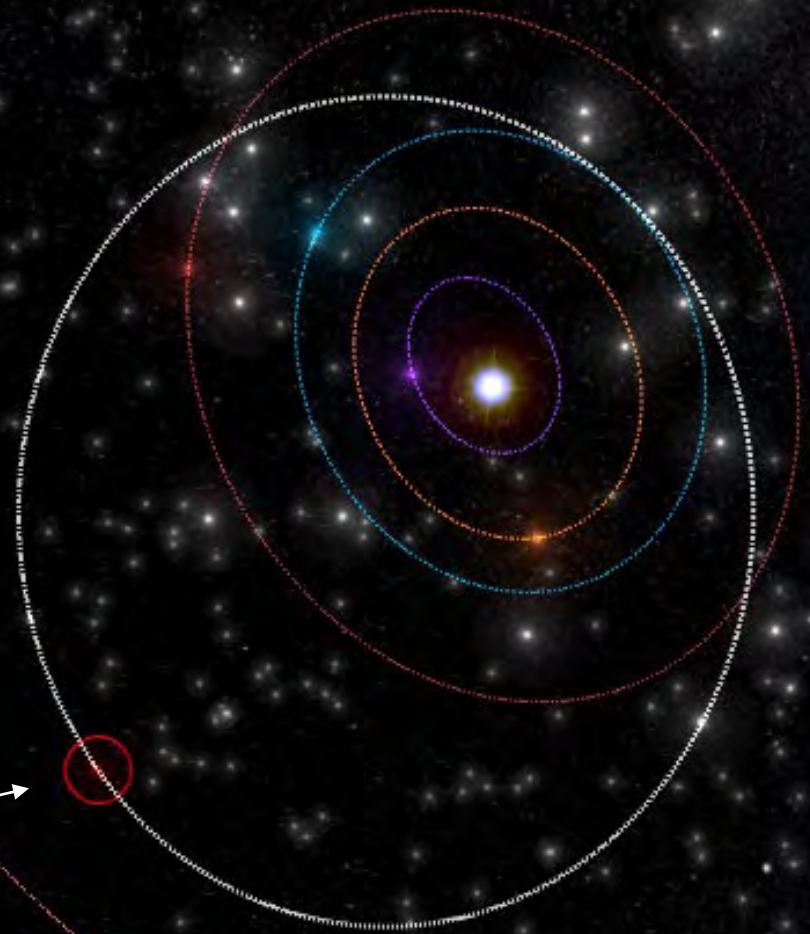


Hein 2016

NATURAL HISTORY MUSEUM

Final frontier?

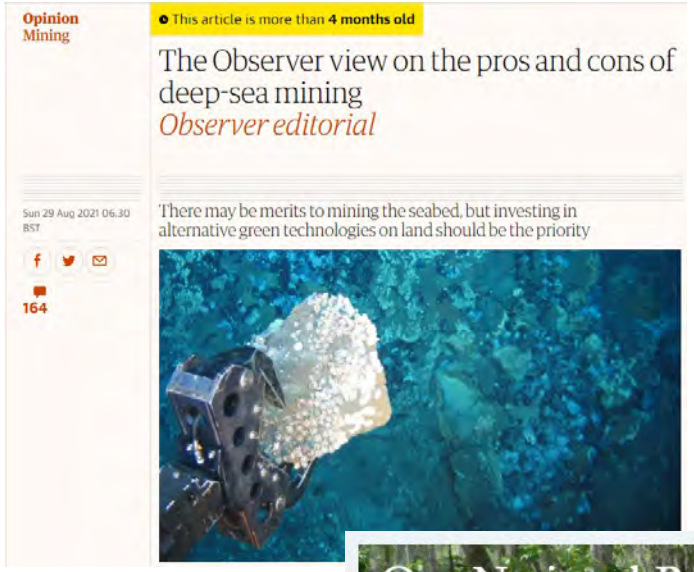
Asteroids



Asteroid KU2
4.6km in diameter
Ni-Fe-Co + volatiles
Estimated value $80 trillion
Closest approach to earth 10 million km in 2069

www.asterank.com

The debate about where our new minerals should come from is very complex


Opinion
Mining

This article is more than 4 months old

The Observer view on the pros and cons of deep-sea mining

Observer editorial

Sun 29 Aug 2021 06.30 BST

164

There may be merits to mining the seabed, but investing in alternative green technologies on land should be the priority


Marine Policy 82 (2017) 134–137

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Should deep seabed mining be allowed?

Rakhyun E. Kim

Copernicus Institute of Sustainable Development, Utrecht University, The Netherlands

ARTICLE INFO

Keywords:
Deep seabed mining
Deep sea minerals
International Seabed Authority
Benefit of humankind
Common heritage of humankind
Law of the sea

ABSTRACT

Commercial interest in deep sea minerals in the area beyond the limits of national jurisdiction has rapidly increased in recent years. The International Seabed Authority has already given out 26 exploration contracts and it is currently in the process of developing the Mining Code for eventual exploitation of the mineral resources. Priority issues have so far been feasibility and profitability of this emerging industry, while relatively little consideration has been given as to how, and to an even lesser extent, whether deep seabed mining should proceed. This article makes a case that the global community should question and scrutinize the underlying assumption that deep seabed mining is going benefit humankind as a whole before commercializing the common heritage of humankind.


Our National Parks

JOURNALISM PROGRAM FEATURE WRITING PROJECT

Mining threatens park wildlife, water, air

By MELISSA MALLIN
School of Communication
University of Miami

Posted December 19, 2013

Mining poses serious threats to national parks.

Although no longer permitted inside park borders, existing mines near and around national parks threaten wildlife, damage water quality and induce air pollution.


Journal of Environmental Law

Issues | Advance articles | Submit | Purchase | Alerts | About

Volume 26, Issue 2
July 2014

< Previous Next >

Conservation and Access to Land for Mining in Protected Areas: The Conflict Over Mining in South Australia's Arkaroola Wilderness Sanctuary

Alexandra Wawryk

Journal of Environmental Law, Volume 26, Issue 2, July 2014, Pages 291–317, https://doi.org/10.1093/jel/equ008

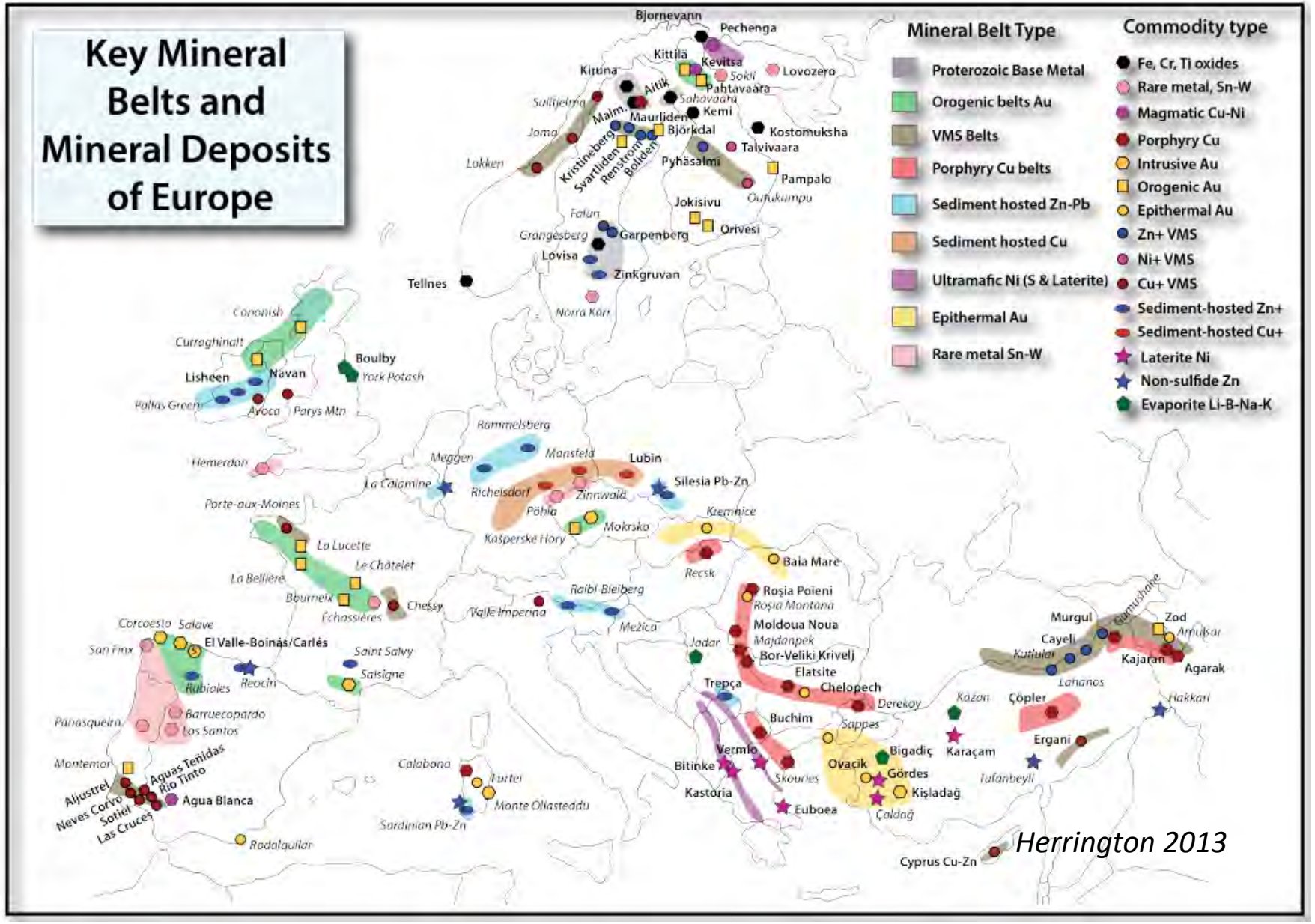
Published: 19 May 2014

- However society is going to have to choose as there is no alternative if we want to hit the climate change targets!

NATURAL HISTORY MUSEUM

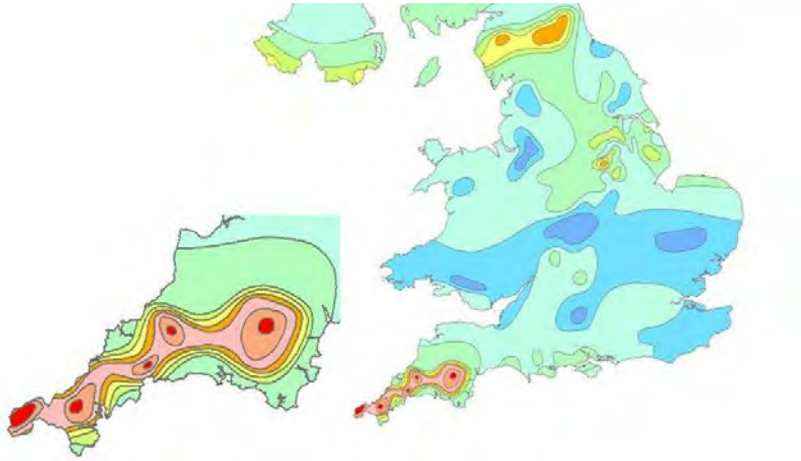
Look for minerals closer to home?

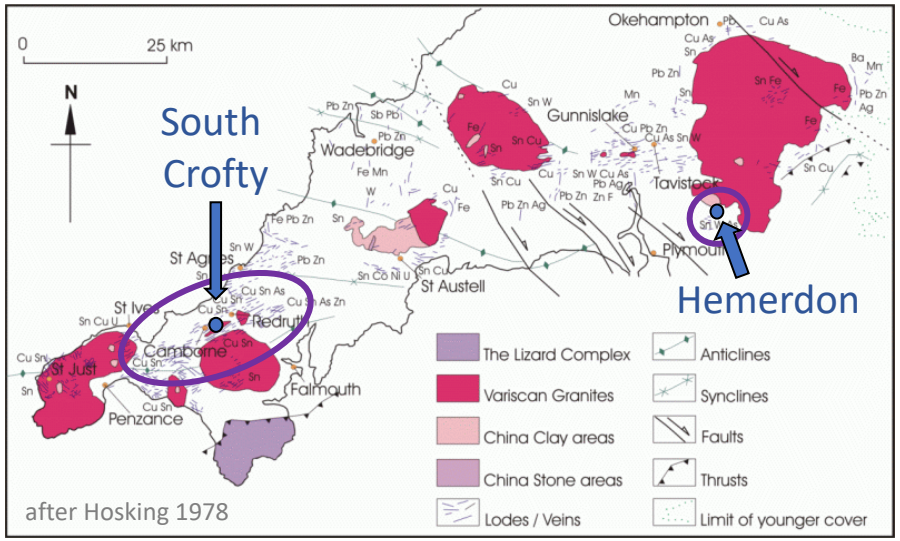
- UK could supply significant W, Li, Sn +
- Europe could be a realistic supplier of many of the green technology metals
- Still a need to source many metals like Fe, Al and Cu from farther afield

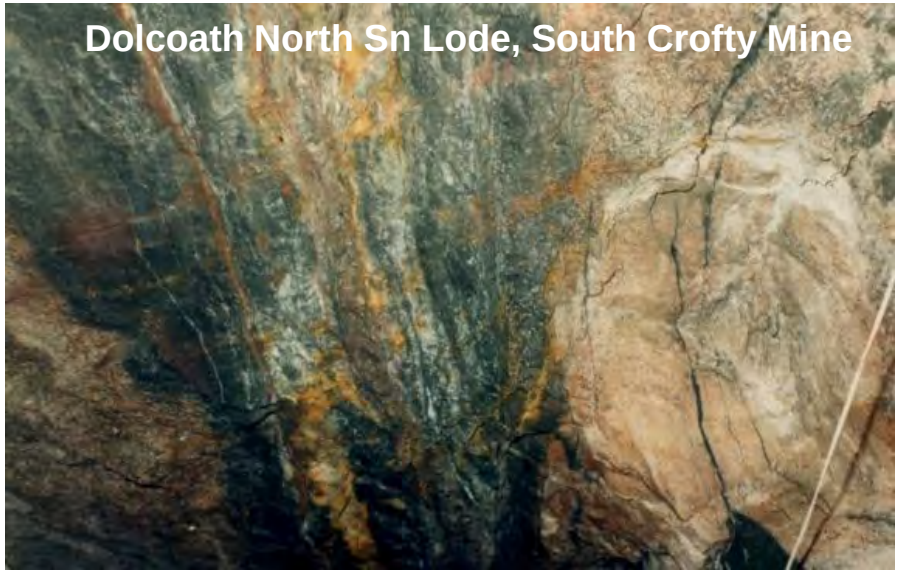


SW England

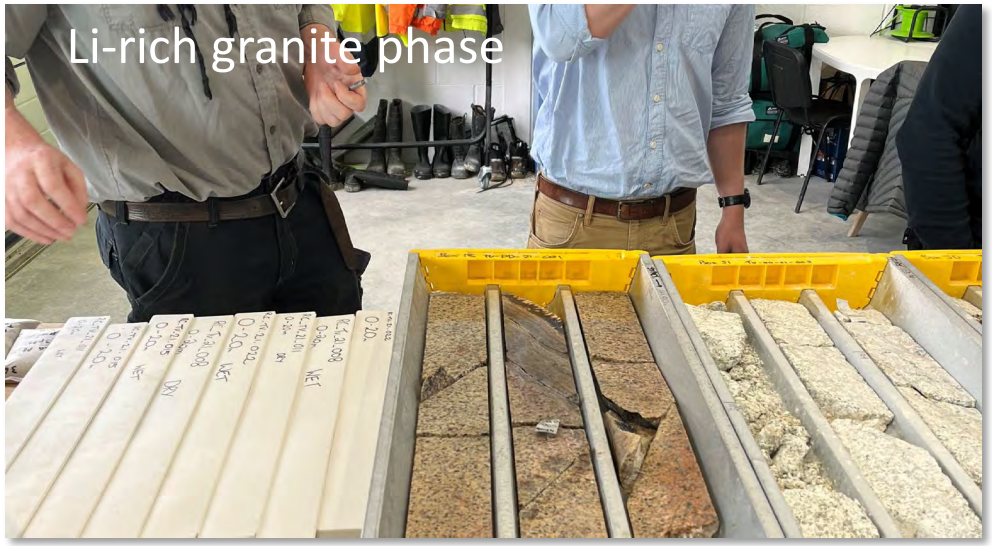
- Pre-Roman Sn and Cu discovery
- Camborne-Redruth Sn-Cu ‘giant’ field produced 310,000 tonnes Sn, 850,000 tonnes Cu
- Minor base metal (Zn-Pb-Sb-Ag) production
- South Crofty mine alone has produced 115,000 tonnes Sn, 34,000 tonnes Cu
- Hemerdon W-Sn deposit is currently being reopened
- Current activity for lithium around granite systems
- Geothermal systems – Li in brine and hard-rock







Old mine – new minerals – Cornish lithium



NATURAL HISTORY MUSEUM

Mining looked on positively in some areas

BBC NEWS

Kiruna: How to move a town two miles east

By Tabby Kinder
Kiruna, Sweden

6 March 2014

The mine provides jobs and wealth for the town's inhabitants

PlymouthLive NEWS

Plymouth's tungsten mine worth £415m as it prepares to reopen

Feasibility study shows Tungsten West's mine is economically viable and has enough ore for 27 years

By William Telford Business Editor

Bookmark Comments 7

Enter your postcode for local news and info Enter your postcode Go In YourArea

Tungsten West's Hemerdon Mine, on the edge of Plymouth

Cornish Lithium raises £6 million in new Crowdfunding Raise

THE TIMES

Investors crowd in to fund Cornish Lithium

Fundraising 'sells out in 15 minutes'

IET January 2023

But less welcome elsewhere

POLITICO

Portugal to scrap lithium mining project

Locals spent years fighting to halt the project, a cornerstone of Lisbon's raw materials policy.

BY AITOR HERNÁNDEZ-MORALES AND SOFIA DIOGO MATEUS

April 27, 2021 | 10:11 pm

Serbia

Rio Tinto plans for Serbia lithium mine suspended after protests

Local authorities put $2.4bn project on hold after scale of opposition shakes country's government

Associated Press in Belgrade

Thu 16 Dec 2021 18.34 GMT

Le Télégramme

Publié le 23 octobre 2015

Manif anti-mines. L'avis en jeu

ESG considerations are paramount for projects

COP 26 had clear messaging relevant for minerals

The four main goals:

- **Secure global net-zero by mid-century and keep limit of 1.5°C temperature increase "within reach"**
- Adapt to protect communities and natural habitats
- Mobilise finance
- Collaborate to deliver

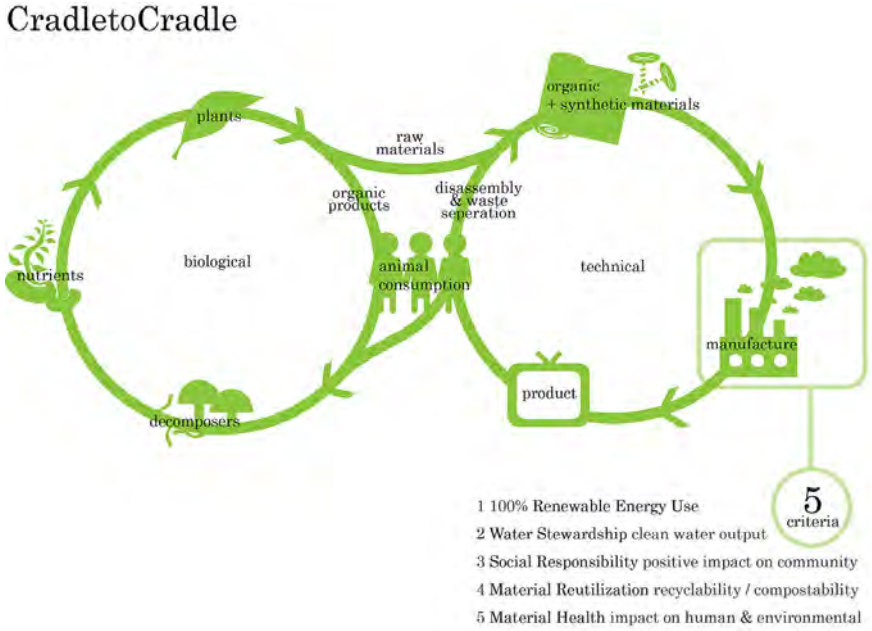
Agenda items:

- Mobilising public and private finance
- **Accelerating the transition to clean energy**
- Elevating the voice of young people and demonstrating the critical role of public empowerment
- **Ensuring sustainable land use**
- Adapting to climate hits and addressing the loss and damage
- Progressing meaningful participation by women and girls
- **Looking at innovative science**
- **Driving towards zero-emission transport**
- Promoting environmental action in cities

New types of mines?

- Less impactful and ‘net positive’ for the planet and people

Flambeau mine, Wisconsin



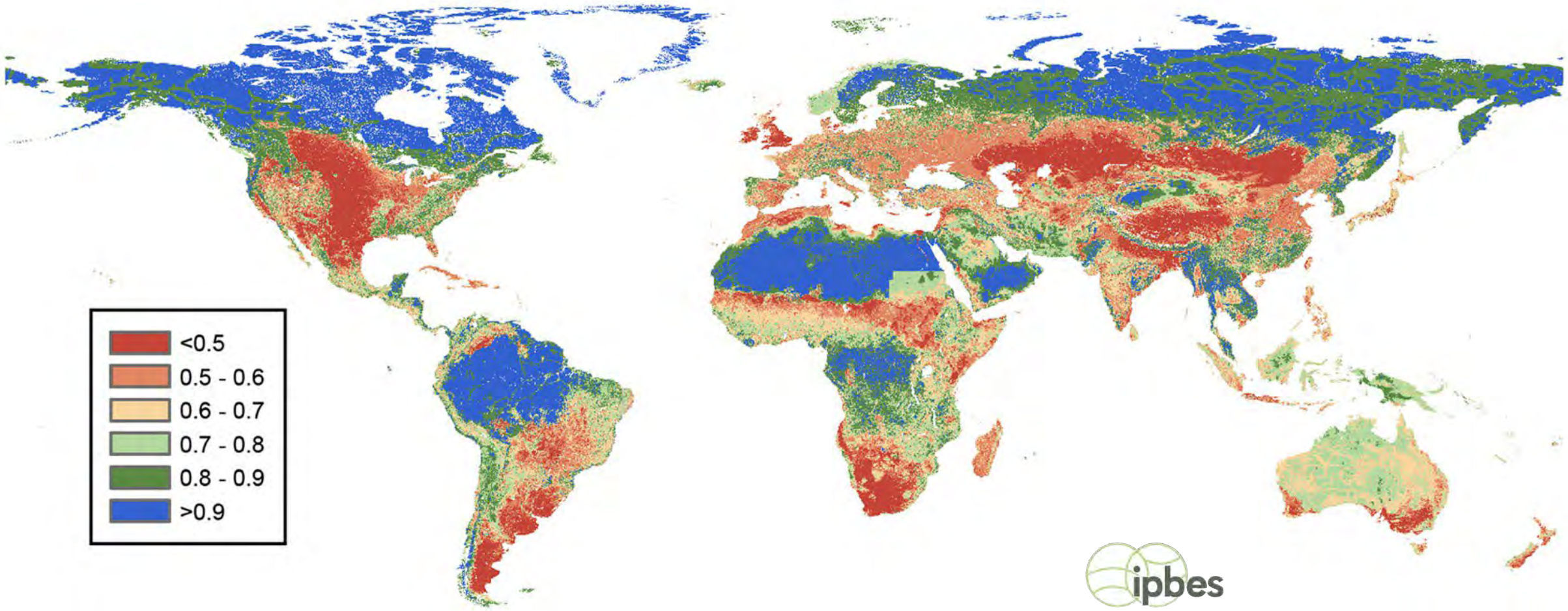
Ellen MacArthur Foundation

- There is a clear need to protect and reconstruct the ecosystem
- Develop a ‘cradle to cradle’ approach to mining not a ‘cradle to grave’!

New frontier exploration now needs to think *biodiversity*

NATURAL HISTORY MUSEUM

Estimated Biodiversity Intactness Index – blue = intact; red = very degraded

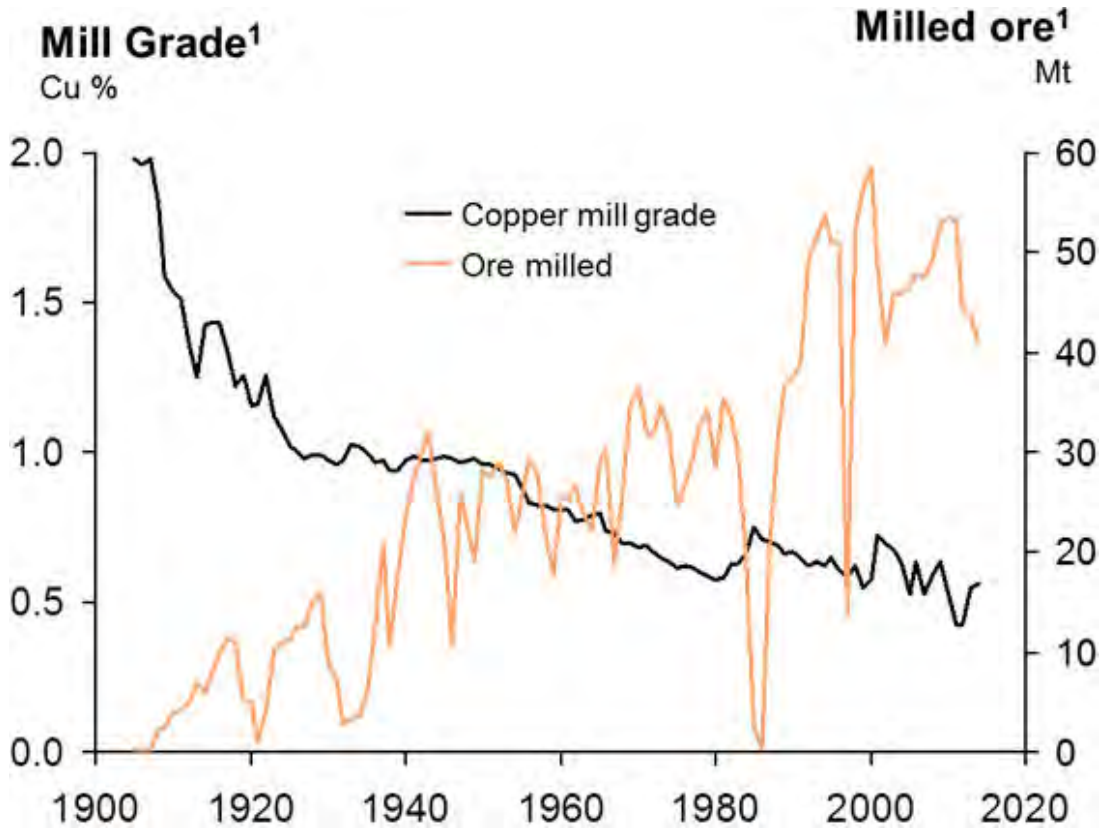


Sanchez-Ortiz et al. in preparation

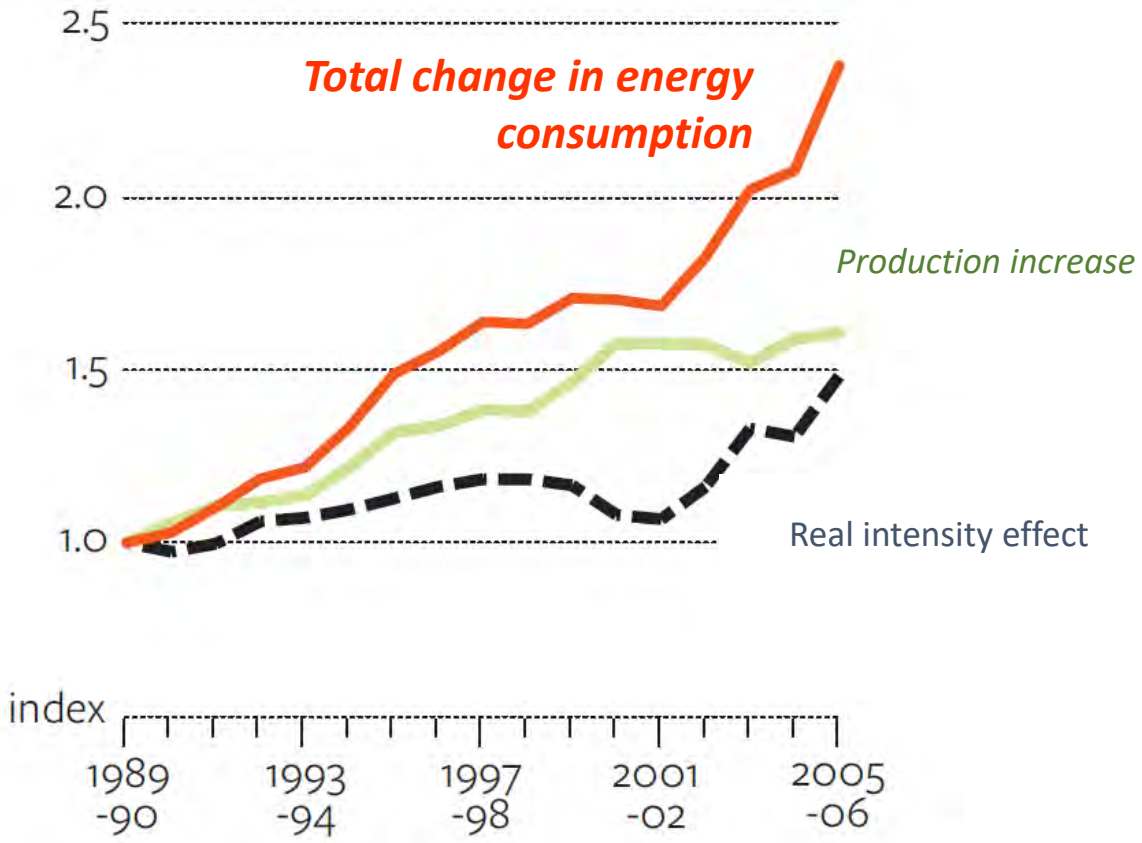
ipbes
Science and Policy for People and Nature

Mining is energy hungry – this has to change

- As the grade of ore goes down, more ore has to be milled, more energy is consumed
- Mining needs to be decarbonized too



source: Intelligence Mine



Source: Sandu & Syed, (2008)
Trends in Energy Intensity in Australian Industry

New technologies can help - using microbes?

Reduced ores (sulfides)

Fungal leaching

Abiotic (chemical) leaching

Oxidized ores (laterites etc.)

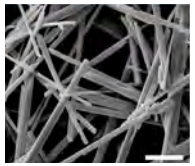
Oxidative (bio)leaching

Reductive (bio)leaching

PLS

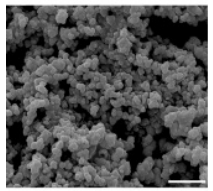
fungi

oxalate



CoC_2O_4

urea



$CoCO_3$

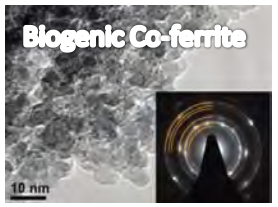
H_2S

SRB

CoS

Direct reductive bio-conversion

Bio-nanomaterials



- Low carbon extractive technologies
- Direct formation of functional downstream materials

Deep eutectic solvents – new type of chemistry

- **New field of chemistry applicable to complex ores**

ELSEVIER

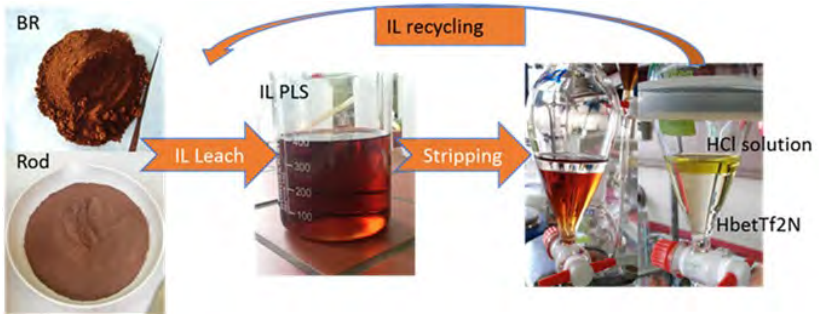
Hydrometallurgy
Volume 164, September 2016, Pages 125-135

Selective leaching of rare earth elements from bauxite residue (red mud), using a functionalized hydrophobic ionic liquid

Panagiotis Davris [a], Efthymios Balomenos [a, b], Dimitrios Panias [a], Ioannis Paspaliaris [a]

Show more

+ Add to Mendeley Share Cite



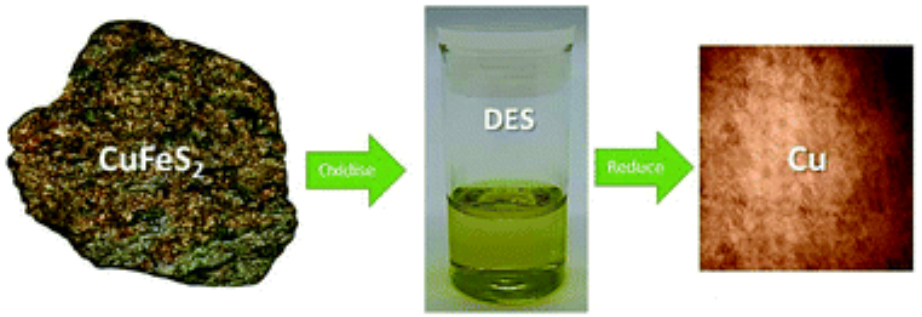
Issue 23, 2019
Previous Article Next Article

From the journal:
Green Chemistry

Direct extraction of copper from copper sulfide minerals using deep eutectic solvents†

Check for updates

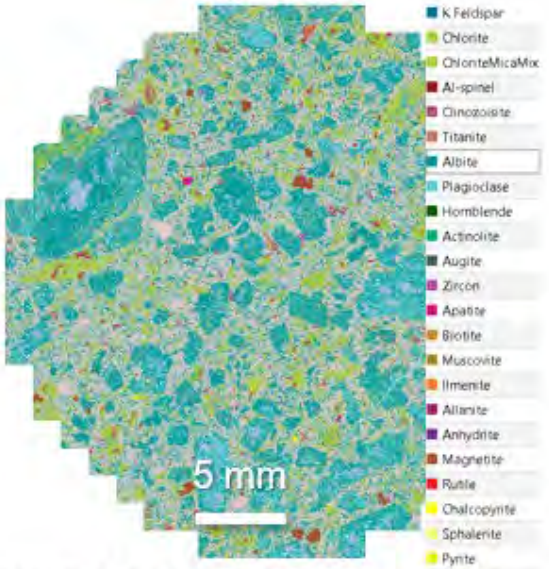
Syahrie Anggara [a], Francesca Bevan [a], Robert C. Harris [a], Jennifer M. Hartley [ab], Gero Frisch [b], Gawen R. T. Jenkin [c] and Andrew P. Abbott *[a]



New ways of mining demands much better mineralogical analysis

Whole rock geochemistry

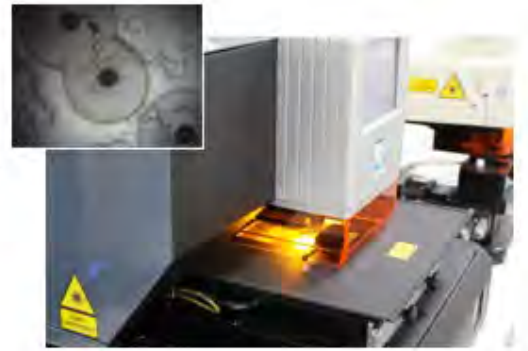
Zeiss axio-imager thin section scan

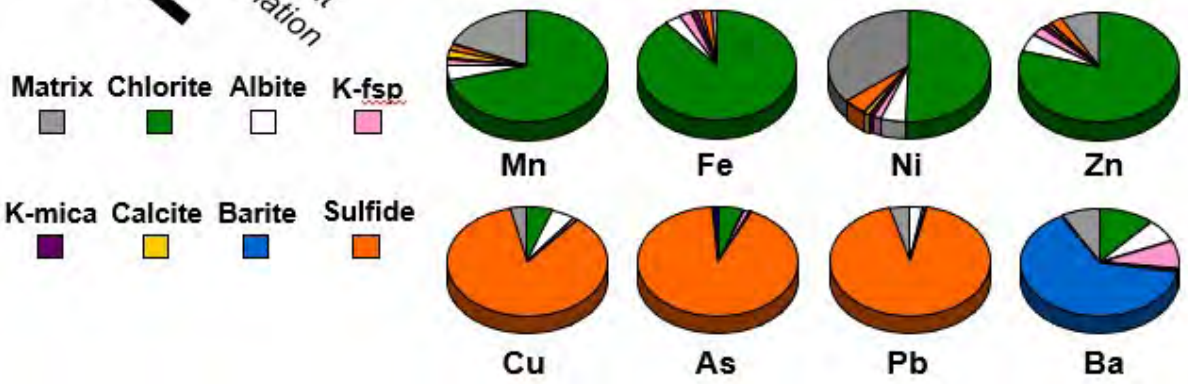


TESCAN TIMA automated SEM mineral classification and modal quantification

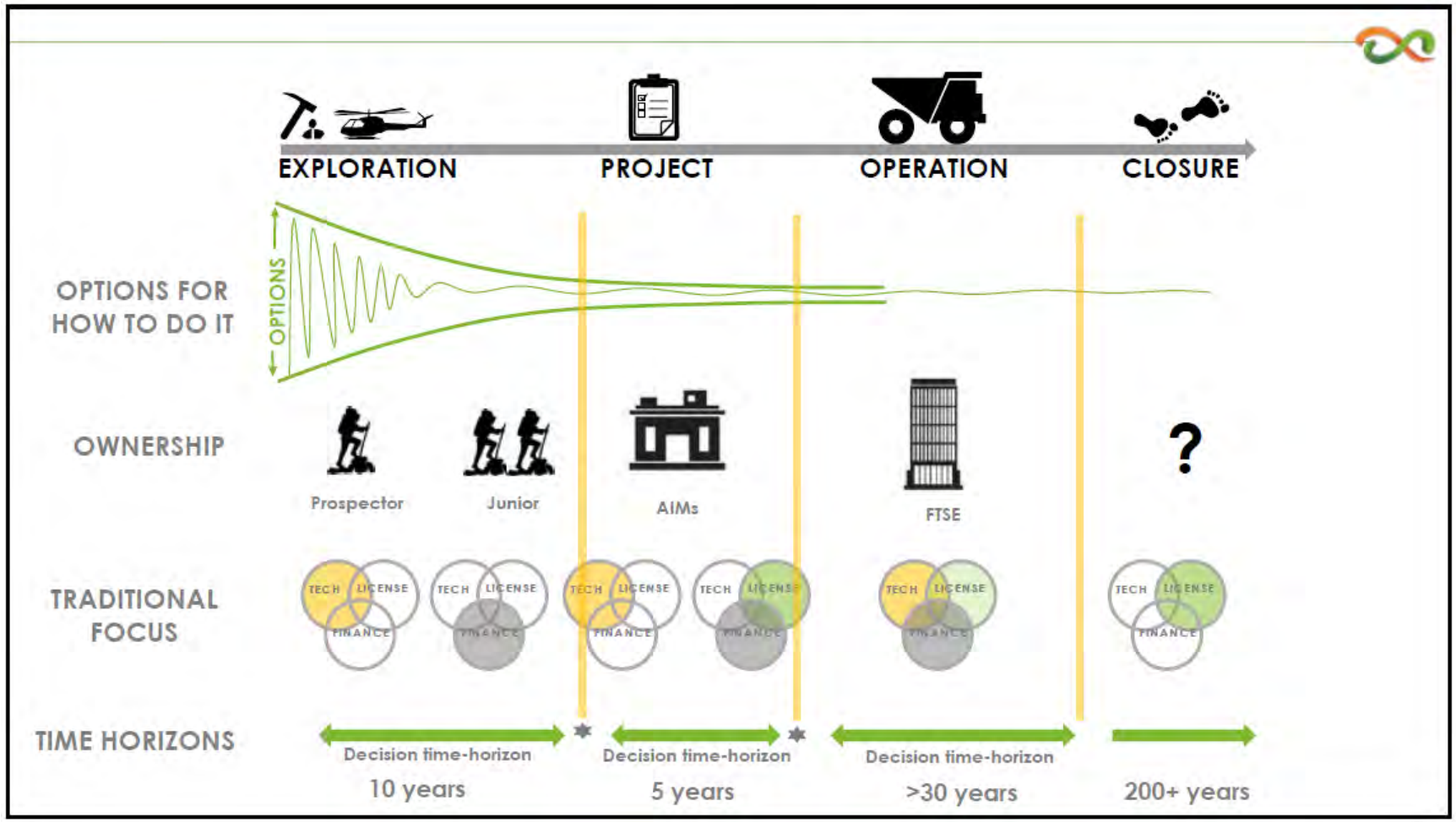
Correlative XRD analysis

LA-ICP-MS for major, minor and trace element analysis





Revolutionising the way mining workflow is structured

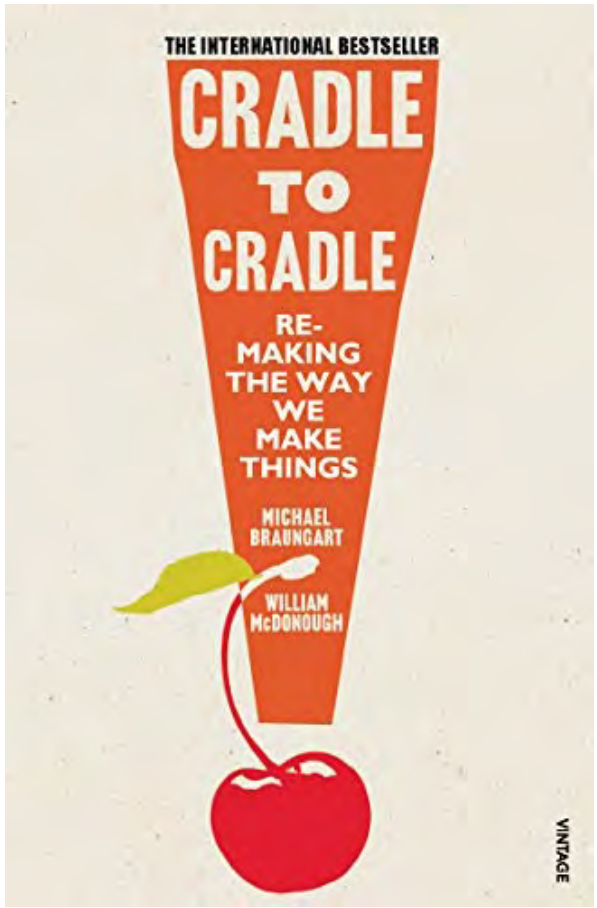


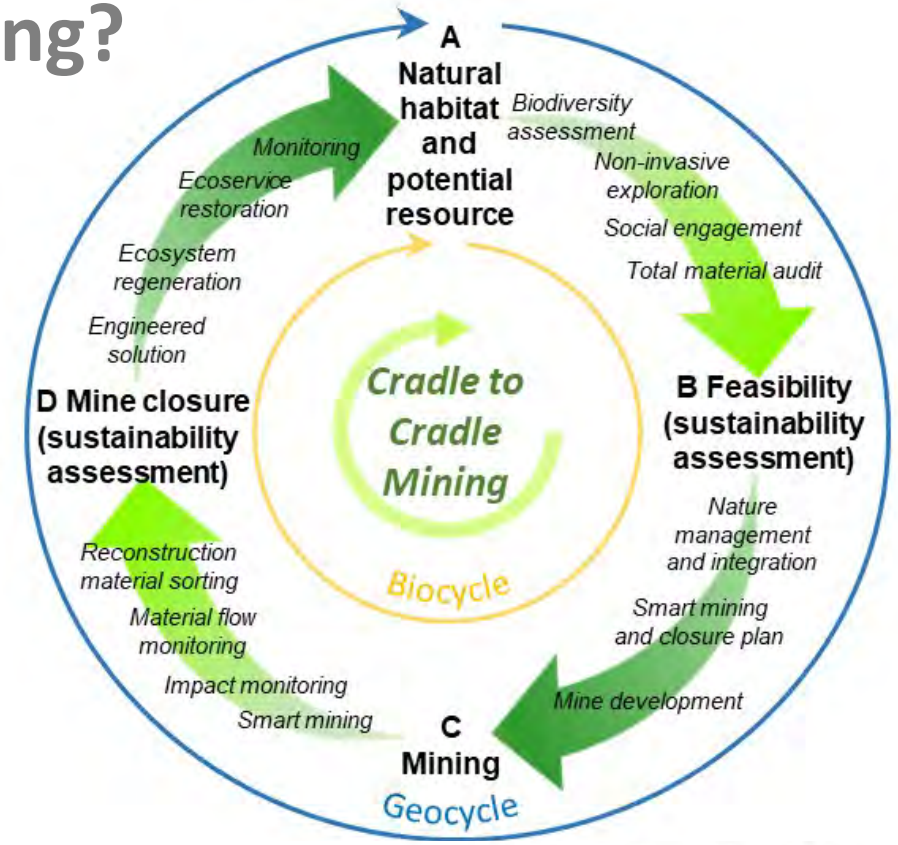
Satarla 2021

Mining projects too readily divided into separate 'business units'

- Exploration is a loss maker (*pressures to reduce costs*)
- Projects may increase stock values (*not conducive to fully testing the potential negatives*)
- Operations are what really makes the money (*tend to be milked dry for profit?)*
- Closure plans have to pick up the pieces of short-cuts in operations plans
- End users need to be a part of this too!

Cradle to Cradle mining?





Mine Closure 2022 - M Tibbett, AB Fourie & G Boggs (eds)

doi:10.36487/ACG_repo/2215_0.02

Cradle-to-cradle mining: a future concept for inherently reconstructive mine systems?

R Herrington *Natural History Museum, UK*
M Tibbett *University of Reading, UK*

Mine Closure 2022
Proceedings of the 15th International Conference on Mine Closure
4–6 October 2022 | Brisbane, Australia

Mining projects should be following the principle of ‘cradle to cradle’

- Mines are temporary interventions
- Mines should therefore be designed with built in
- Projects designed from the start to create net positive outcomes people and planet

Takeaway messages

- There is a clear need to mine an increased volume of a range of metals in order to deliver the net zero pledge of decarbonisation
- This new sourcing must be done in a way that there is a net positive impact for both people and the planet
- Optimised recycling and use of waste a key component of the package but is not enough
- Mining is both inevitable and essential and it is for society to choose where that will happen
- Mining should follow ‘cradle to cradle’ principles
- It is prudent to source at least some of our new metals closer to home since:
  - Regenerating old districts may have a lower impact
  - This could drive other social and economic benefits (localisation of industry, clean up of environmental legacies, positive biodiversity impacts, stronger supply chains etc.)

Papers available online