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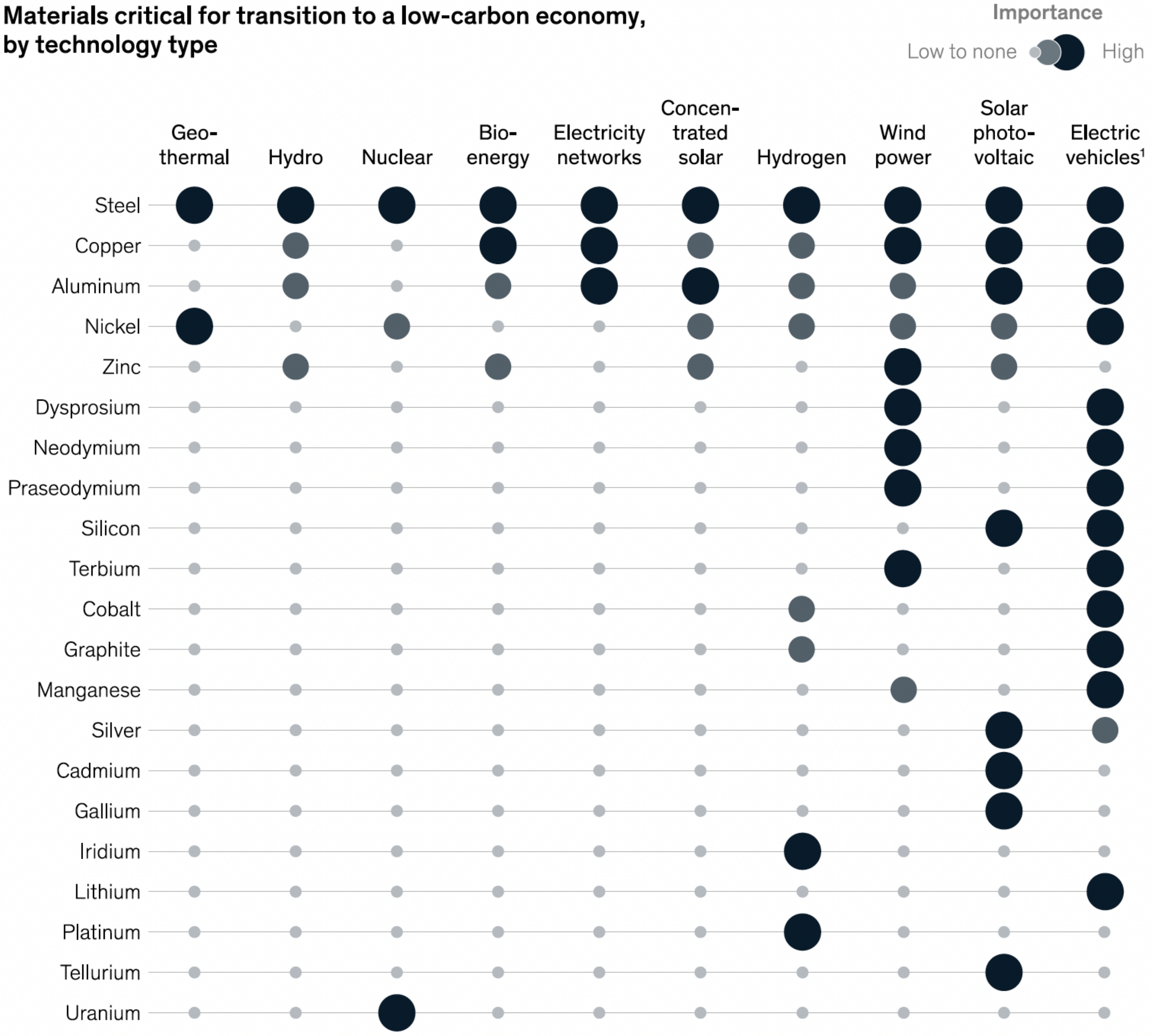
UNIVERSITY OF OXFORD
NET ZERO
ZERO INSTITUTE
OXFORD EARTHSCIENCES
THE REALITY OF NET ZERO
SEMINAR SERIES

Equitable Access to the Natural Resources Needed to Achieve Net Zero

Michael Kendall

Motivation

The transition towards a low-carbon or post-carbon ‘Net-Zero’ future - unprecedented demand on a wide range of natural resources:



[1]Includes energy storage.
Source: *Critical raw materials for strategic technologies and sectors in the EU*, A foresight study, European Commission, Mar 9, 2020; *The role of critical minerals in clean energy transitions*, IEA, May 2021; McKinsey analysis

McKinsey analysis, 2021

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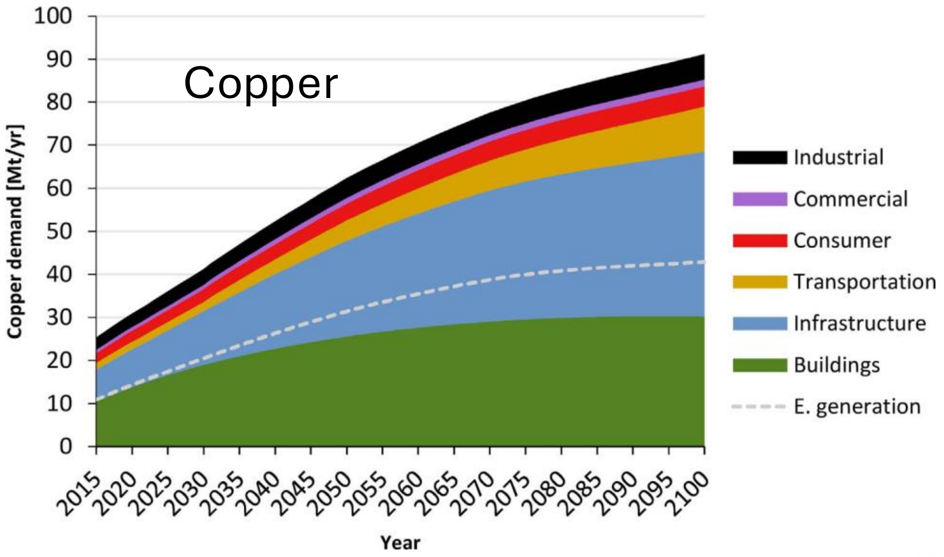

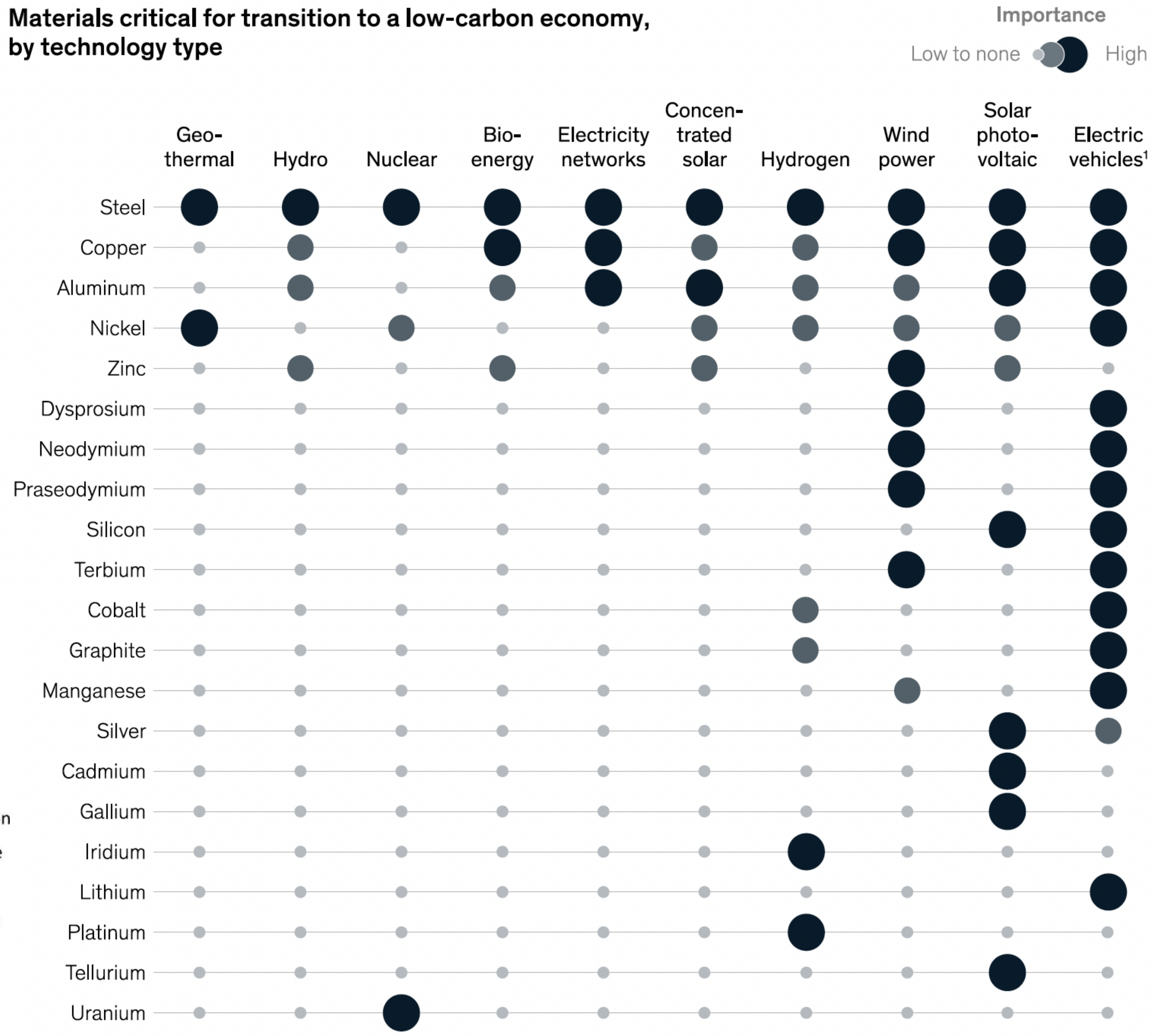

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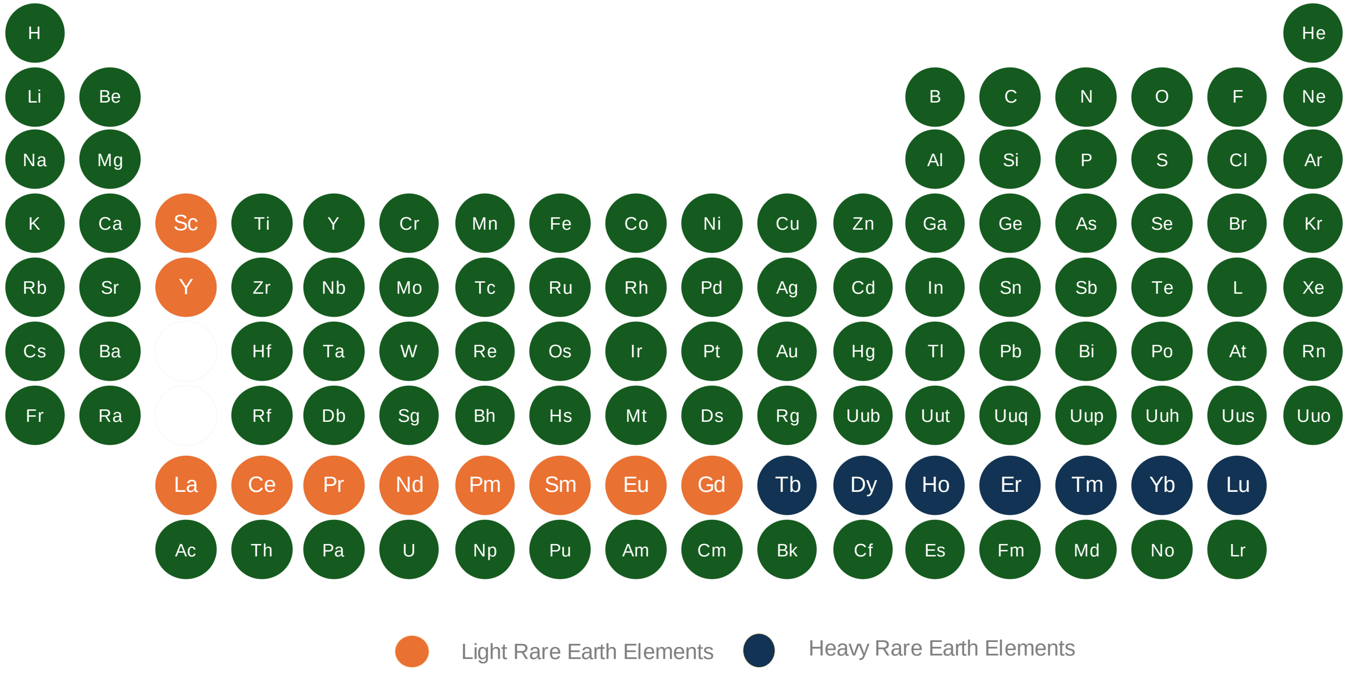
McKinsey analysis, 2021

Rare Earth Elements (REE) are versatile and their unique properties play a critical role in a wide array of **high-performance devices** and **industrial processes**, including steel production.

REE are essential for the Net Zero energy transition

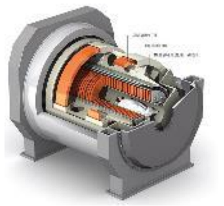


Pr Nd Dy

Wind turbine

Pr Nd Sm Gd Tb Dy

Electric vehicle

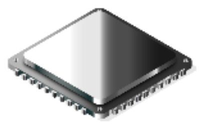


Pr Nd

MRI Scanner

Y Pr Nd Sm Gd Er

Defence



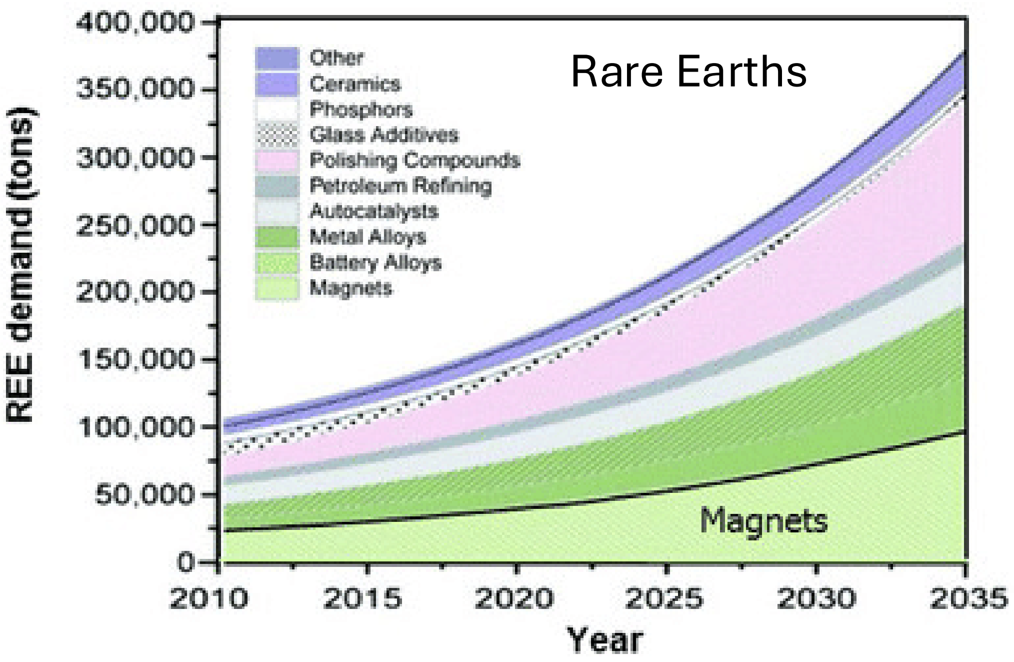
Sc Y Nd Eu Tb Dy

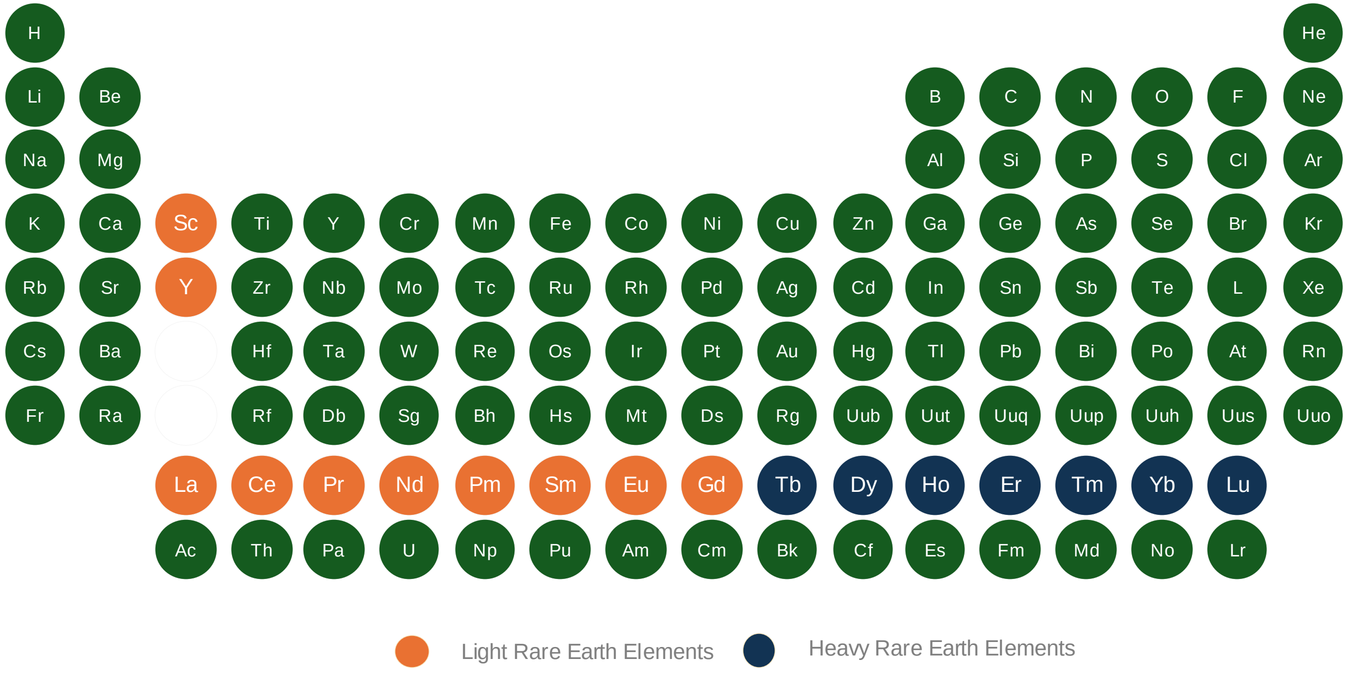
Semiconductor

La Pr Nd Eu Tb Dy

Smart phone

REE are essential for the Net Zero energy transition





Pr Nd Dy

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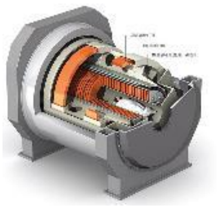

Pr Nd

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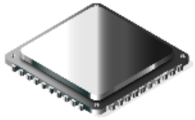

Sc Y Nd Eu Tb Dy

Semiconductor

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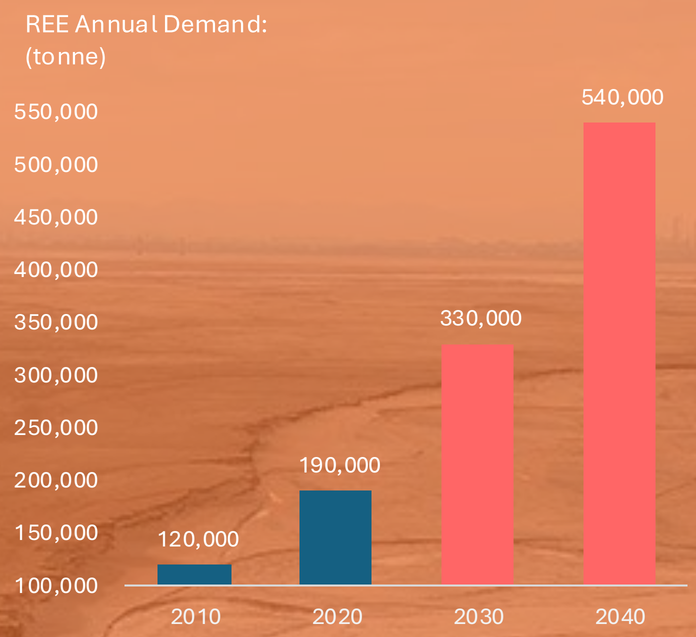
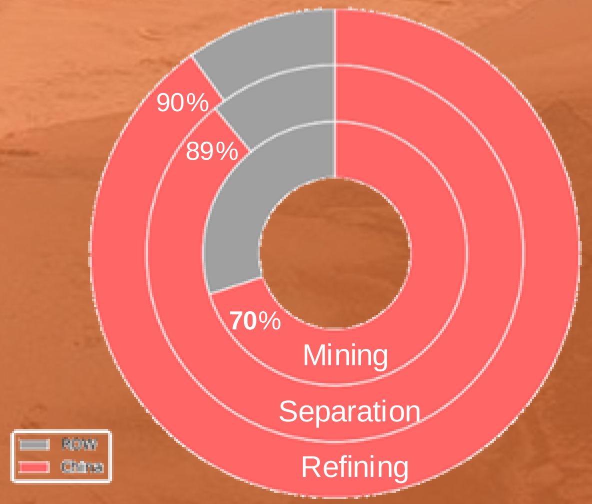
Smart phone

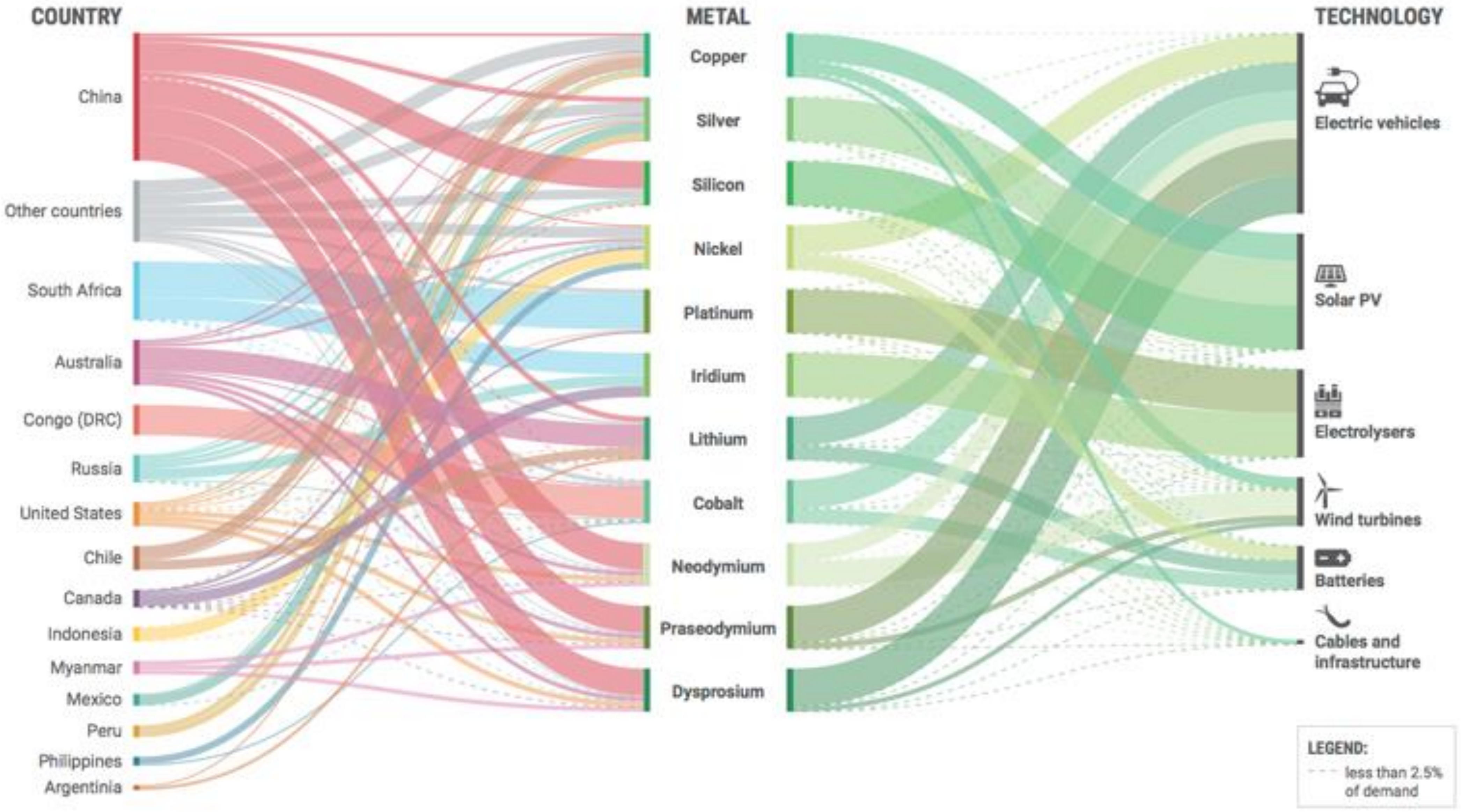
Global REE economic landscape



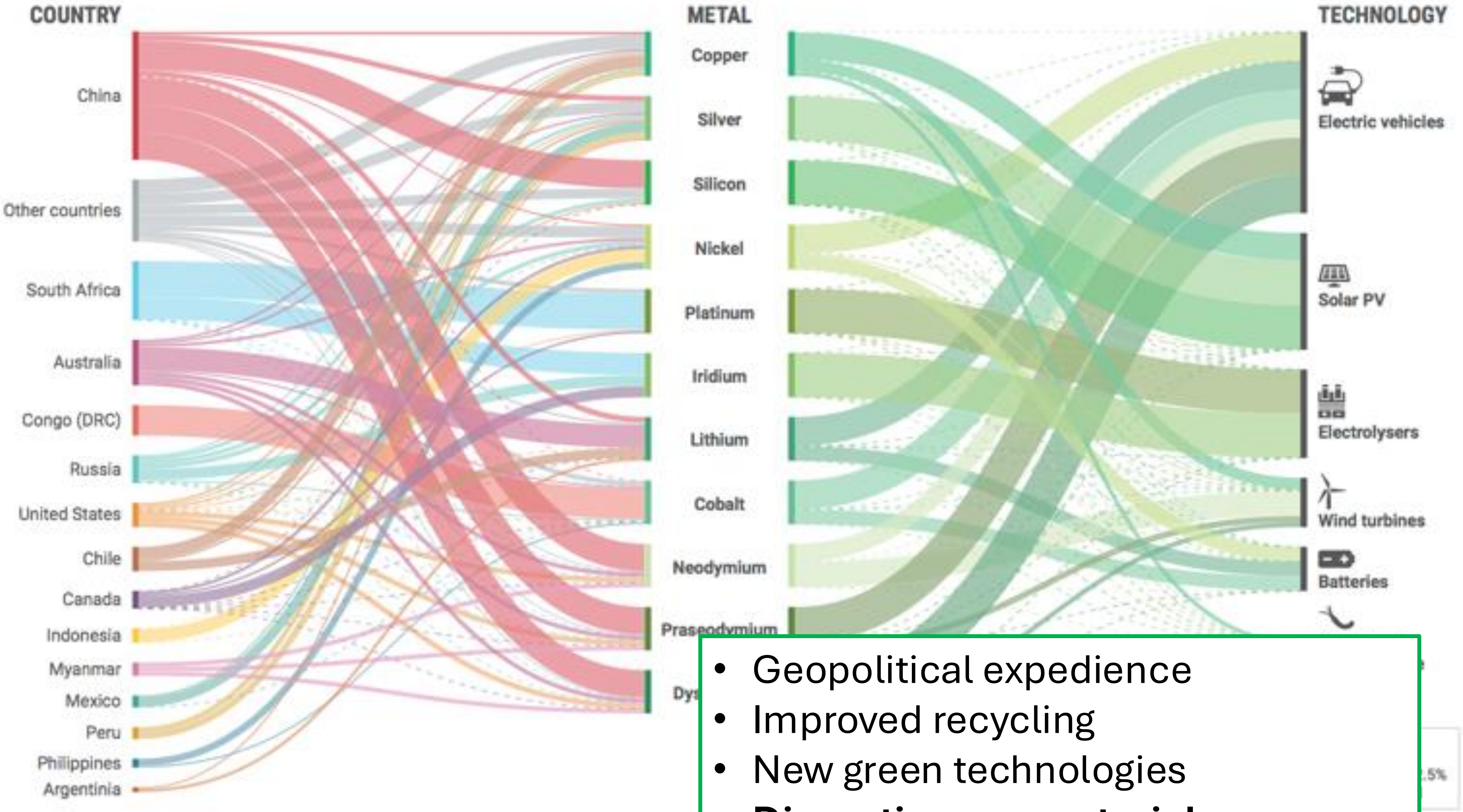


CHINA
RoW

Critical metals for the Energy Transition



Challenges: Increased demand - Security of supply - Diversity of sources - Sustainable recovery



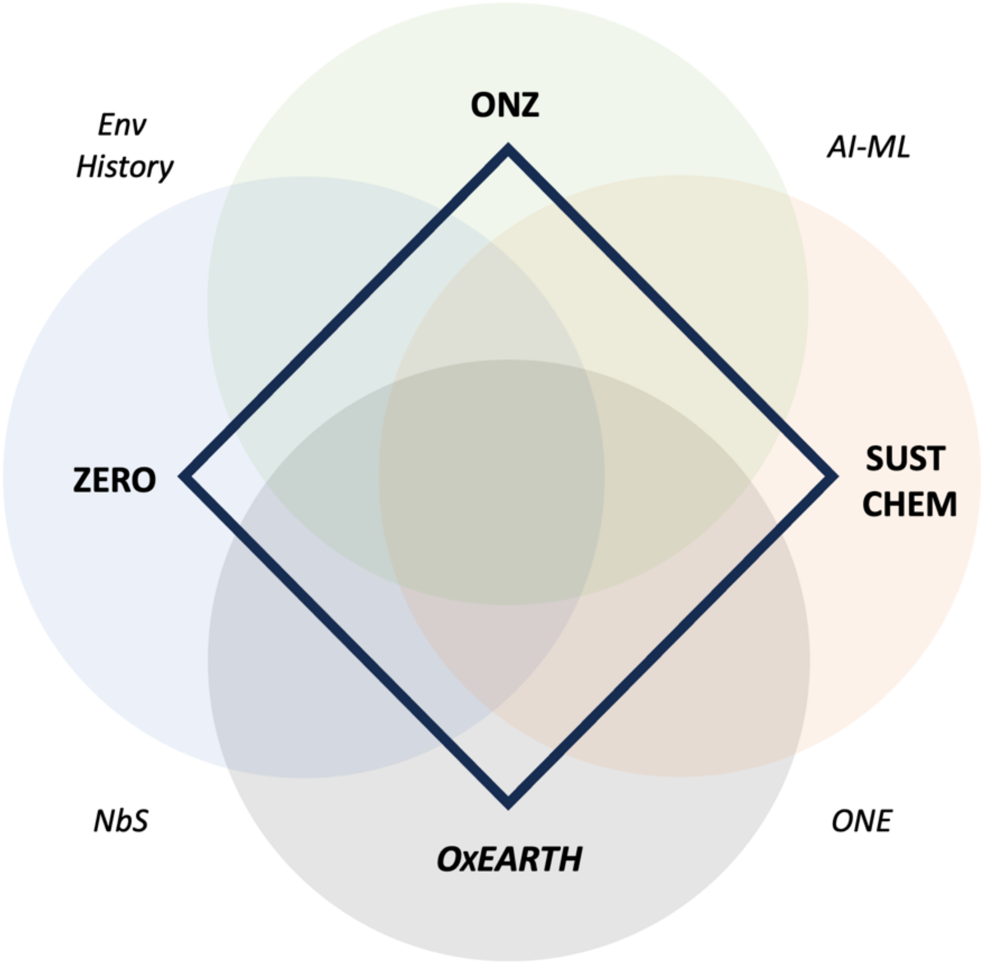
- Geopolitical expedience
- Improved recycling
- New green technologies
- **Disruptive raw materials recovery**

Key challenges!

- How do we supply these resources to a growing and energy hungry population?
- How do we do this in an environmentally responsible way?
- How do we this in an equitable way?
- How do manage a quickly changing geopolitical landscape?

Oxford initiatives – net zero and the environment

- Oxford Net Zero programme – how to reach net zero
- ZERO Institute – zero carbon energy systems
- Sustainable chemistry
- *New CDT in AI-ML – Intelligent Earth*
- *Nature based solutions; decarbonizing fuel; Oxford network for the environment*



Oxford Equitable Access to sustainable Resources for a Thriving Habitat (OxEARTH)

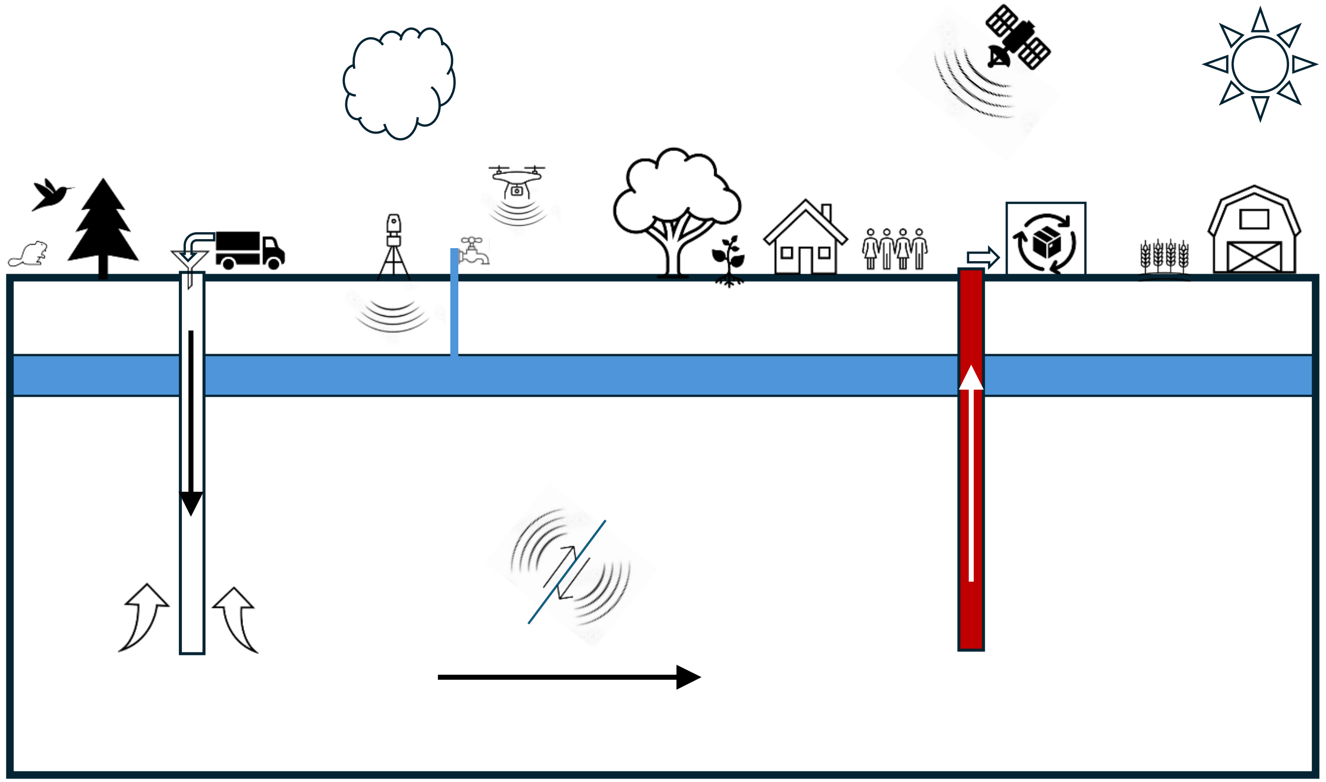
How do we sustainably resource our transition to a net zero world?

- Cross-departmental institute (9 departments across 2 divisions)
- Sustainably resources and waste management: geothermal, biomaterials, CO_2 storage, H_2, He, critical metals, ...
- Cross-disciplinary approach (ethics, policy, biology, chemistry, law, engineering, economics, ...)
- Stakeholder engagement (industry, policy makers, regulators, NGOs, public)

Oxford EARTH - Ensuring equitable access to sustainable resources for a thriving habitat

The research themes that will be covered in the programme are:

1. Critical metals (e.g., copper, lithium, REEs, etc,)
2. Critical gases (hydrogen and helium)
3. Microbial metal recovery and reuse (e.g., waste recycling, biomanufacturing, etc.)
4. Environmental impact (e.g., bioremediation, waste treatment, hazards, etc.)
5. Circular economy (supply chain analysis, recycling, repurposing)
6. History and ethics; social license
7. Policy and regulation



Mine of the future?

Examples of current progress

Microbial mineral bioproduction

MICROBIAL BIOTECHNOLOGY
Open Access

OPINION | Open Access

Will tomorrow's mineral materials be grown?

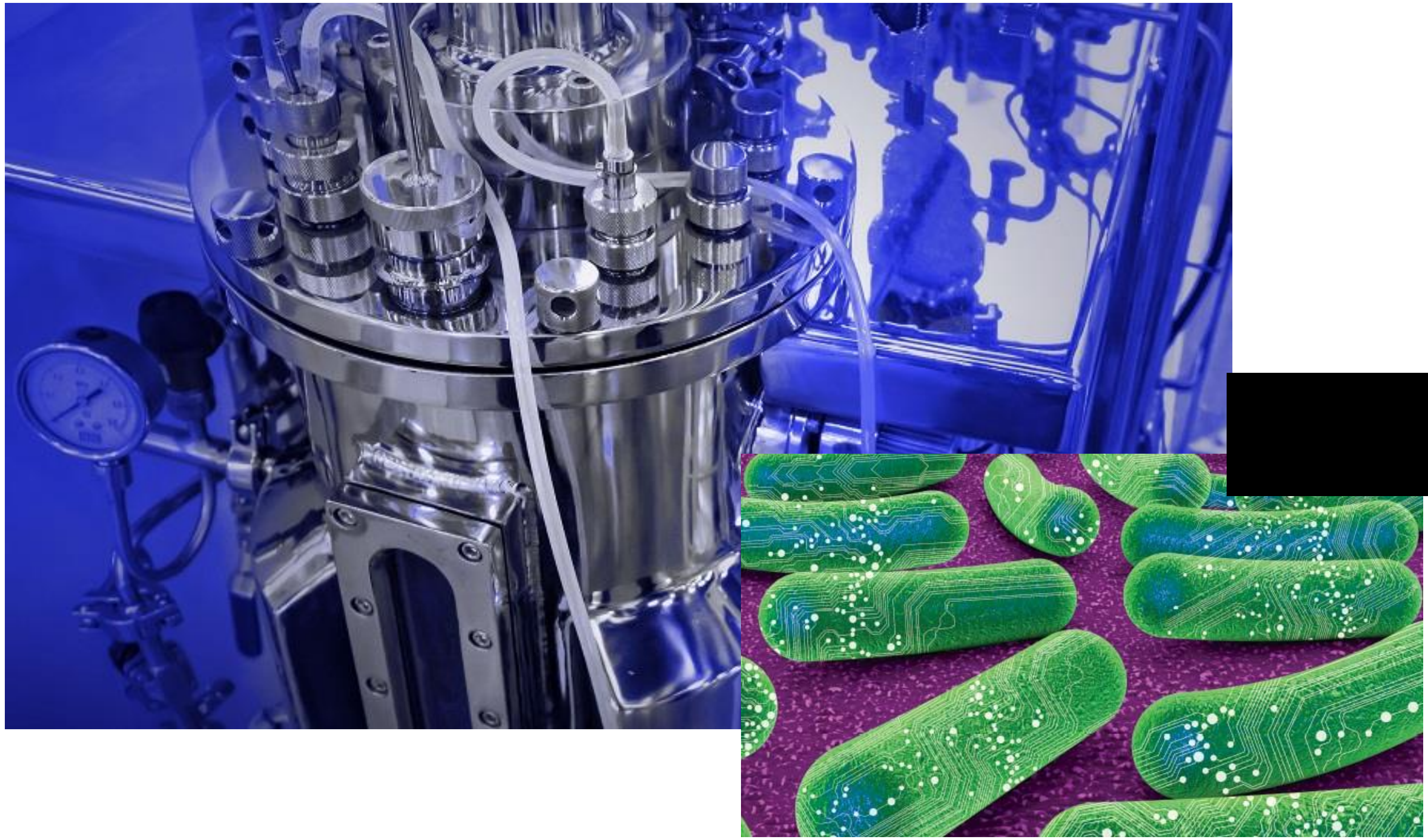
Julie Cosmidis

First published: 31 July 2023 | https://doi.org/10.1111/1751-7915.14298

Julie Cosmidis – Department of Earth Sciences
Harrison Steel – Department of Engineering

OXFORD EARTHSCIENCES

Microbial biomanufacturing

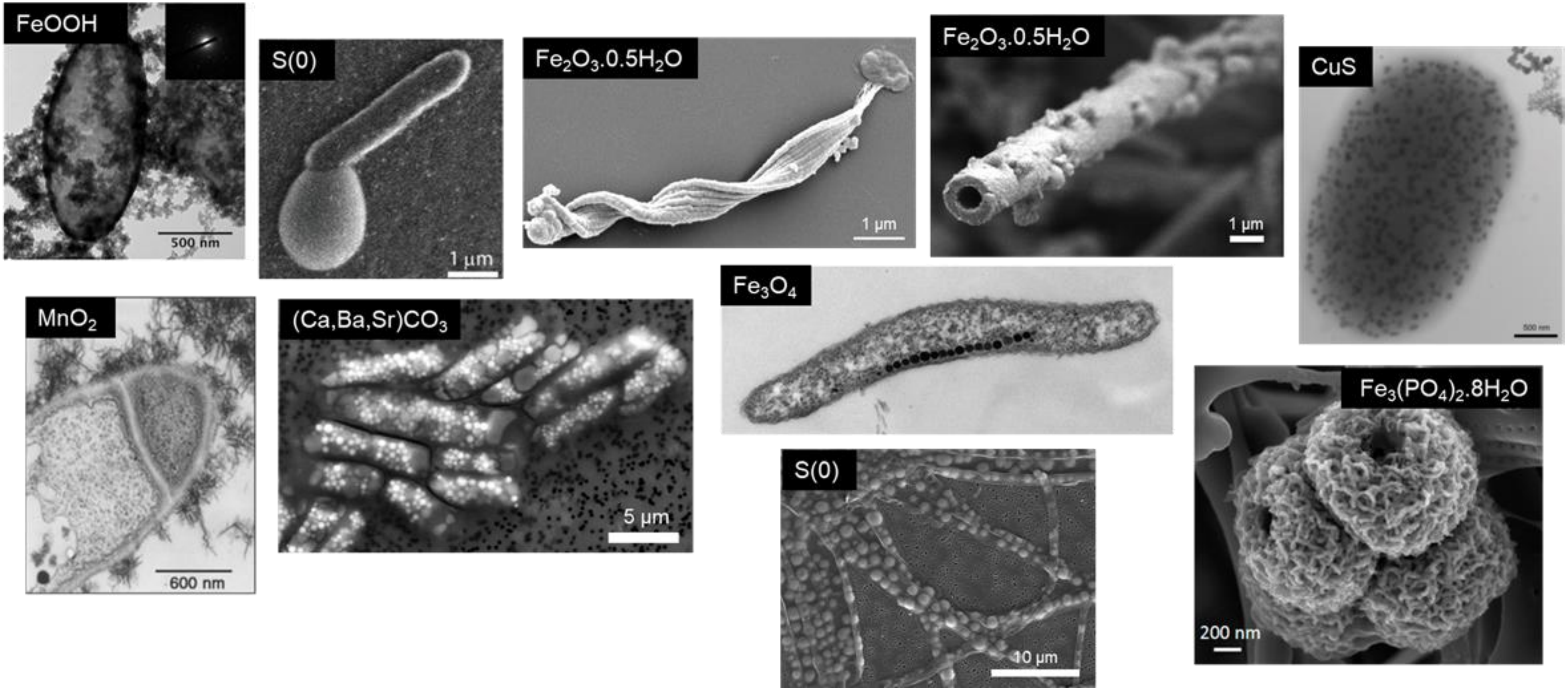


- Food
- Pharmaceuticals
- Bulk chemicals
- Biofuels
- Polymers
- **Minerals?**

Advantages: Energy efficiency, <u>Reduced Carbon emissions</u>, Reduced Waste, Circularity

Opportunities: Bioengineering and synthetic biology

Microbes produce biominerals

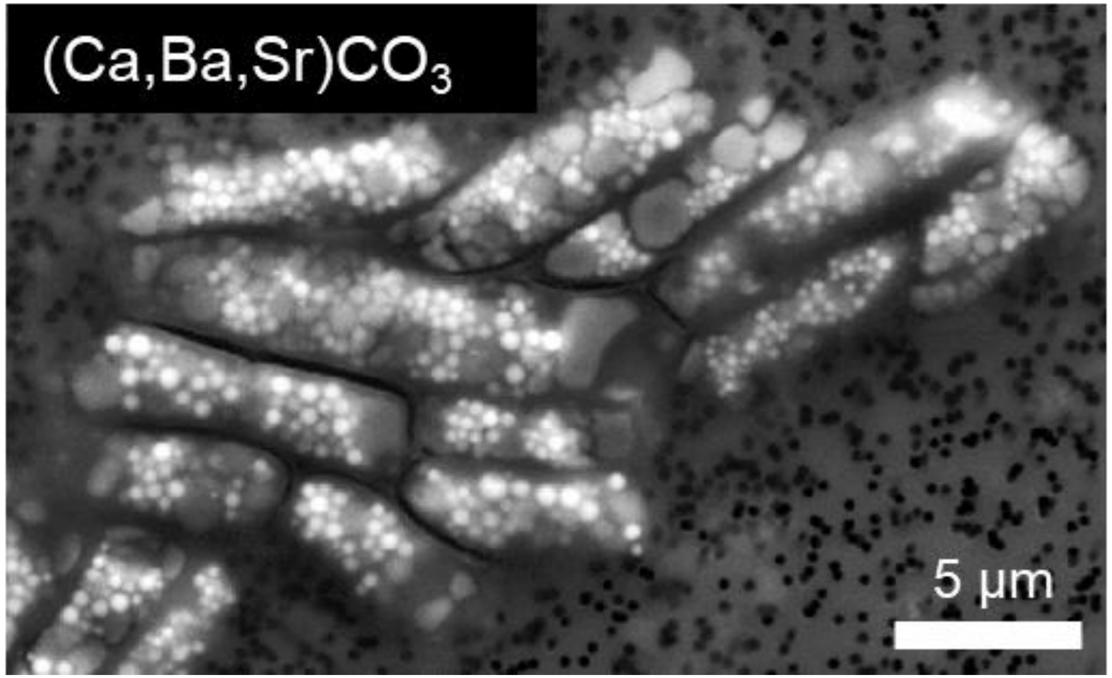


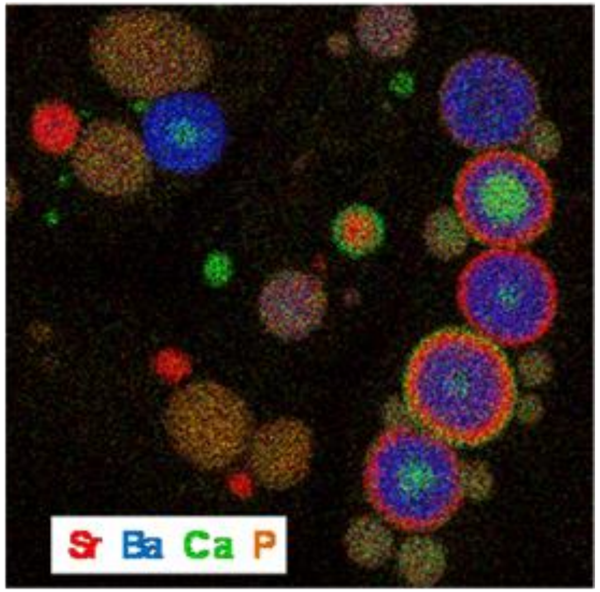
Microbial biominerals incorporate elements covering **most of the periodic table**

Metal biorecovery

Microbes can **concentrate and mineralize elements** even when present in the environment at **trace concentrations**

Applications: biomining metals from waste sources, bioremediation of contaminants



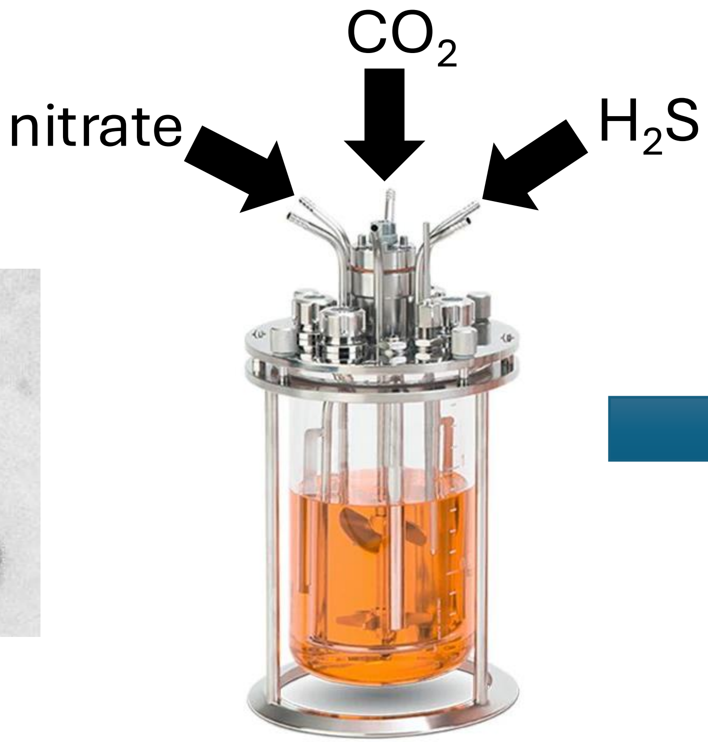


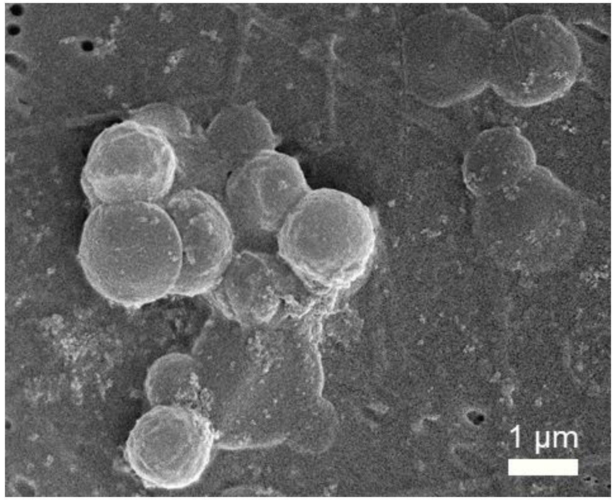
Intracellular Sr accumulation by a carbonate-forming cyanobacterium

Mineral material biomanufacturing

Microbes can produce **mineral materials with well-defined properties for technological applications** (energy storage, construction, etc.)

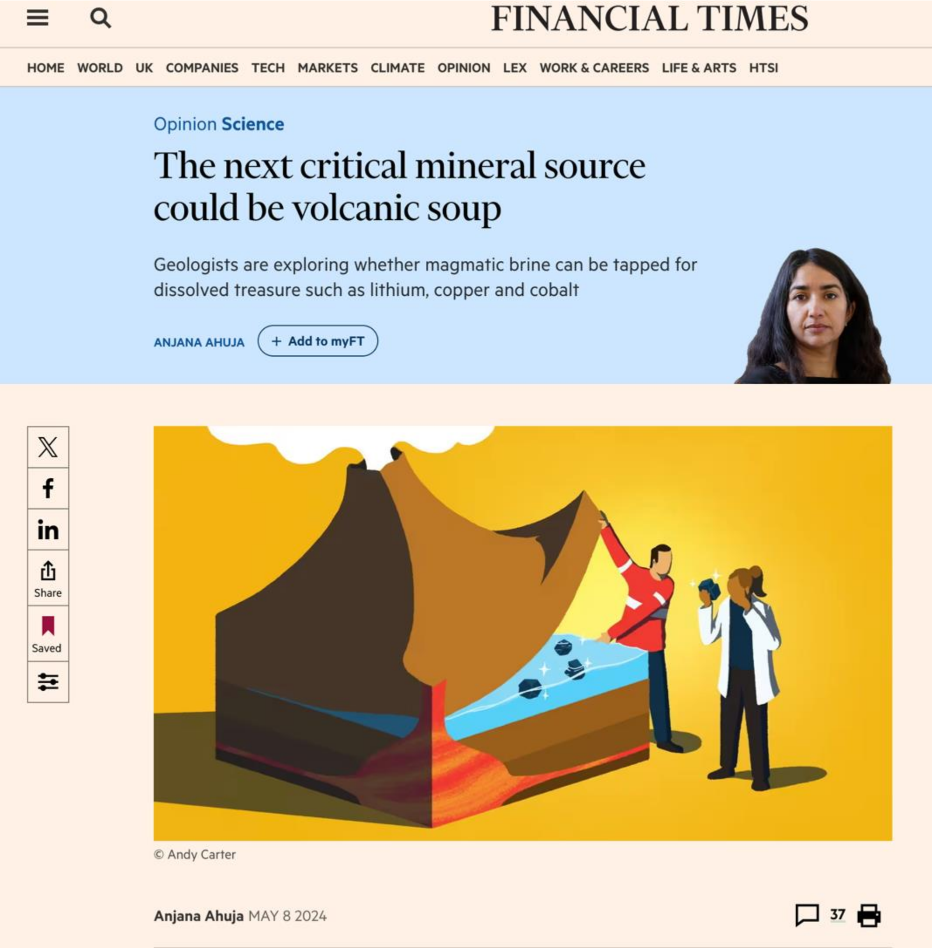
Sulfuricurvum kujiense





Carbon-encapsulated sulfur biominerals
for **Li/S battery applications**

Co-recovery of metals and geothermal energy


FINANCIAL TIMES

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Opinion Science

The next critical mineral source could be volcanic soup

Geologists are exploring whether magmatic brine can be tapped for dissolved treasure such as lithium, copper and cobalt

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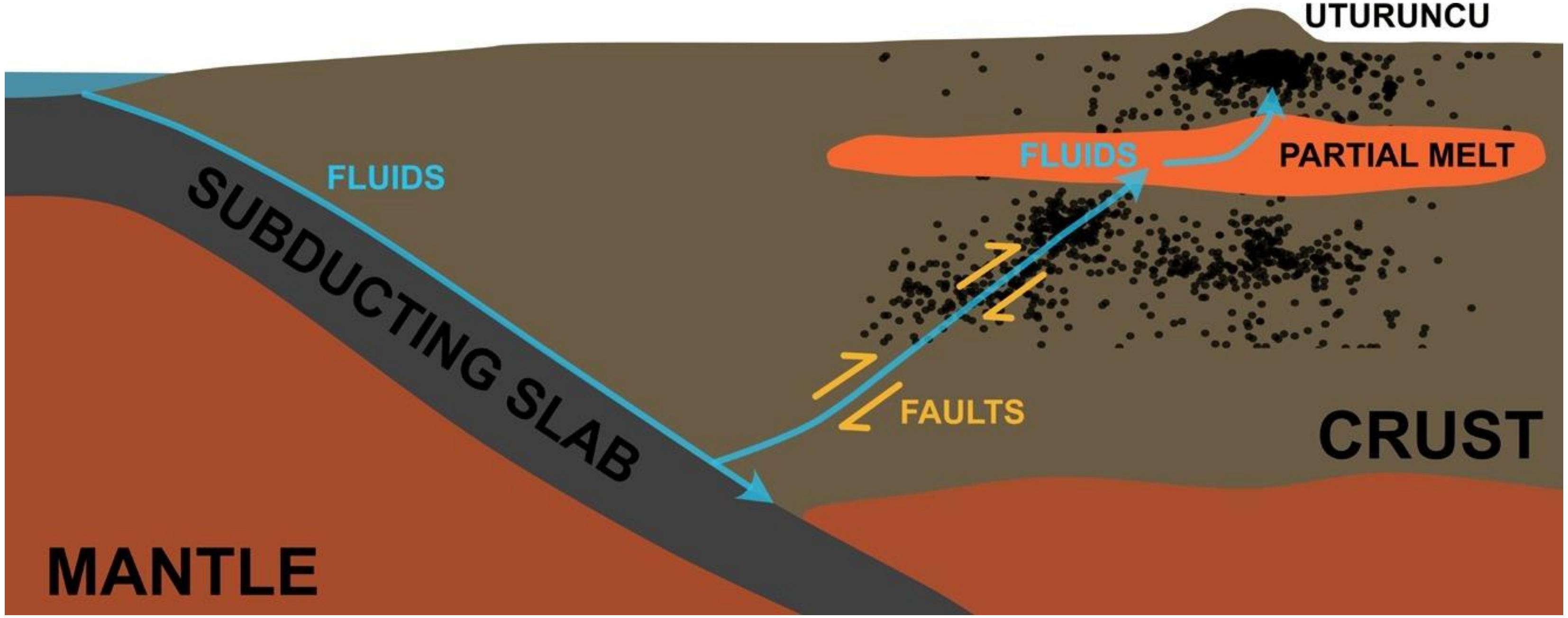
Jon Blundy and others – Department of Earth Sciences
Dermot O'Hare – Department of Chemistry

Earth – the ultimate recycler



Hudson et al., 2022

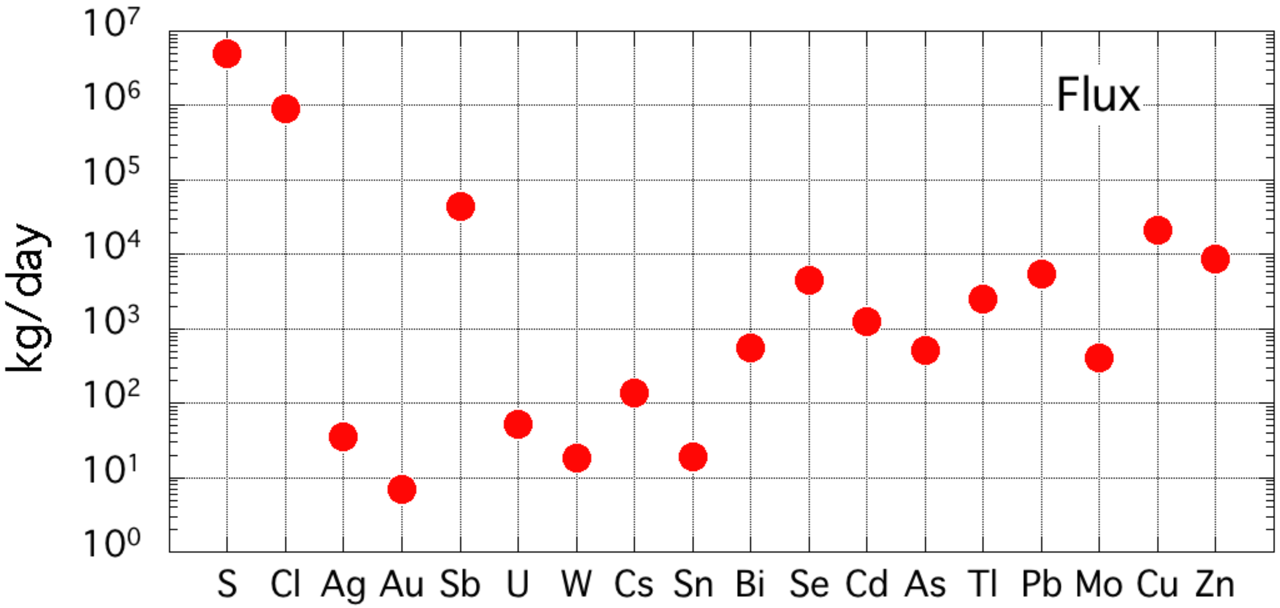
Fluids driven of the subduction slab are rich in critical metals and REEs

Mining for metals – extinct volcanoes (hard to find)

Photo – Jon Blundy

Volcanoes – rich source of critical metals (easy to find)

Gas flux - Mount Etna



Edmunds et al, 2018

Source: Jacopo Werther, Wikipedia

- Volcanic gases carry a **diverse portfolio** of metals and metalloids in huge abundance
- Much more metal is retained in trapped, condensed fluids **underground**
- Approximately **2,000** degassing volcanoes worldwide
- Can this resource be accessed economically?

Mining volcanoes – a blueprint

The economic potential of metalliferous sub-volcanic brines

Jon Blundy[1], Andrey Afanasyev[2], Brian Tattitch[3], Steve Sparks[3], Oleg Melnik[2], Ivan Utkin[2] and Alison Rust[3]

[1]Department of Earth Sciences, University of Oxford, South Parks Road, Oxford OX1 3AN, UK
[2]Institute of Mechanics, Moscow State University, 1 Michurinsky Prospekt, Moscow 119192, Russia
[3]School of Earth Sciences, University of Bristol, Wills Memorial Building, Bristol BS8 1RJ, UK

Royal Society Open Science

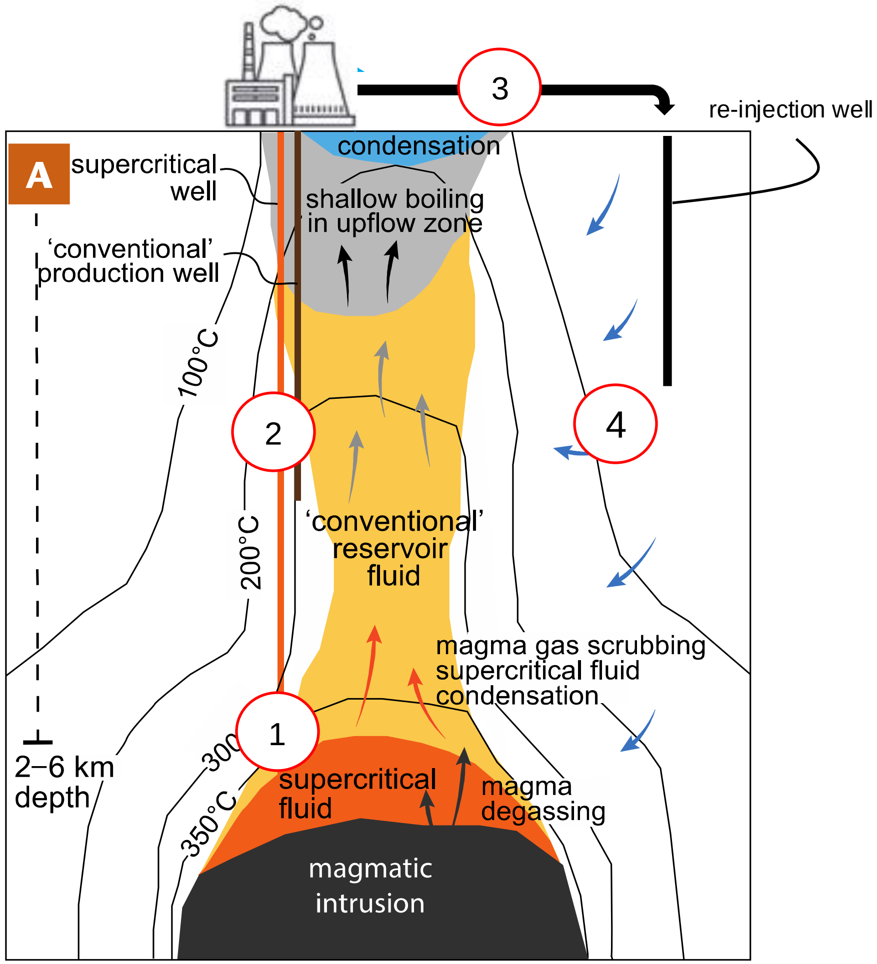
Whakaari (White Island), New Zealand

Photo: R. Arculus

Disruptive strategies for metals recovery

2. Mechanical extraction of mineral scales

1. Direct metals capture from hot fluids



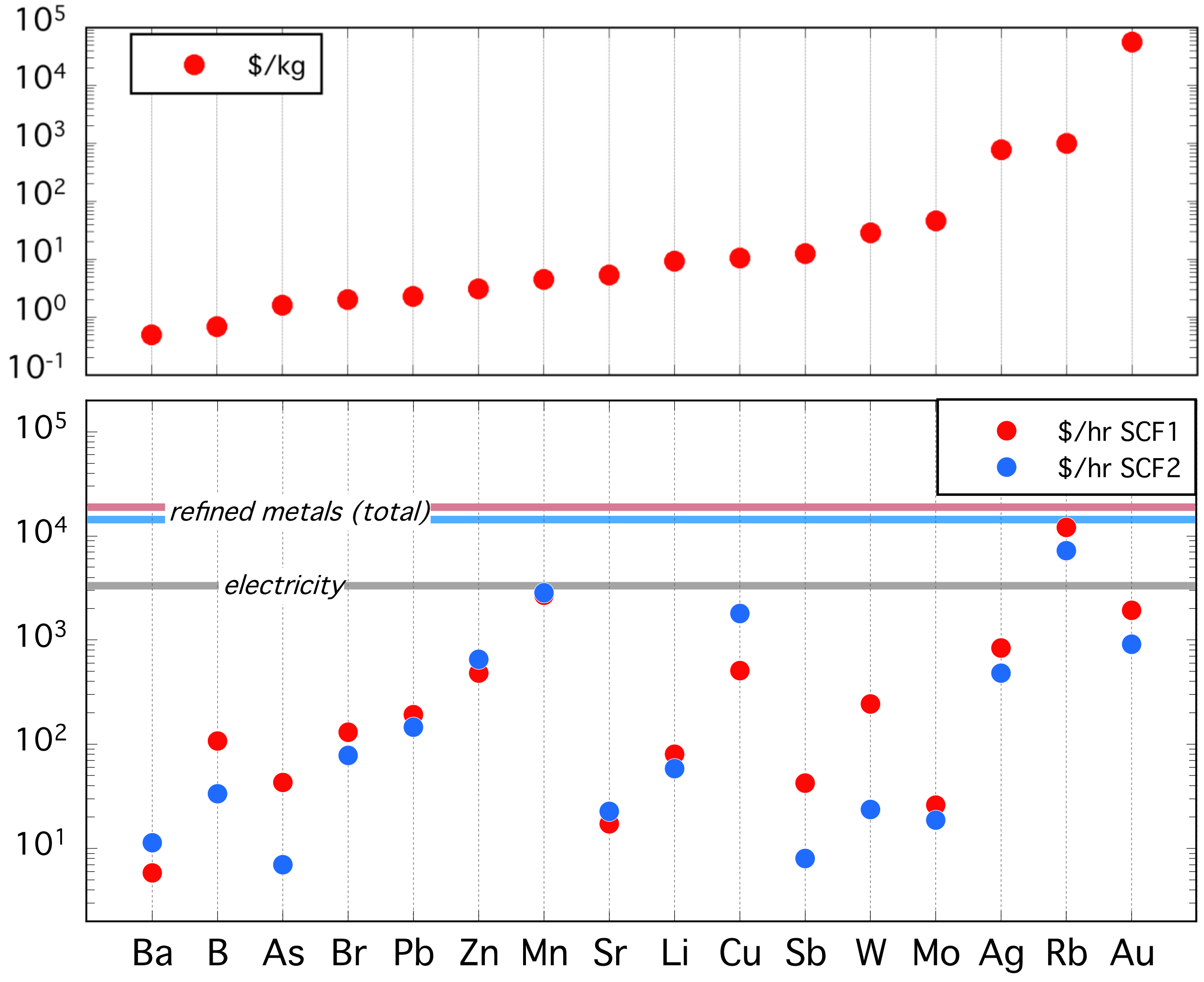
Geothermal System
Heat + Metals

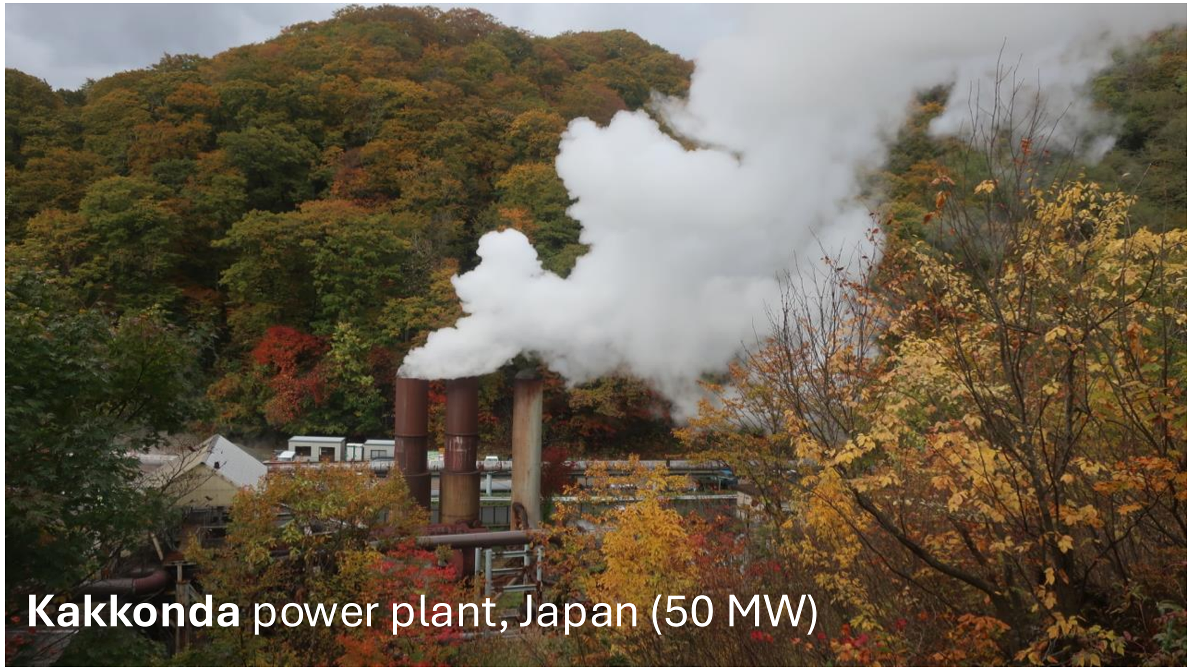
3. Processing of spent geothermal fluid

4. Reservoir leaching by re-injected fluids

Power plant with metals

- Supercritical fluid (SCF - 8% $NaCl_{eq}$) **200 t/hr** per well
- *refined* metal prices, $0.10/kWh electricity

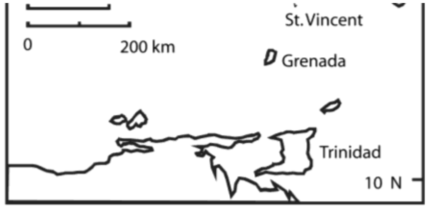


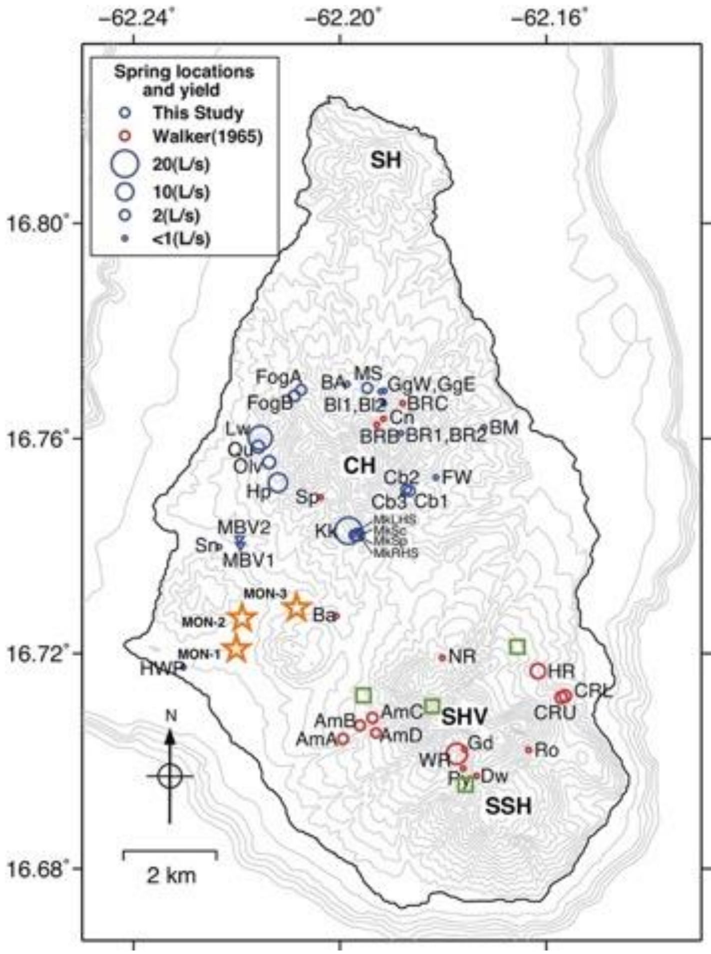


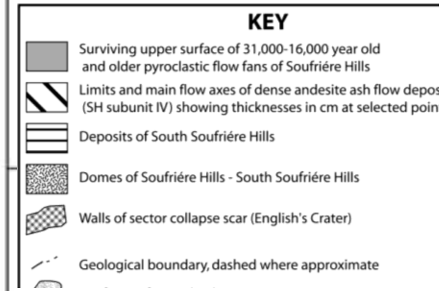
- **89,000 yr-old** granite heat source
- Hot metal-rich fluids at 3 to 5 km depth
- WD1a drilled to 3729 m in 1995; **510 °C** BHT.
- **Brines** recovered at 3707-3488 m
- Potential **supercritical geothermal** site (100 MW)

ReSET – Reframing metal mining for a Sustainable Energy Transition

- Funded by the Oxford Martin School
- Montserrat – recovery of metals and geothermal energy
- Programme led by Earth Sciences: brings together researchers from Earth Sciences, Economics, the Smith School, Chemistry, History and Law
- Interconnected issues across the broad themes of Resources, Rights, Risks and Resilience.







OXFORD MARTIN SCHOOL

UNIVERSITY OF OXFORD

Team

Rethinking Natural Resources

Researchers

- Jon Blundy, Earth Sciences (Director)
- Mike Kendall, Earth Sciences
- Tamsin Mather, Earth Sciences
- David Pyle, Earth Sciences
- **Petros Bogiatzis, Earth Sciences (PDRA)**
- **Lupita Olguin, Earth Sciences (PDRA)**
- Dermot O'Hare, Chemistry
- Caitlin McElroy, Smith School
- **Metehan Ciftci, Smith School (PDRA)**
- Rick van der Ploeg, Economics
- Venus Bivar, History
- Amanda Power, History
- **Julio Rodríguez Stimson, History (PDRA)**
- Thom Wetzler, Law

Programme Manager

- Maria Petrunova, Earth Sciences

Advisory Board

- Sir Steve Sparks, University of Bristol
- Richard Herrington, Natural History Museum, London
- Pat Joseph, University of West Indies, Trinidad
- Vernaire Bass, 664Connect Media, Montserrat

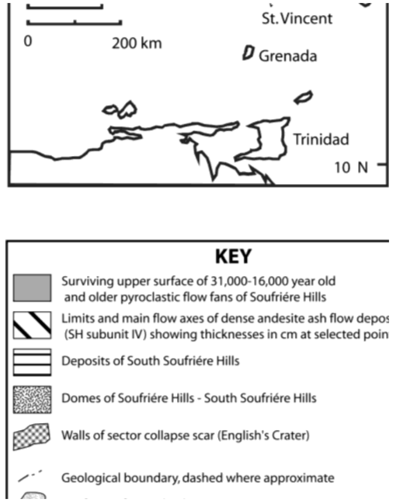
Martin School Visiting Fellows

- Pat Joseph, University of West Indies, Trinidad (July, 2024)
- Martyn Unsworth, University of Alberta, Canada (March, 2025)
- John Mavrogenes, Australian National University (May, 2025)
- Yael Parag, Reichman University, Israel (June, 2025)

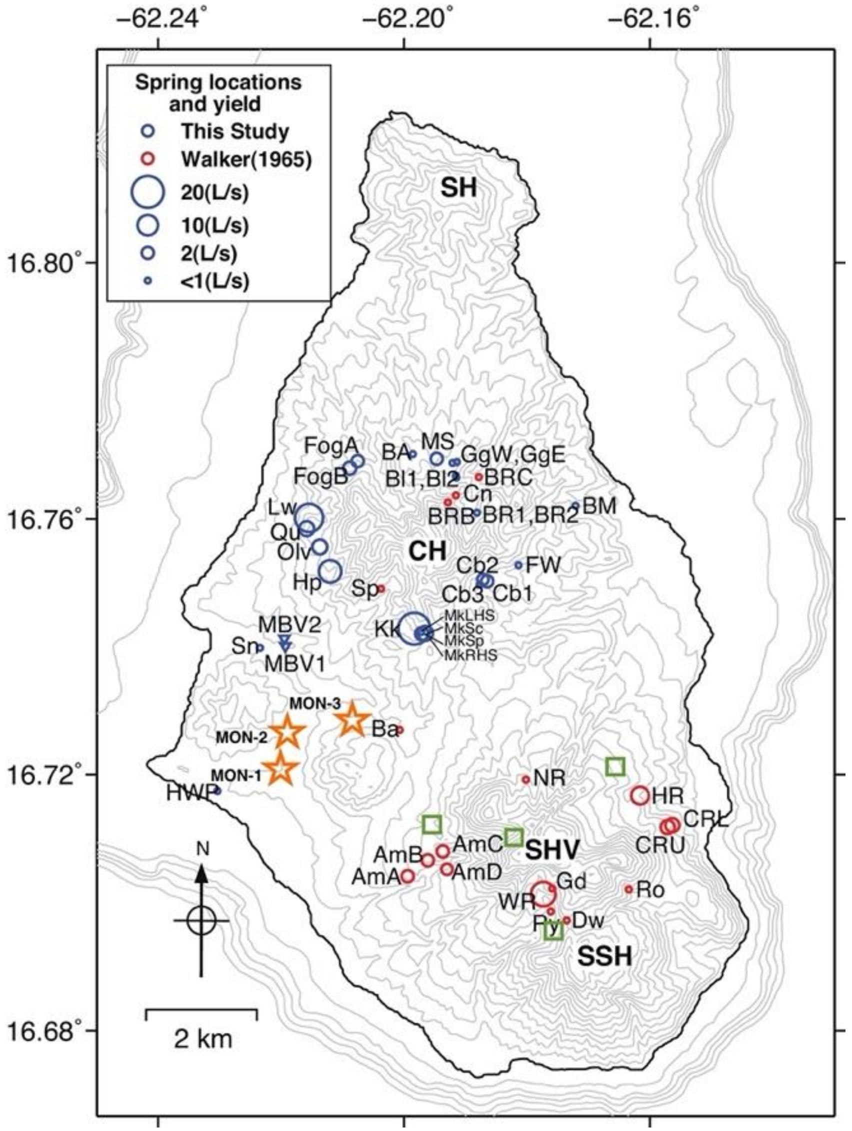
Partner Organisations

- Montserrat Volcano Observatory (MVO)
- Government of Montserrat (GoM)
- Foreign, Commonwealth and Development Office (FCDO)

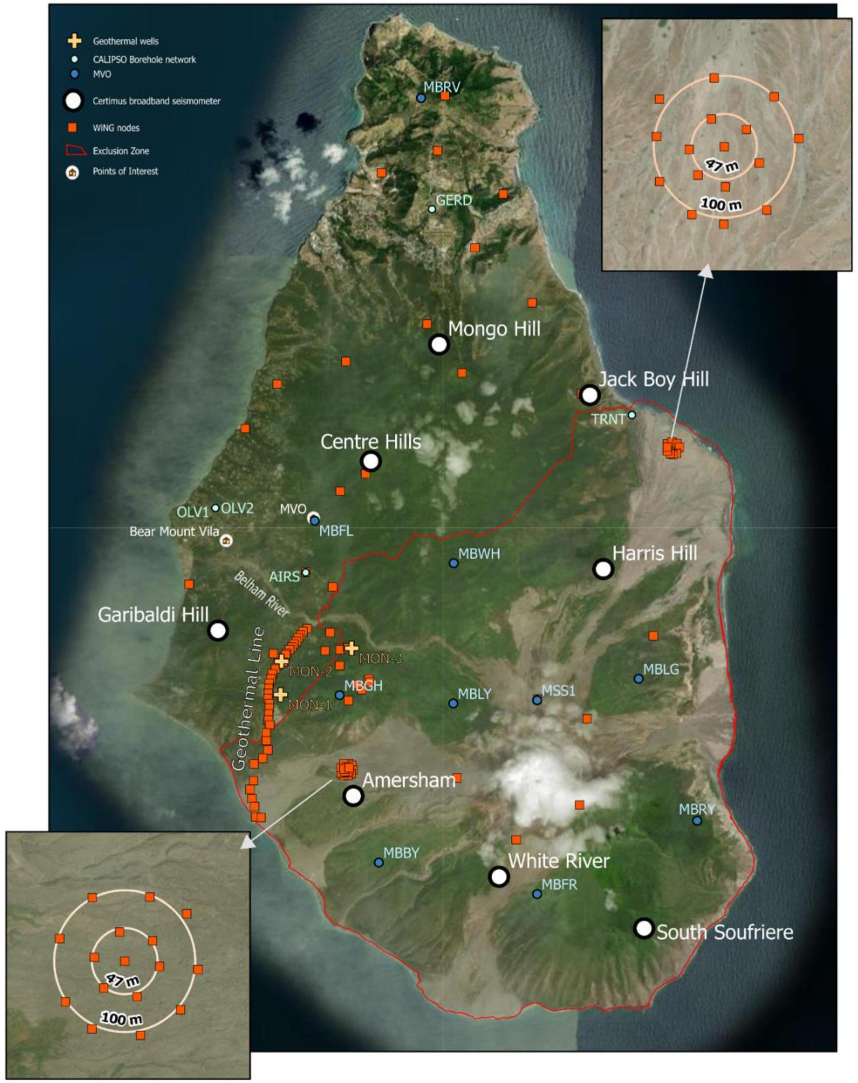
Work packages



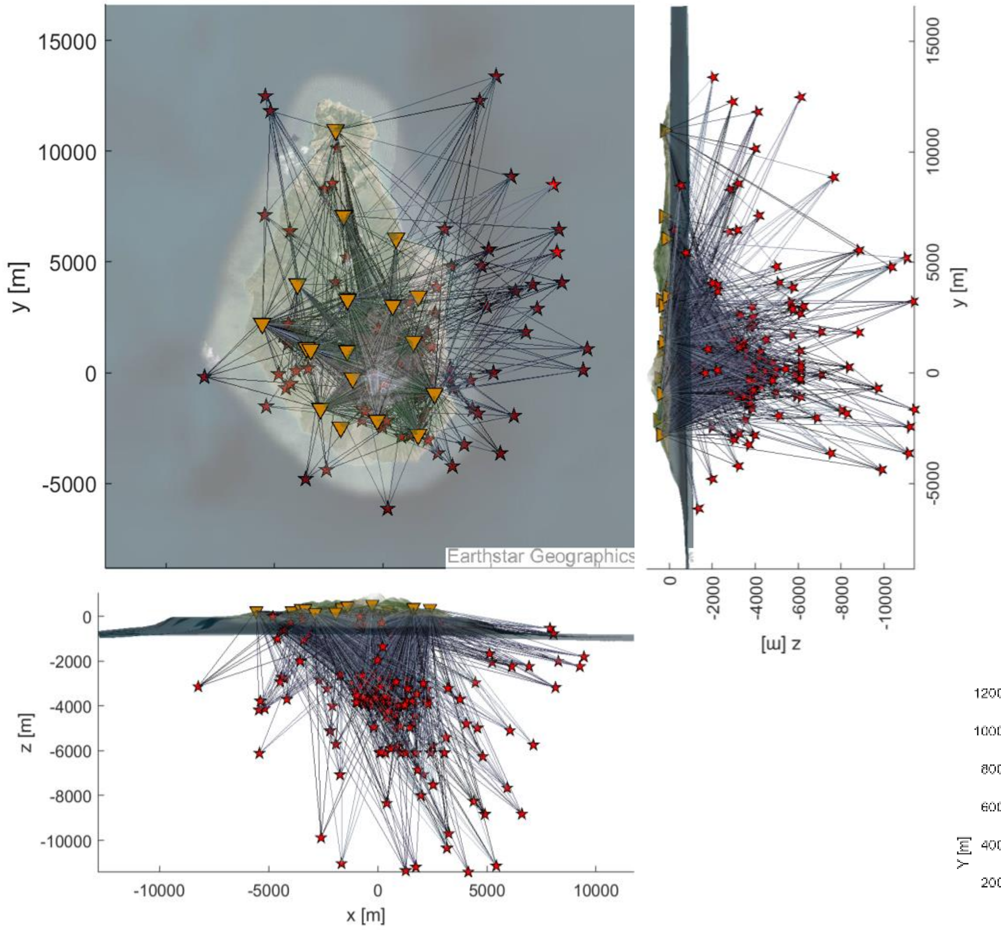
- WP1 – Optimising Exploration
- WP2 – Metals Endowment and Recovery
- WP3 – Economic and Regulatory Framework
- WP4 – Equitable Extraction and Social License

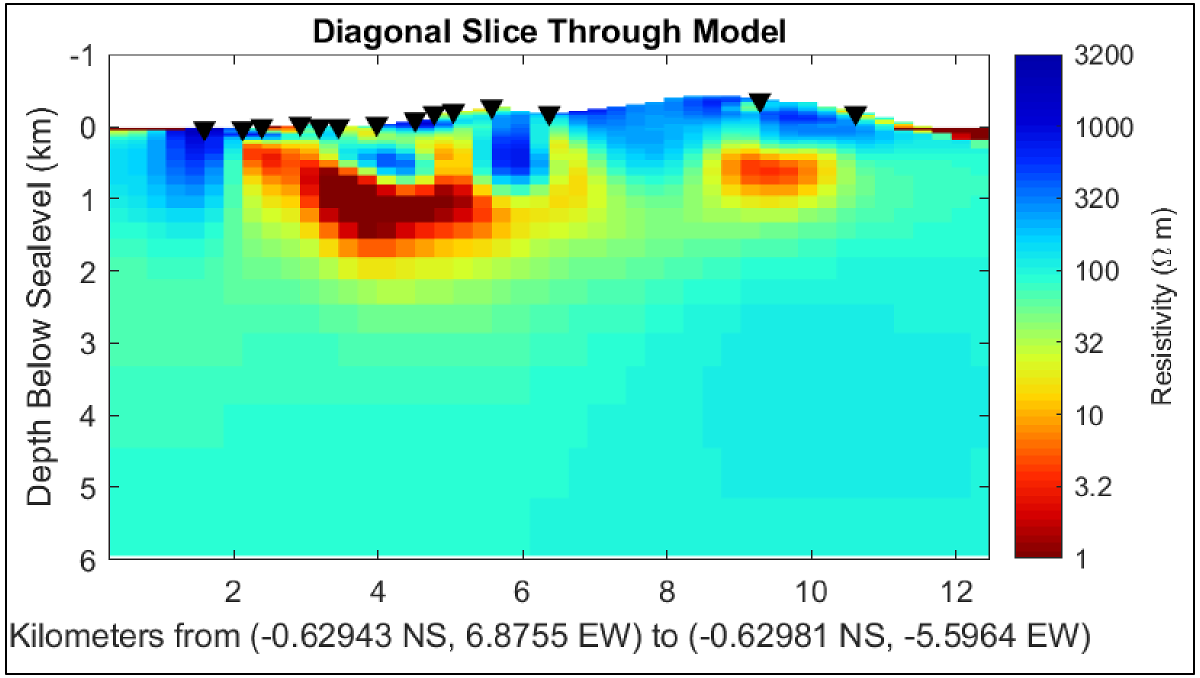


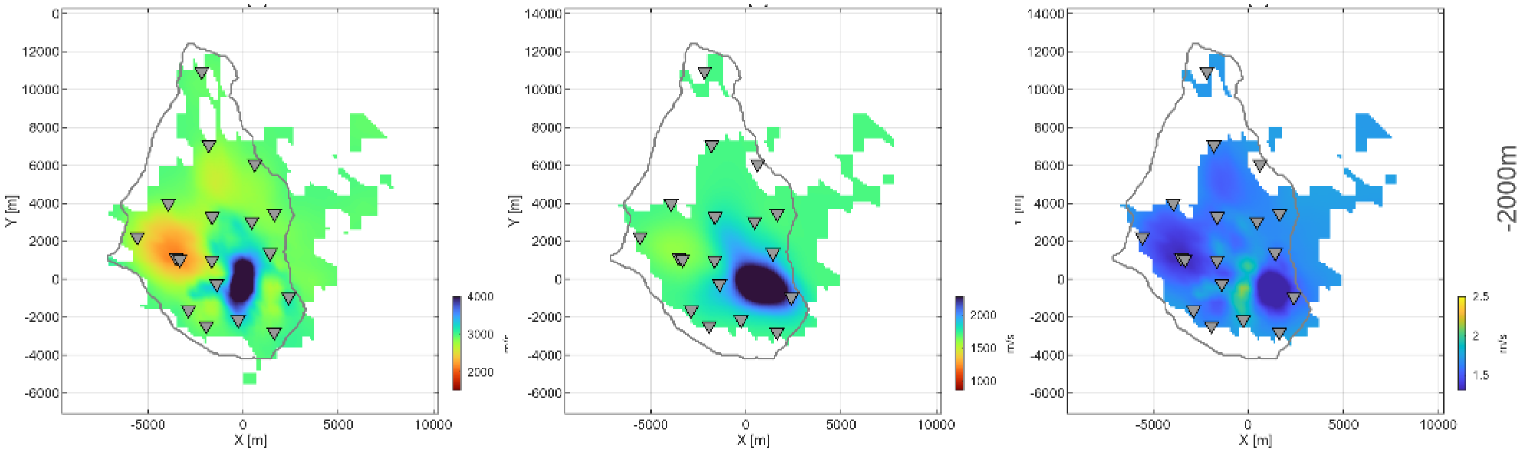
WP1 – seismometer and MT - deployment (and recovery)



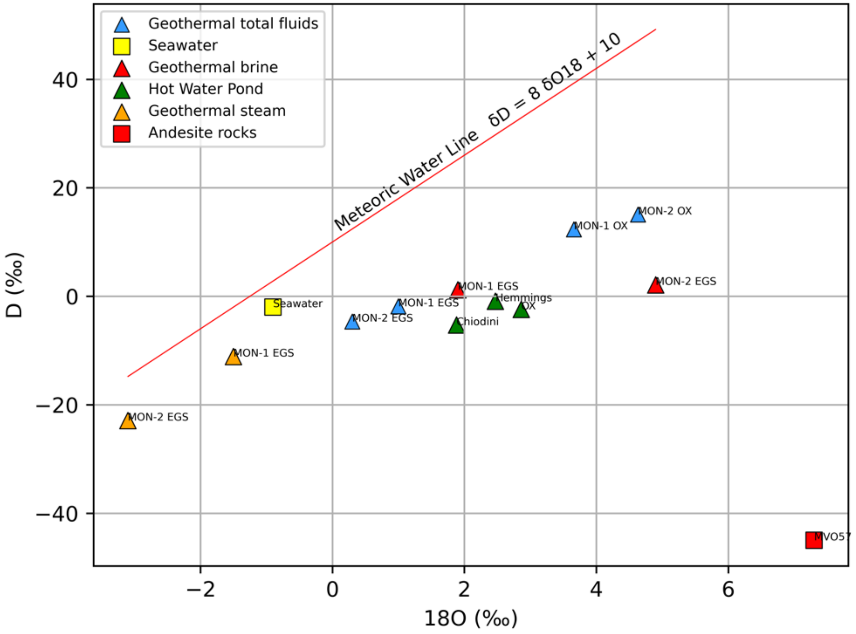
WP1 – geophysics results







WP2 – reservoir geochemistry



WP2 – fluid sampling

High concentrations of some critical metals in sludge

WP3 – regulatory framework

The Power to Change

THE MONTSERRAT ENERGY POLICY 2016 – 2030

MONTSERRAT

CHAPTER 8.12

MINERALS (VESTING) ACT

Revised Edition
showing the law as at 1 January 2002

MONTSERRAT

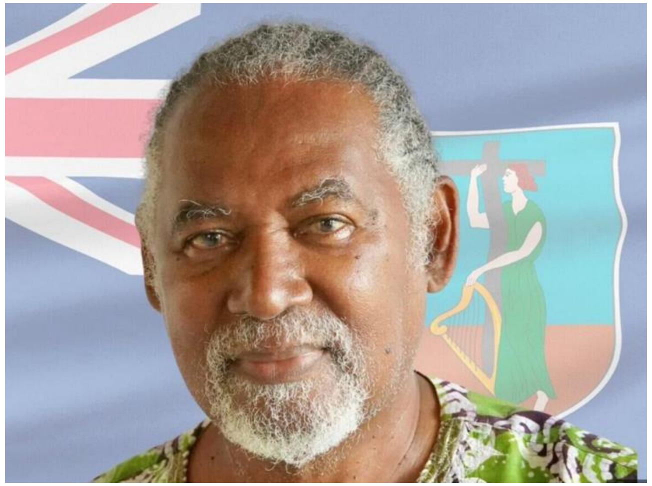
CHAPTER 18.01

MONTSERRAT UTILITIES LIMITED (MUL) ACT

WP4 – Ethnographic study

- Ethnographic fieldwork
- Interviews with Montserratians on island
- Interviews with the diaspora
- Widespread support for geothermal
- Concerns about political/economic framework
- Volcano fatigue

Public and Stakeholder Engagement



MONTSERRAT NATIONAL TRUST

mvo
Montserrat Volcano Observatory

Spinout companies

Ascension

Our mission

Harnessing the metal richness and the natural power of volcanic systems to recover critical materials in a responsible, efficient and sustainable way

Ascension

Project Members

Ascension | Marriott | University of Oxford

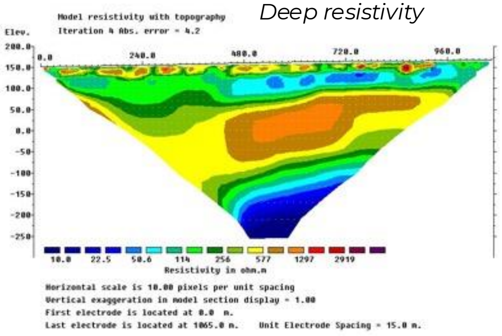
Steering Committee

Department for Business & Trade | Foreign, Commonwealth & Development Office

In partnership with Oxford University and Marriott Drilling, Ascension is currently conducting a techno-economic feasibility study on producing Rare Earth Elements (REE) from Ascension Island. This study is sponsored by UKRI – Innovate UK (CLIMATE).

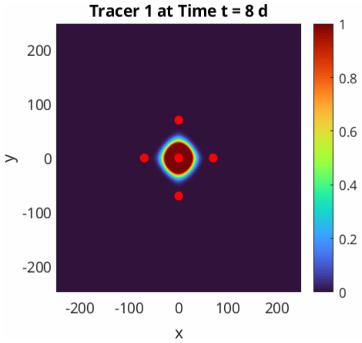
Geophysics (field survey)

Deep resistivity



Geochemistry

Hydrogeology (reservoir)



Snowfox Discovery

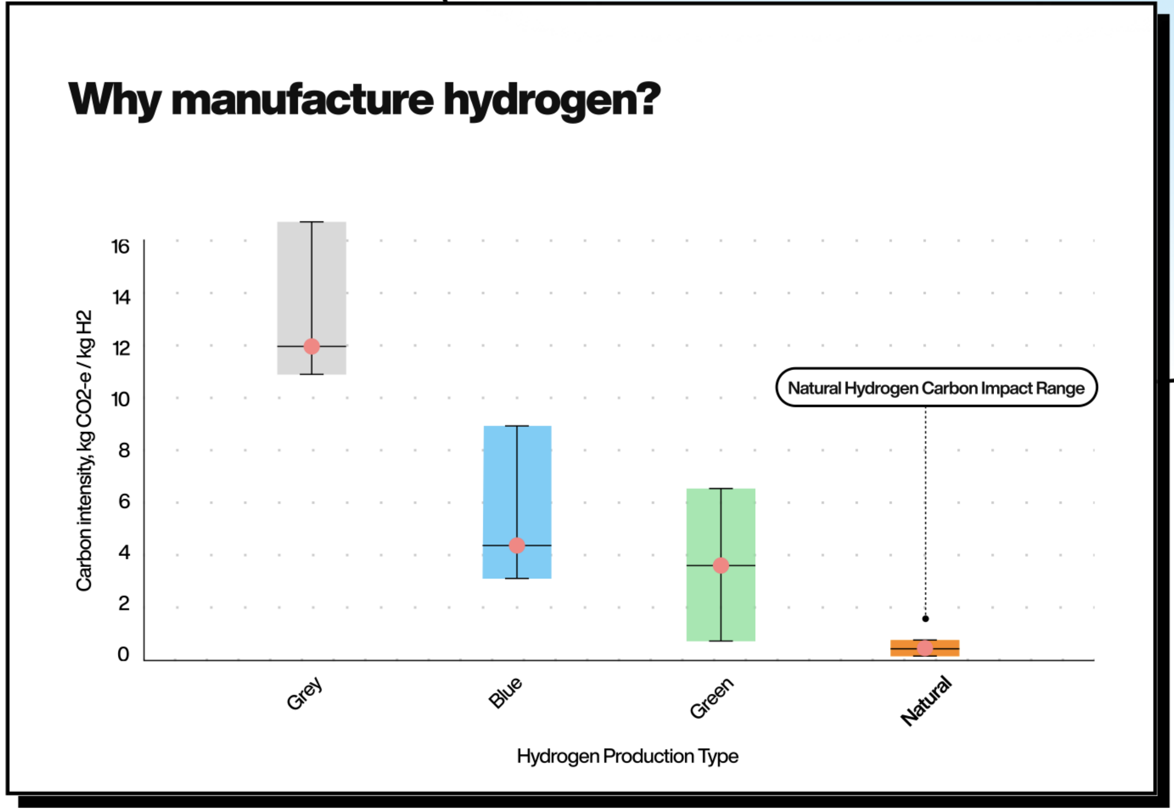
Low Carbon

95 Gt CO_2 avoided

if 50% of future hydrogen demand switches from grid connected green hydrogen (IEA, 2023) to natural hydrogen from 2030 - 2050.

Natural hydrogen

- Zero carbon in generation
- Low emissions in extraction
- Limited broader impact

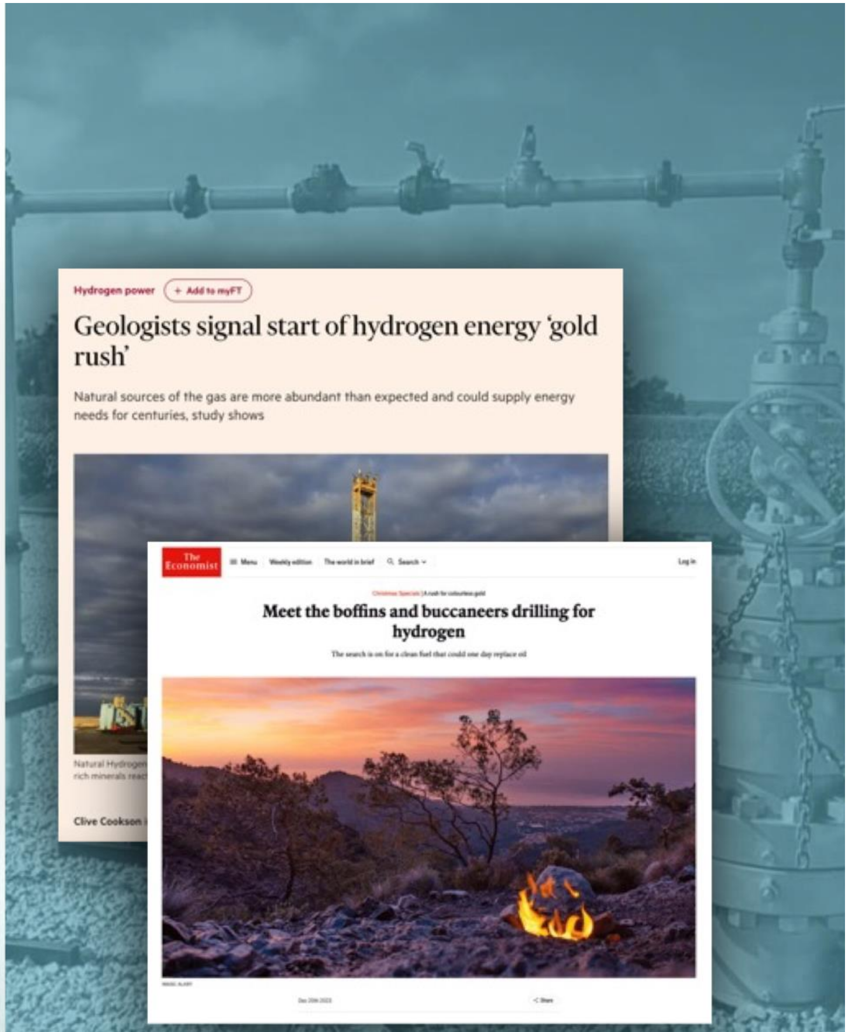


Snowfox Discovery

Natural hydrogen: a vast, untapped resource potential

Generated in huge volumes by carbon-free geological processes deep in the Earth's crust.

- Enough natural hydrogen to power the world's needs for generations.
- Resource potential initially articulated by Snowfox founding team in 2014 Nature paper.
- Low carbon and cost-competitive.

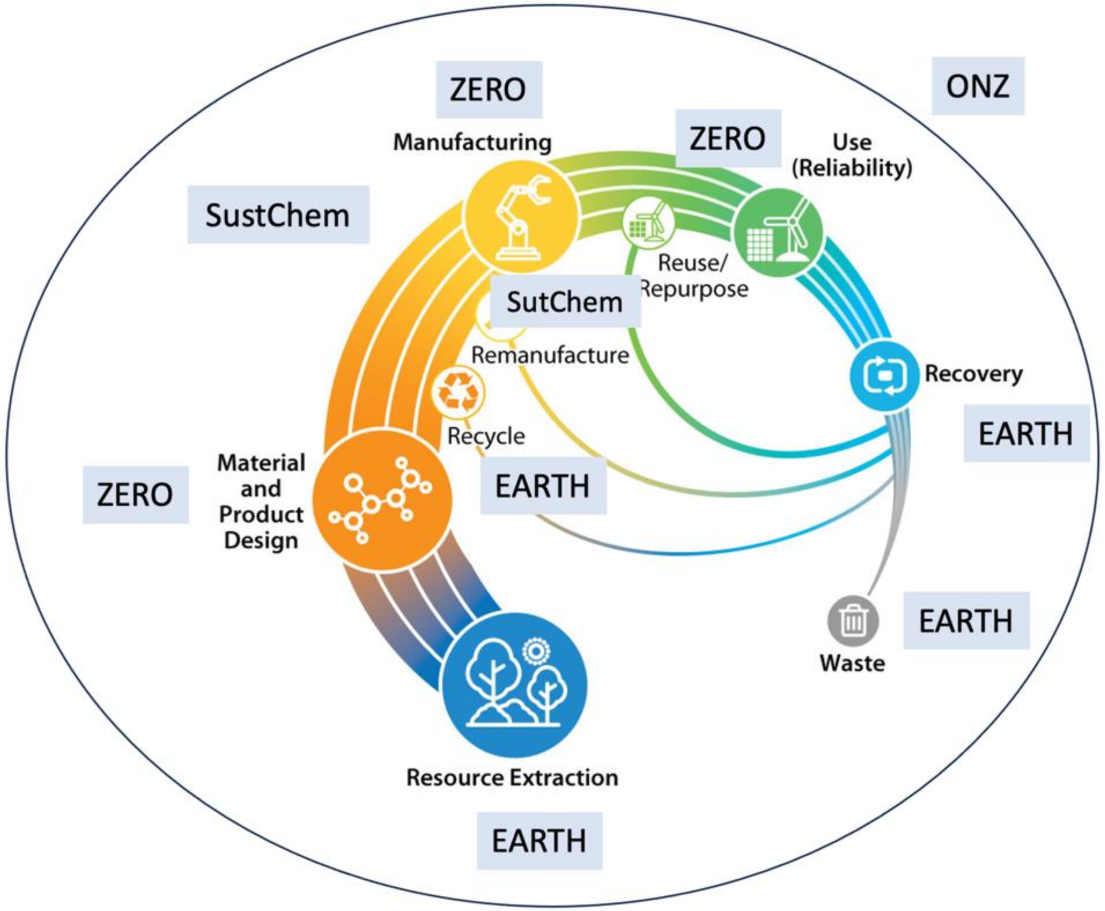


Way forward ....

- Earth Sciences research will provide solutions needed to obtain Net Zero – e.g., resources from geofluids; waste storage
- Working with industry is crucial
- Acute need to reduce, reuse and recycle
- Co-recovery of geothermal energy and critical metals
- Hydrogen and helium exploration
- Bioremediation and bio-mining (e.g., Li-S batteries)
- CCS necessary to achieve net zero
- Social license is crucial

An important objective is to ensure that achieving Net Zero in one part of the world does not lead to deleterious consequences in another part of the world

Oxford



Source: NREL, Circular Economy for Energy Materials

- Climate change is one our most pressing societal issues and reducing our dependency on fossil fuels is a key challenge
- Humans are great innovators and now more than ever we are seeing innovations in a wide range of areas
- The field of Earth Sciences is providing solutions!
- Interdisciplinary collaboration is key

JOIN US NEXT WEEK

netzeroclimate.org/events/reality/

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