A view from the front of the Circular Economy

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The Climate Challenge

Each year, the UK requires 1.2Bn tonnes of materials to sustain the current economy.

Climate change is as much an economic and social crisis as it is an environmental crisis: the costs of climate change to the global economy are projected to amount to **$54 trillion** by the end of the century.
UKRI Interdisciplinary Centre for Technology Metals
(21 Co-Is, 9 PDRAs, 8 PhD Students, 3 man./policy 38 partners (£1.6 million cash/in-kind)

Theme 1 – Virtual Data Observatory – Stocks / Flows & Practices
Li, Co, REE, Te, Se, PGM, In, W, Sn, Ta, Ga, Nb, Sb …

Theme 2 -
CE Principles for Raw materials & new Geomodels

Theme 3 -
Design, Manufacturing, & Recycling Technologies

Theme 4 - Roadmap for a new technology metals circular economy system

• POLICY & GOVERNANCE
• ENVIRONMENTAL & LCA

• SOCIAL SCIENCES & VALUE CHAINS
• RESPONSIBLE INNOVATION
Circular economy approach is based on:

1. Designing out waste and pollution,
2. Keeping products and materials in use
3. and regenerating natural systems
CE approaches - start at the beginning – with geology

‘Design out waste and pollution’

Geology
- Grade of ore
- Composition and mineralogy of the ore
- Size of ore deposit
- Depth of ore deposit
- Location of ore deposit

Geometallurgy

Mining and Processing
- Resource efficiency
- Energy use
- Carbon footprint
- Water use
- Environmental contamination
- Financial profitability
- Biodiversity and landscape degradation

Corporate Social Responsibility
- Health and safety and well-being of workforce
- Community interaction and well-being
- Contribution to national economy
- Compliance with regulatory frameworks
- Land use during and after mining

Photos and diagram: Frances Wall
Comparison of four main rare earth deposit types

MINERAL SANDS
Reasonably large
But low grade
REE minerals (monazite and xenotime) are by-products of Ti minerals
Radioactivity.

CARBONATITES
• Reasonably large
• Higher grade
• Fresh/weathered can be put together in this comparison
• Usually light REE

ALKALINE ROCKS
• Large
• Lower grade
• Hard rock
• Complex mineralogy
• Higher amounts HREE

ION ADSORPTION
• Small/shallow
• Easy to mine, might be leached ‘in situ’
• Higher amounts HREE
• Low grade

See Wall et al (2017) Elements, 13, 313-318 for discussion of responsible sourcing of rare earths
Exploration - new geomodels for REE in alkaline rocks and carbonatites

Le Bas (1977) → 3D pdfs

*Charlie Beard, Kathryn Goodenough, Anouk Borst, Frances Wall et al (Economic Geology, 2022, https://doi.org/10.5382/econgeo.4956)
Life cycle assessment

‘quantitative assessment of the environmental performance of a product or process over its entire life cycle’ (ISO 14044a)

Example of Rare Earths

- Koltun and Tharumarajah (2014) for 1kg RE oxide

REIA- Life Cycle Inventory Database

1. Concept

- To create a benchmark for the industry and to measure and communicate the environmental impact of rare earth oxide-containing (REO) products
- To develop the most up-to-date LCI for rare earth production by and for Rare Earth Industry Association members
Life cycle assessment is not just for mining

Wall et al (2017) Elements, 13, 313-318 for discussion of use of LCA in responsible sourcing of rare earths
Start early with LCA to design out pollution and waste

Environment and Social responsibility

Desk study

First results, e.g. preliminary economic assessment

Prefeasibility study

Feasibility study

Life Cycle Assessment

Mine
LCA to monitor predicted environmental performance through the mine life using **pre-feasibility study - geometallurgy**

Bear Lodge REE carbonatite

**Lower grade**

= **Higher global warming potential**

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**www.sosrare.org**, part of NERC SoS MinErals programme


Resource models - include CE thinking……
Design out waste and pollution’ ‘optimise resource yields’

Economic block model

Carbon footprint block model with global warming impact value for block (or waste, by-products, water use…….)

‘Regenerating natural systems’
A more integrated approach to exploration

- Develop CE Principles for integrated Raw Materials & new Geo-Models

**Met4Tech Thematic Area 2 (TA2)**
Karen Hudson-Edwards, Eva Marquis, Aleks Cavoski, Jyoti Ahuja

- Integrated study in Cornwall, UK (technology metals: Li, Sn, W, geothermal, mine waste, ?addition of a smelter?)
Two views of sustainability in mining

1. Turning geological natural capital into human, infrastructure, and environmental capital for the producers

- **Supply chain to mines**

2. Metals as sustainable materials, a service? right from first stages of exploration, and retaining highest value for as long as possible in circular economy

- **Manufacturing supply chain**

  - **Consumers**

  - **Governments** (legislation)

  - **‘Banks and shareholders’**

  - **‘Public’ (direct neighbours and societal acceptance)**

Frances Wall
Rio Tinto aluminium customers in North America have a new (2021) scrap take-back solution for production of high quality alloys made with recycled content.
Global REE resources - lots of potential……
UK Rare earth resources?

Frances Wall, f.wall@exeter.ac.uk
UK Rare earth resources?

Nd$_2$Fe$_{14}$B magnets

Hypromag – recycling REE magnets
https://hypromag.com/

Part owned by Mkango Resources, who are exploring for REE
Integrated approach to primary and recycled material
One 5 MW turbine - one tonne rare earth oxide alloy

Gareth Hatch, Adamas
## Global context of UK wind farm magnets

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<th>2021 (t)</th>
<th>Reserves (t)</th>
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<tr>
<td>China</td>
<td>168,000</td>
<td>44,000,000</td>
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<tr>
<td>United States</td>
<td>43,000</td>
<td>1,800,000</td>
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<td>2,900</td>
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<td>3,200</td>
<td>NA</td>
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<tr>
<td>Russia</td>
<td>2,700</td>
<td>21,000,000</td>
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<tr>
<td>Hornsea Project 1</td>
<td>1714</td>
<td>(decommissioned in one year)</td>
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<tr>
<td>Brazil</td>
<td>500</td>
<td>21,000,000</td>
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<tr>
<td>Burundi</td>
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<td>NA</td>
</tr>
<tr>
<td>Canada</td>
<td>-</td>
<td>830,000</td>
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<td>World wind by 2030</td>
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Global REE production in 2021 (USGS Mineral commodity summaries)

Magnets grade 27% Nd and 100% magnet. Complication of Dy, Tb, Pr

If all was decommissioned in one year
Applying primary raw materials expertise to secondary materials

- Exploration protocols especially for resource models and reporting codes are applicable to ‘urban mining’. Codes like UN Framework Classification already being applied to anthropogenic resources.

- Many processing techniques can be applied to a primary and secondary materials.

- Both primary and secondary are ‘raw materials’.

- Tracking and tracing of materials is equally relevant.
'The technical circular economy view’ – almost misses the point of the high value circles of the butterfly – the demand reduction side of CE ‘
Material inefficiency in ore processing due to market factors/limitations

‘Balance problem’ – mismatch between ore composition and relative demand for individual REEs

Lack of margin for remanufacturers

Difficulty of demonstrating economic and sustainability case for potential reverse cycles/processing routes

Varying degrees of material recycling technology readiness

Lack of user incentive to return products

Urban/post-consumer mining

Difficulty of removing magnets from motors

Difficulty/inefficiency of resizing/shaping magnets for other uses

OEMs’ conservative product design and material use driven by short-term cost considerations

Lack of collection infrastructure

Insufficient market size for OEMs acting alone to take back products for component reuse or material recycling

Varying degrees of material recycling technology readiness

Variation in NdFeB alloy composition, grain boundary chemistry, etc

Consumer reluctance to accept remanufactured products

Constraint on material supply, value chain capture by China, potential price volatility

Lack of UK-based refinery capacity inhibits local processing and revalorisation

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Reverse loops

Linear chain

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Maintain

Re-manufacturing / component reuse

Alloy recycling (as good as new)

Re-disaggregation / reassembly parts reuse

End of life treatment

Redisaggregation

Disaggregation

End of life treatment

Mine

Manufacture

USE

Redistribution

OEMs’ conservative product design and material use driven by short-term cost considerations

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Lack of user incentive to return products

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Urban/post-consumer mining

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Material recycling (as good as new quality)
Conclusions

Much opportunity for integrating primary raw materials into circular economy research

Circular economy principles absolutely apply to mining - can be part of the ESG toolkit

Joining up the value chain is key – we need to move out of our comfort zones to do this

Lessons from primary raw materials can be applied to secondary raw materials