Towards a Future Circular Economy of NdFeB Rare Earth Magnets

METAL RECYCLING EXPO

Frankfurt, Germany, 17-Jun-2026 15:45 – 16:05
Main Expo Hall 3.0

Dr. Gavin D. J. Harper

Critical Materials Research Fellow
Birmingham Business School
College of Social Sciences
University of Birmingham

Affiliated Researcher / Academic Collaborator
Cambridge Industrial Resilience Group
Institute for Manufacturing
University of Cambridge

ELEMENTS

Source: USGS Mineral Commodity Summaries (2022)

*Ore production does not reflect actual metal production as metals only make up a certain portion of ores.

**Smelter/refinery production.

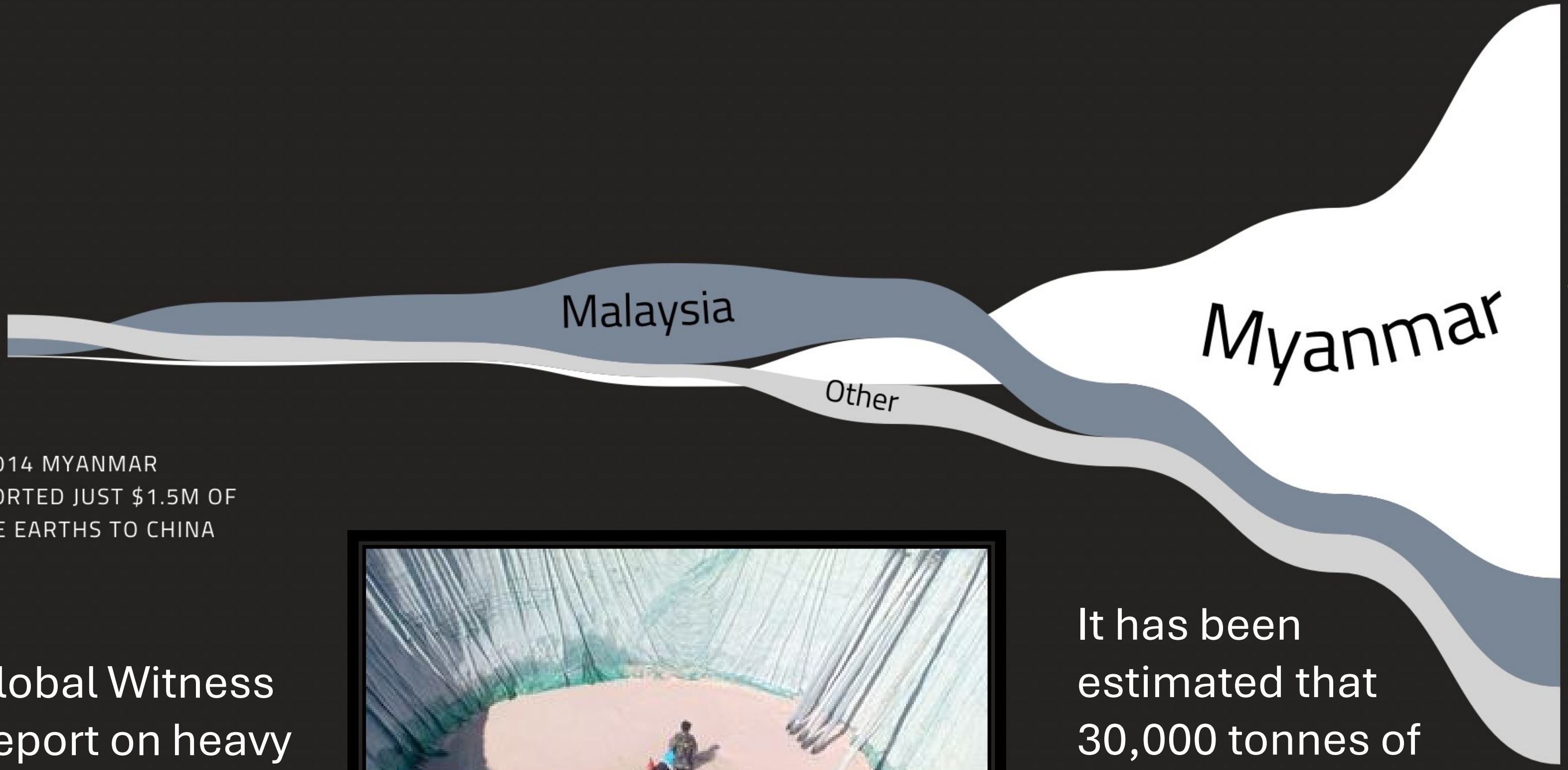
***Represents titanium mineral concentrate production.

The Impacts of Primary Rare Earth Production

Heavy rare earths mined in Myanmar

https://www.globalwitness.org/en/campaigns/natural-resource-governance/myanmars-poisoned-mountains/

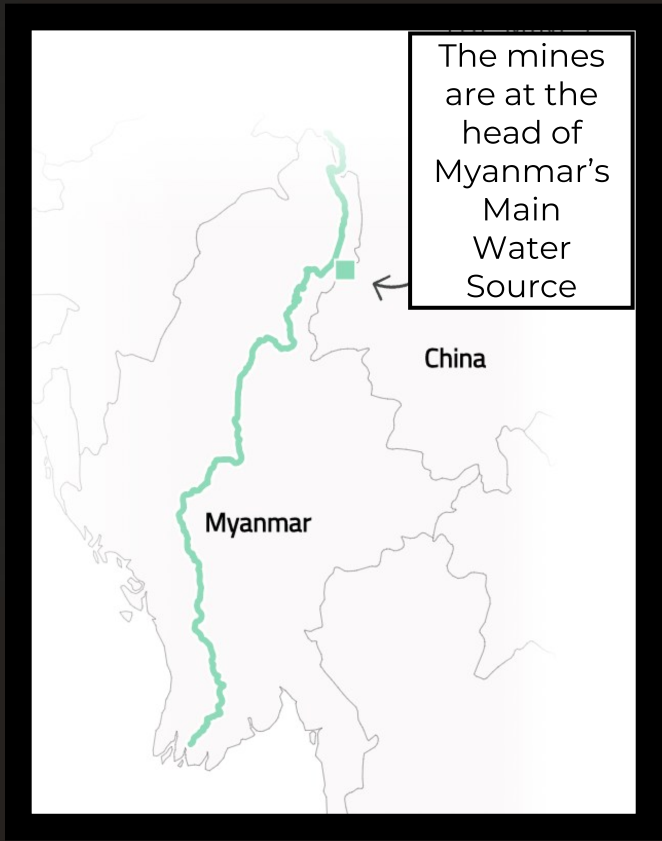
BY 2021 THIS SUM HAD REACHED $780M



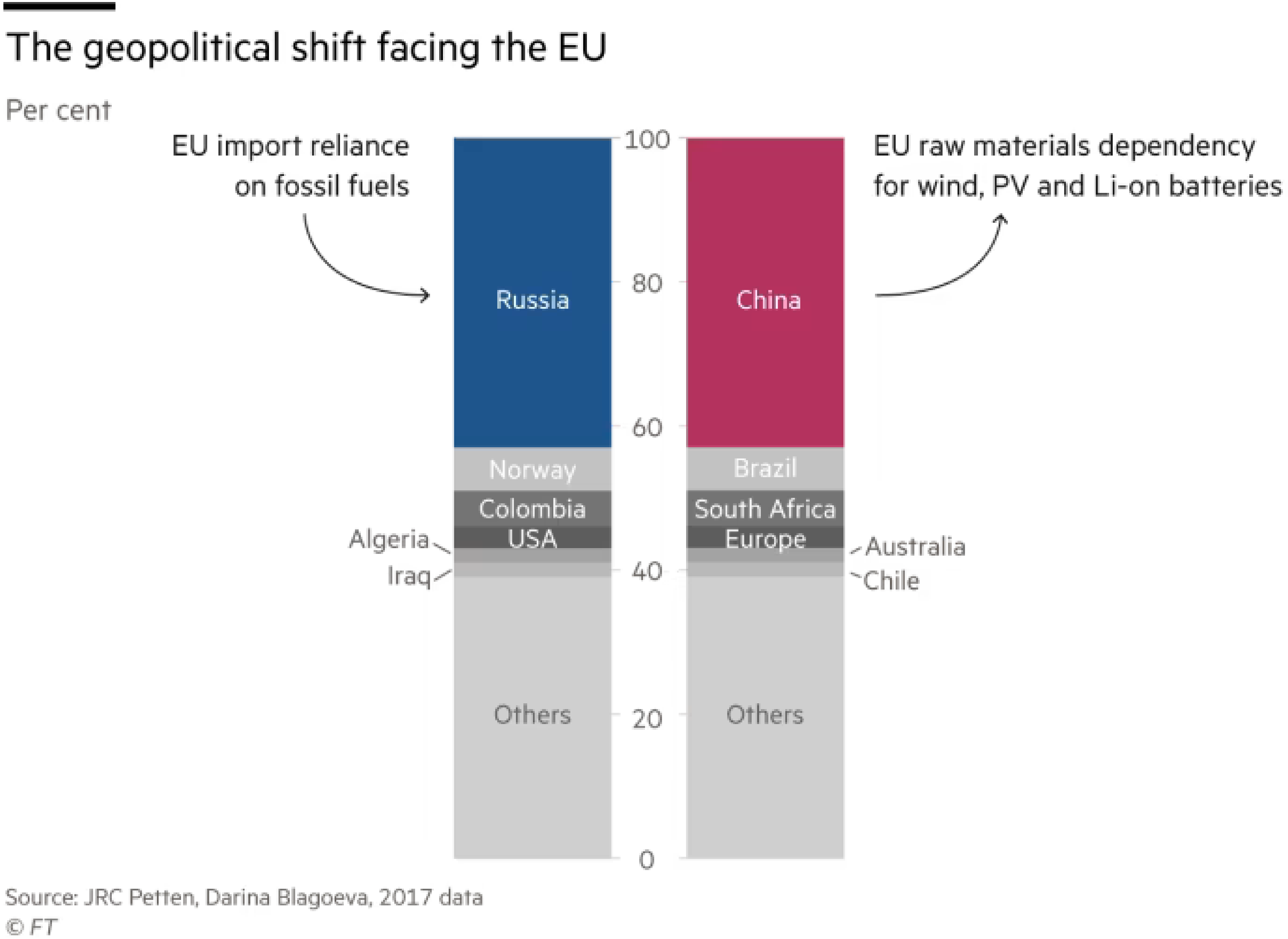
IN 2014 MYANMAR EXPORTED JUST $1.5M OF RARE EARTHS TO CHINA

Global Witness Report on heavy rare earths produced from Myanmar.

It has been estimated that 30,000 tonnes of REO is being exported across the border into Myanmar.



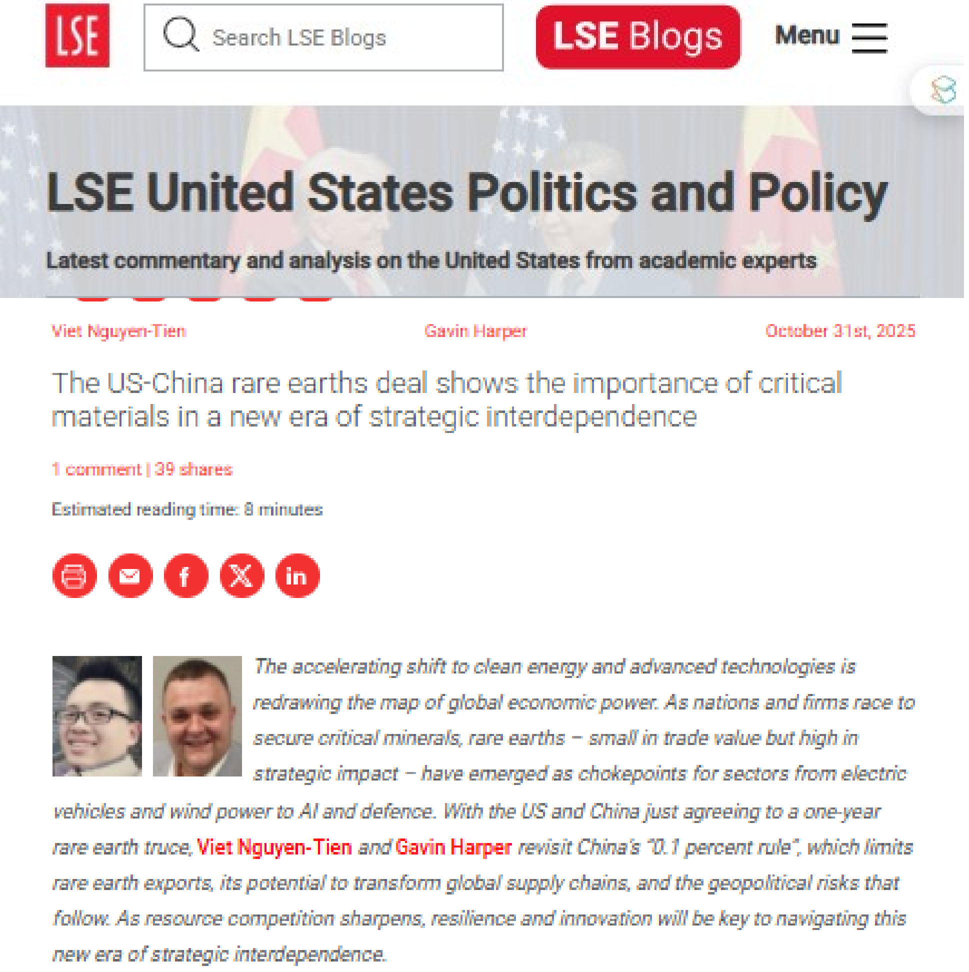
Transition from a hydrocarbon based economy to a electrified economy will shift the geopolitical balance.



FT FINANCIAL TIMES

Rare Earth Materials will be increasingly important in the future as a bargaining tool for trade given the centrality of the material properties to modern technology.

Secondary supply is one way for the West to regain sovereign control over these materials.


LSE Search LSE Blogs LSE Blogs Menu

LSE United States Politics and Policy

Latest commentary and analysis on the United States from academic experts

Viet Nguyen-Tien Gavin Harper October 31st, 2025

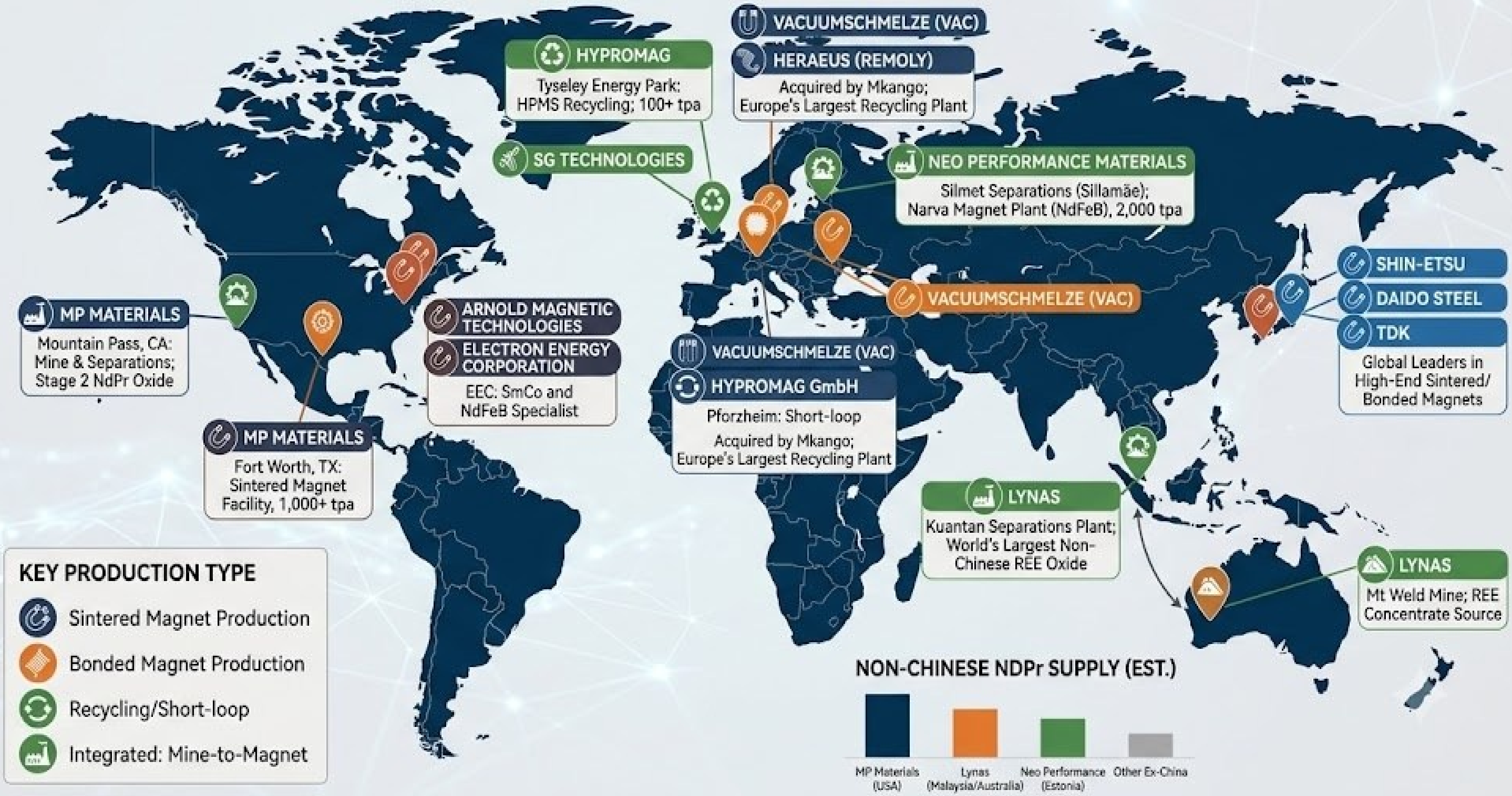
The US-China rare earths deal shows the importance of critical materials in a new era of strategic interdependence

1 comment | 39 shares

Estimated reading time: 8 minutes

The accelerating shift to clean energy and advanced technologies is redrawing the map of global economic power. As nations and firms race to secure critical minerals, rare earths – small in trade value but high in strategic impact – have emerged as chokepoints for sectors from electric vehicles and wind power to AI and defence. With the US and China just agreeing to a one-year rare earth truce, Viet Nguyen-Tien and Gavin Harper revisit China's "0.1 percent rule", which limits rare earth exports, its potential to transform global supply chains, and the geopolitical risks that follow. As resource competition sharpens, resilience and innovation will be key to navigating this new era of strategic interdependence.

NON-CHINESE RARE EARTH MAGNET PRODUCERS: A GLOBAL SUPPLY CHAIN OVERVIEW

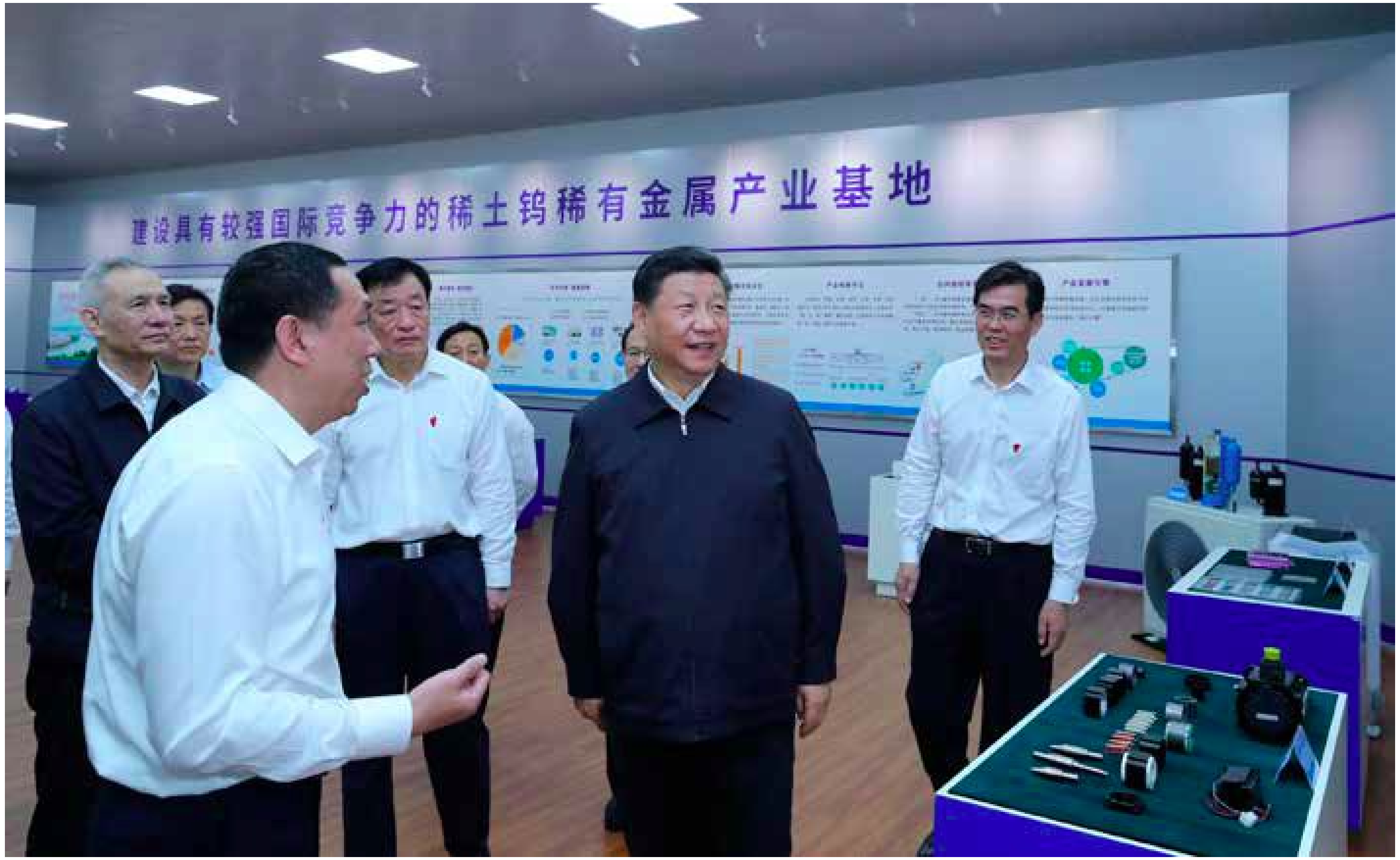


EU CRITICAL RAW MATERIALS: GLOBAL END-OF-LIFE RECYCLING RATES (EoL-RR)

A comprehensive visualization based on European Commission Data

The use of rare earths in trade disputes

- Jul 2018: US imposes 10% tariff on Chinese REEs.
- Aug 2018: US National Defence Authorization Act explicitly prohibits US Department of Defense from sourcing REE-containing magnets from China, Russia, North Korea and Iran.
- Aug 2018: China imposes 5-25% tariffs on US REE products.
- Sep 2018: US removes tariffs on Chinese REEs.
- 2020 – The US authorized the Defence Production Act to streamline the construction of domestic mines whilst prioritizing the expansion and protection of minerals in secured supply chains.
- 2022 – Biden inflation reduction act

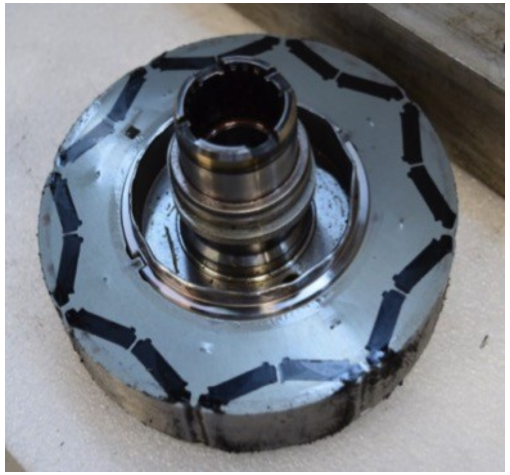


Chinese President Xi visits the largest rare earth magnet producer in the world (JL MAG Rare-Earth Co), a few days after trade negotiations broke down with President Trump.

The separation problem and the reality today

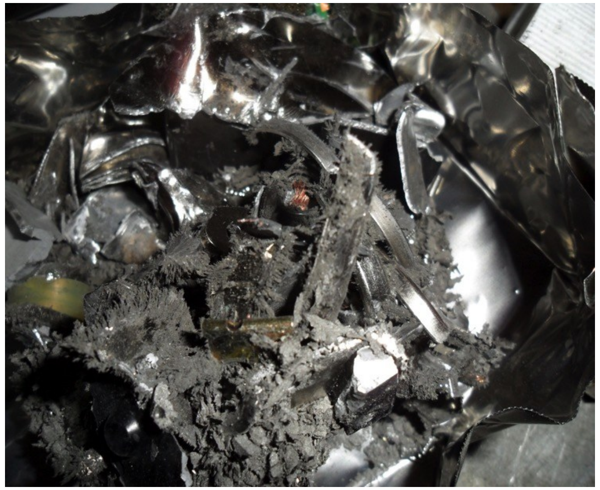
UNIVERSITY OF BIRMINGHAM

Hard disk drives



Rotor from an automotive drive motor

Shredding

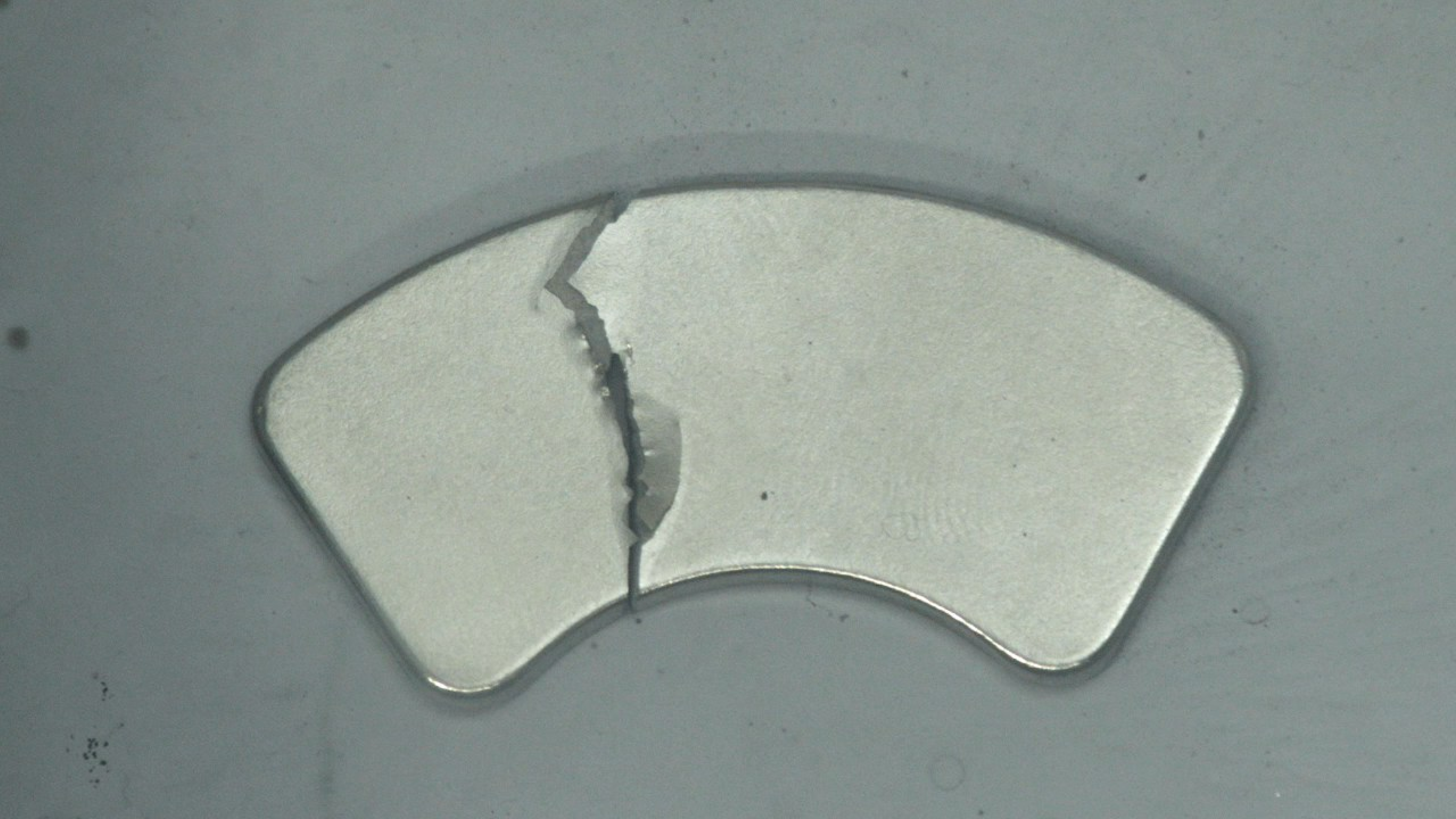


Shredded HDDs

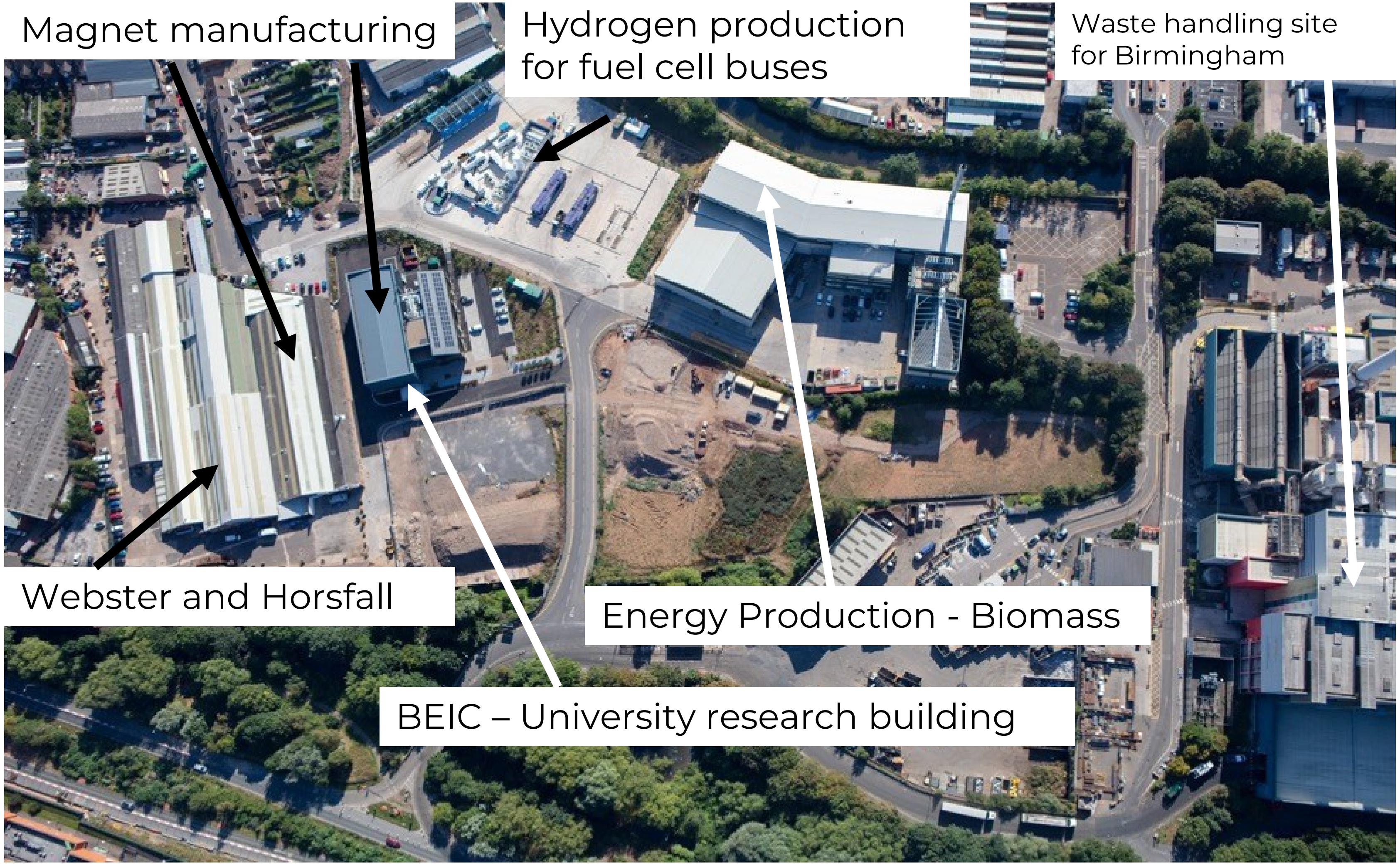
Shredded automotive motor

(courtesy of Axion)

Current recycling processes are not suitable for NdFeB magnets (image from EMR in Birmingham)



Scale up – Tyseley Energy Park (2023)



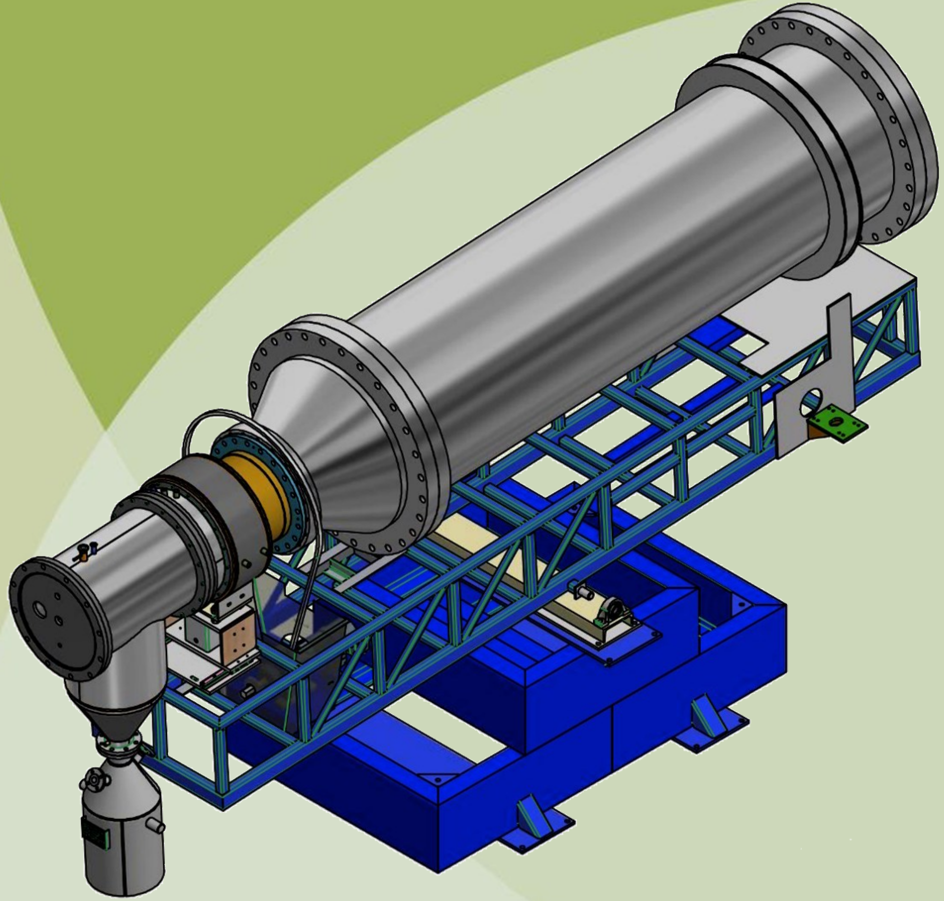
DER (UK) have provided £4.4 million of predominantly capital funding to scale up the HPMS process and magnet manufacture. HPMS at 400kg batch sizes (semi continuous).

SCALE UP OF THE HPMS PROCESS

Larger HPMS Vessel – 300-400kg output per batch from a total processing load of up to **6 tonnes**

DER industrialisation centre equipment -

- HPMS reactor
- Inert sintering system
- Powder processing (sieving, milling, blending)
- Transverse aligning press
- Pellet press
- EDM
- Axial aligning press
- Grinding



UNIVERSITY OF BIRMINGHAM

Separation of REE magnets (400kg batch sizes)

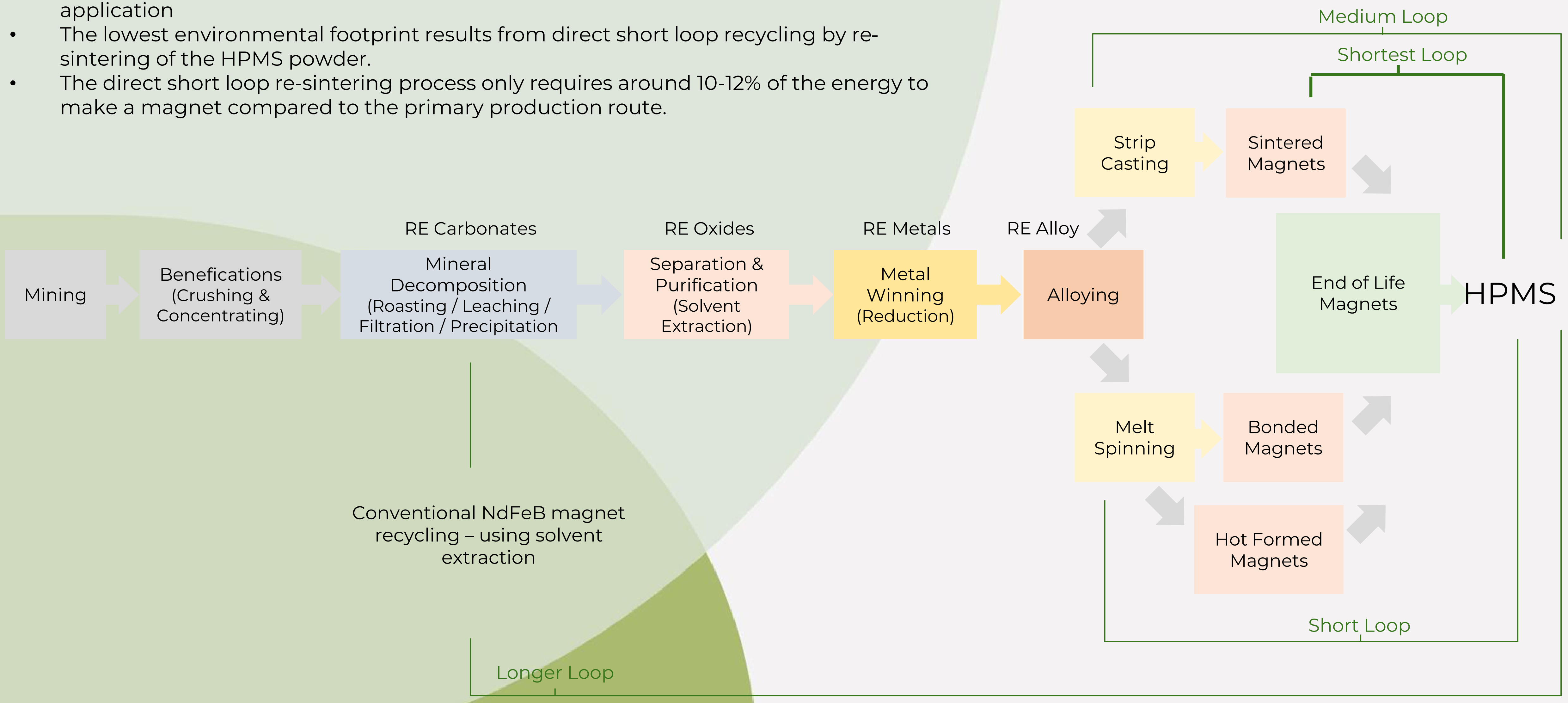
Automated powder processing – Sieving, jet milling, blending

Tyseley REE Magnet Recycling Facility

- >100 tonne capacity recycling facility for REEs
- The only facility in the UK for manufacturing rare earth magnets
- The HPMS Technology is the most efficient method to separate magnets from waste globally.
- The technology has been supported by the Mineral Security Partnership for scaling globally.
- New company created (Hypromag) which is scaling this technology in the UK, Germany and the USA.

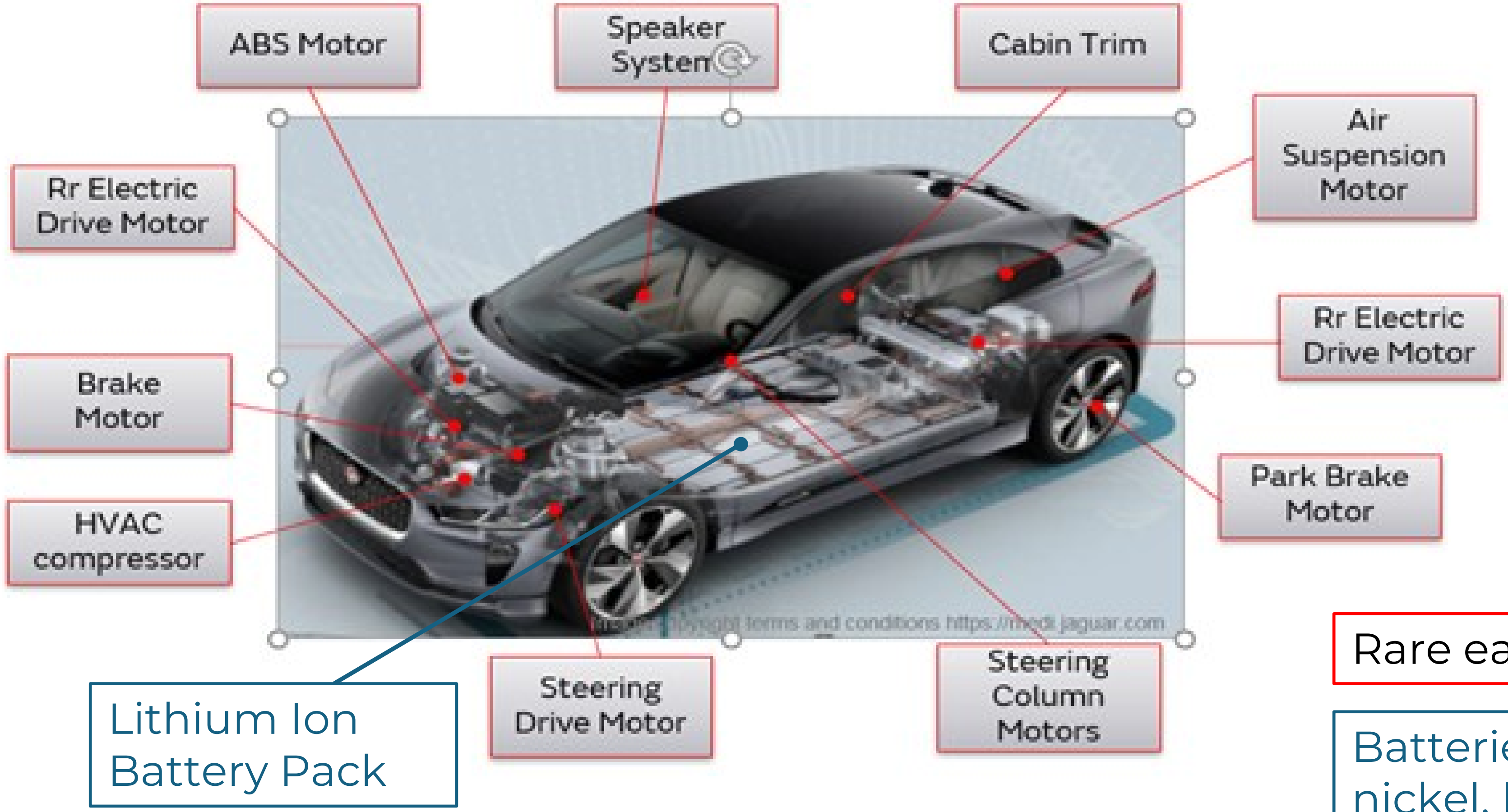
Recycling options for extracted REE alloy powder or magnets

- There are multiple routes to reprocess EoL NdFeB magnets once extracted from the application
- The lowest environmental footprint results from direct short loop recycling by re-sintering of the HPMS powder.
- The direct short loop re-sintering process only requires around 10-12% of the energy to make a magnet compared to the primary production route.



Separation of components

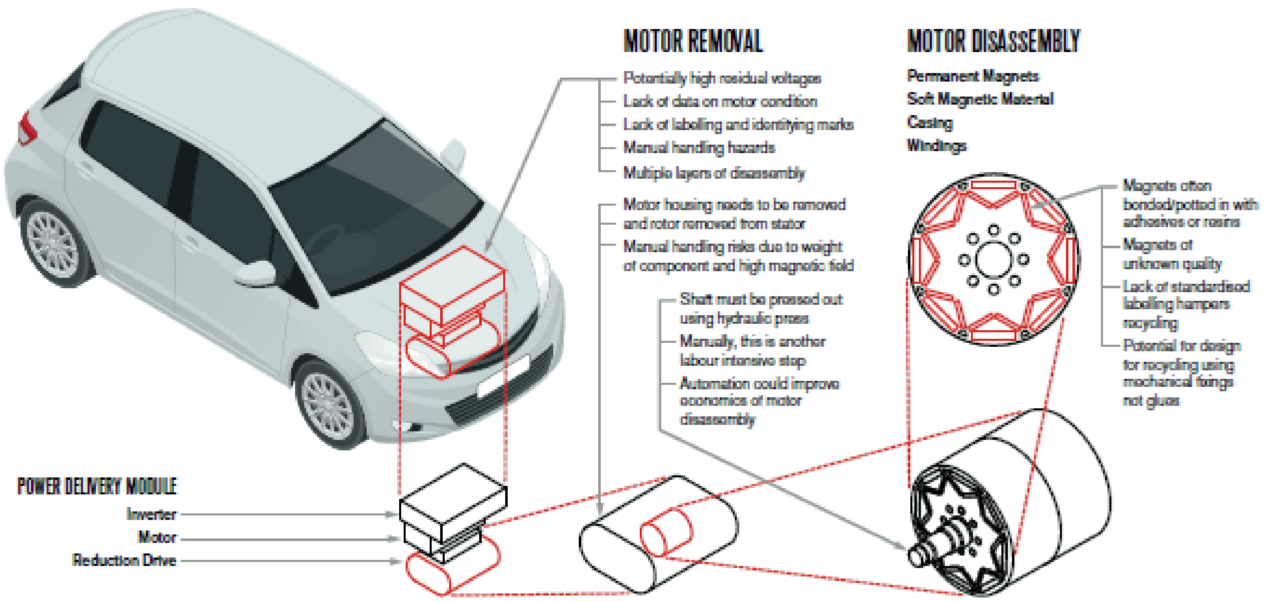
Critical materials in the automotive sector

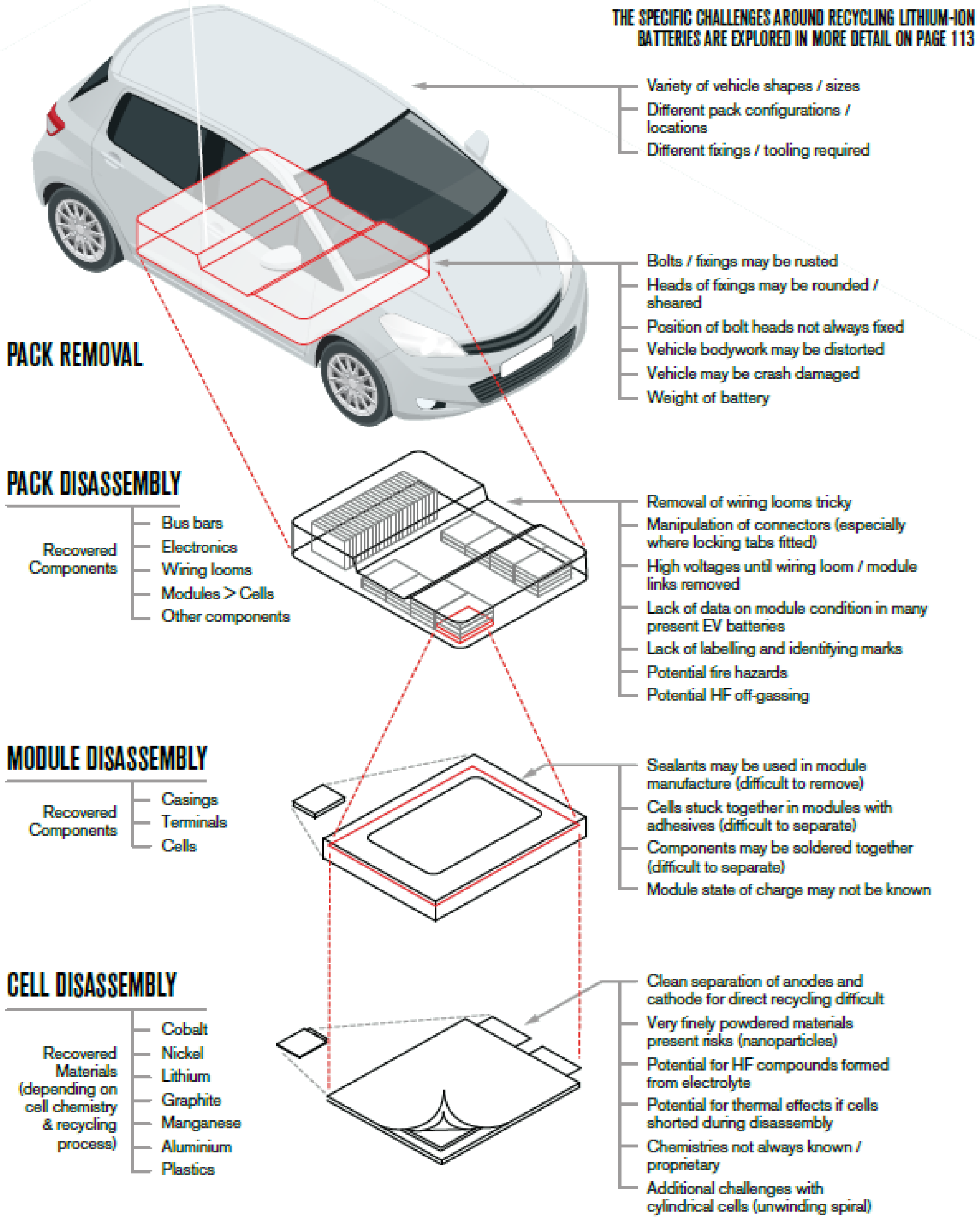


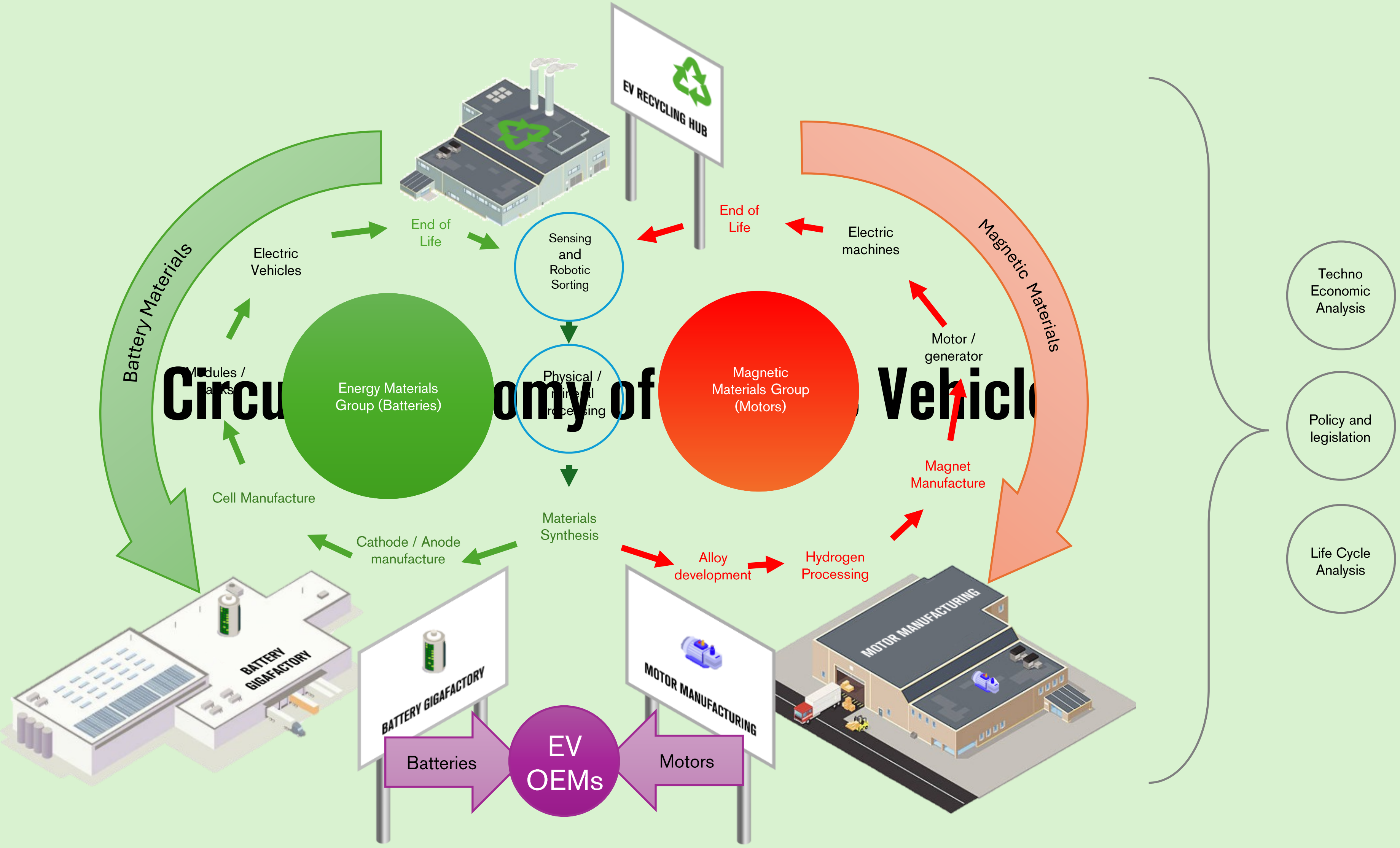
Rare earth magnets

Batteries – cobalt, nickel, lithium, graphite

Synergy between the automated disassembly of Lithium Ion Batteries and Electric Vehicle Motors





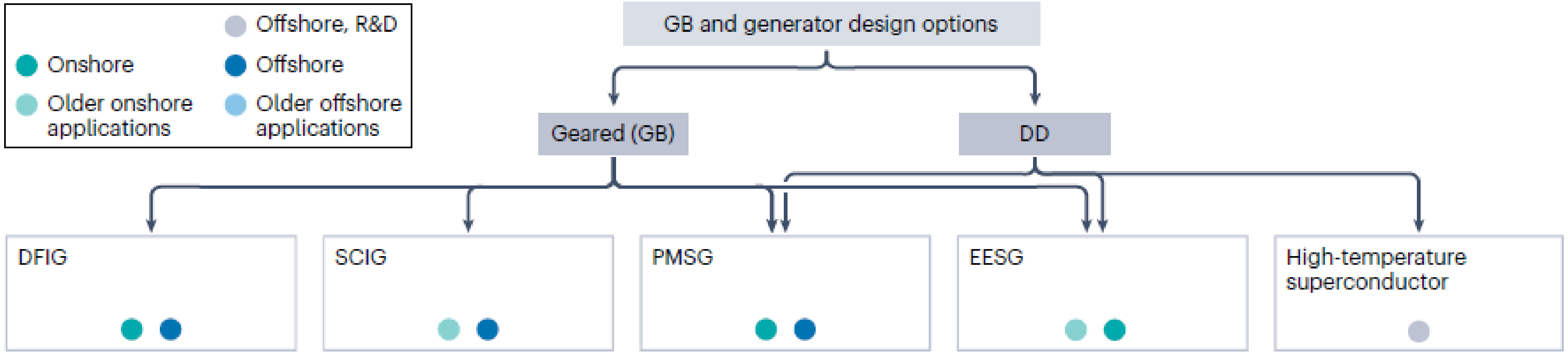


EV RECYCLING HUB
End of Life
Sensing and Robotic Sorting
Electric Vehicles
Battery Materials
Energy Materials Group (Batteries)
Cell Manufacture
Cathode / Anode manufacture
Materials Synthesis
BATTERY GIGAFACTORY
BATTERY GIGAFACTORY
Batteries
EV OEMs
Motors
MOTOR MANUFACTURING
MOTOR MANUFACTURING
Alloy development
Hydrogen Processing
Magnet Manufacture
Magnetic Materials Group (Motors)
Motor / generator
Electric machines
End of Life
Magnetic Materials
Techno Economic Analysis
Policy and legislation
Life Cycle Analysis

End-of-life management for wind turbines

nature reviews clean technology

Fanran Meng[1]✉, Jennifer L. Hawkin[1], Lukas Gast[2,3], Stella Job[4], Conchúr M. Ó Brádaigh[1], Jonathan M. Cullen[5], Gary A. Leeke[6], Jon McKechnie[7], Allan K. Poulsen[8], Rachael Rothman[1,9], Anthony J. Ryan[9,10], Iain Todd[1], Allan Walton[11,12], Gavin D. J. Harper[11,12], Zhifeng Yang[13] & Lixiao Zhang[14]✉



Double-fed Induction Generator

Squirrel Cage Induction Generator

Permanent-magnet Synchronous Generator

Electrically Excited Synchronous Generator

Rare-earth magnets used in PMSGs pose critical material concerns; a 10 MW DD-PMSG turbine can contain >2,500 kg of NdFeB magnets

nature reviews clean technology

Review article

End-of-life management for wind turbines

Fanran Meng[1]✉, Jennifer L. Hawkin[1], Lukas Gast[2,3], Stella Job[4], Conchúr M. Ó Brádaigh[1], Jonathan M. Cullen[5], Gary A. Leeke[6], Jon McKechnie[7], Allan K. Poulsen[8], Rachael Rothman[1,9], Anthony J. Ryan[9,10], Iain Todd[1], Allan Walton[11,12], Gavin D. J. Harper[11,12], Zhifeng Yang[13] & Lixiao Zhang[14]✉

Abstract

Global installed capacity of wind power reached 1,136 GW in 2024 (representing 8.1% of total electricity generation), and continued installation of new capacity is needed to provide renewable energy. Effective end-of-life (EOL) management strategies are, therefore, needed to recover materials from wind turbines. This Review assesses current and emerging EOL practices, comparing the environmental and economic trade-offs across mechanical, thermal and chemical recycling technologies. Wind turbines are built from a range of materials, including structural metals, concrete, composites and magnetic materials, which have distinct recovery pathways and barriers. Structural metal recycling is well developed and used commercially, but concrete recycling is more nascent and not competitive. Near-term scalable composite recycling technologies – including mechanical recycling and cement kiln co-processing – cannot recover the structural strengths of the original composite, but more advanced technologies – such as thermal fibre recovery and solvolysis – face energy and economic barriers to wide-scale deployment. Magnet recycling can either preserve material in its intact form through shorter loop processes or recover valuable rare-earth elements through longer loop processes. The size of the magnets could enable direct reuse of magnets, but it is complicated by changing designs. Further development of recycling and reuse pathways should be complemented by design that enables EOL management and materials circularity.

Sections

Introduction

Materials usage and management

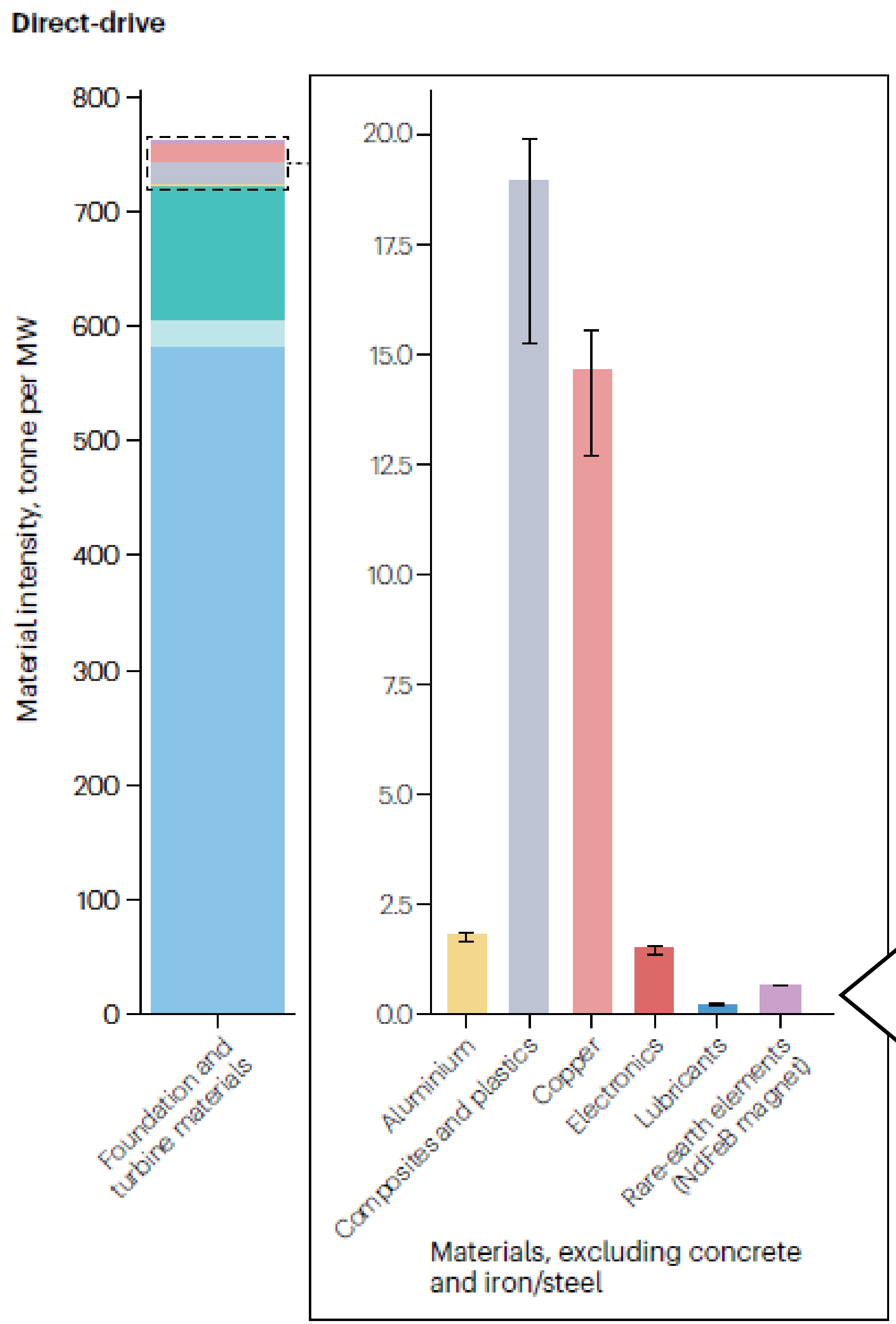
Material reuse and recycling

Design for circularity

Summary and future perspectives

A full list of affiliations appears at the end of the paper. ✉e-mail: f.meng@sheffield.ac.uk; zhanglixiao@bnu.edu.cn

Nature Reviews Clean Technology



End-of-life management for wind turbines

Fanran Meng[1], Jennifer L. Hawkin[1], Lukas Gast[2,3], Stella Job[4], Conchúr M. Ó Brádaigh[1], Jonathan M. Cullen[5], Gary A. Leeke[6], Jon McKechnie[7], Allan K. Poulsen[8], Rachael Rothman[1,9], Anthony J. Ryan[9,10], Iain Todd[1], Allan Walton[11,12], Gavin D. J. Harper[11,12], Zhifeng Yang[13] & Lixiao Zhang[14]

nature reviews clean technology

Rare-earth magnets used in PMSGs pose critical material concerns; a 10 MW DD-PMSG turbine can contain >2,500 kg of NdFeB magnets

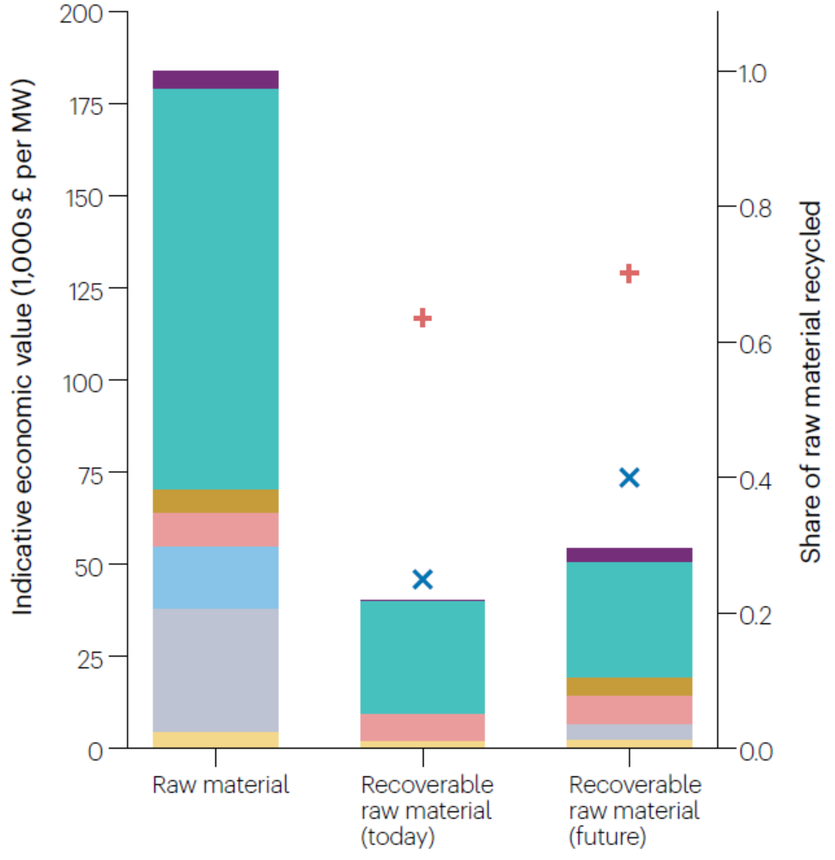
Material intensity of direct-drive onshore wind turbines

End-of-life management for wind turbines

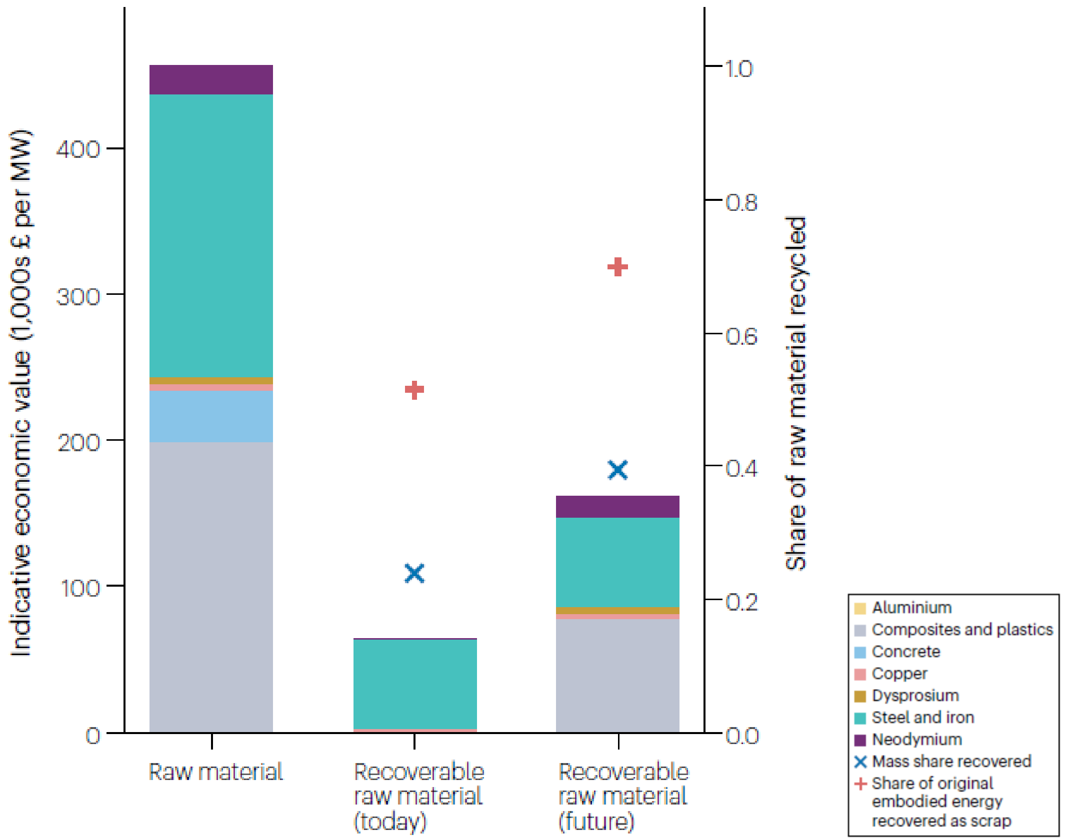
Fanran Meng[1], Jennifer L. Hawkin[1], Lukas Gast[2,3], Stella Job[4], Conchúr M. Ó Brádaigh[1], Jonathan M. Cullen[5], Gary A. Leeke[6], Jon McKechnie[7], Allan K. Poulsen[8], Rachael Rothman[1,9], Anthony J. Ryan[9,10], Iain Todd[1], Allan Walton[11,12], Gavin D. J. Harper[11,12], Zhifeng Yang[13] & Lixiao Zhang[14]

nature reviews clean technology

Material economic value and recycling potential (existing onshore fleet)



Future offshore material economic value and recycling potential




nature reviews clean technology https://doi.org/10.1038/s44359-025-00097-3

Review article

Check for updates

End-of-life management for wind turbines

Fanran Meng[1], Jennifer L. Hawkin[1], Lukas Gast[2,3], Stella Job[4], Conchúr M. Ó Brádaigh[1], Jonathan M. Cullen[5], Gary A. Leeke[6], Jon McKechnie[7], Allan K. Poulsen[8], Rachael Rothman[1,9], Anthony J. Ryan[9,10], Iain Todd[1], Allan Walton[11,12], Gavin D. J. Harper[11,12], Zhifeng Yang[13] & Lixiao Zhang[14]

Abstract

Global installed capacity of wind power reached 1,136 GW in 2024 (representing 8.1% of total electricity generation), and continued installation of new capacity is needed to provide renewable energy. Effective end-of-life (EOL) management strategies are, therefore, needed to recover materials from wind turbines. This Review assesses current and emerging EOL practices, comparing the environmental and economic trade-offs across mechanical, thermal and chemical recycling technologies. Wind turbines are built from a range of materials, including structural metals, concrete, composites and magnetic materials, which have distinct recovery pathways and barriers. Structural metal recycling is well developed and used commercially, but concrete recycling is more nascent and not competitive. Near-term scalable composite recycling technologies – including mechanical recycling and cement kiln co-processing – cannot recover the structural strengths of the original composite, but more advanced technologies – such as thermal fibre recovery and solvolysis – face energy and economic barriers to wide-scale deployment. Magnet recycling can either preserve material in its intact form through shorter loop processes or recover valuable rare-earth elements through longer loop processes. The size of the magnets could enable direct reuse of magnets, but it is complicated by changing designs. Further development of recycling and reuse pathways should be complemented by design that enables EOL management and materials circularity.

Sections

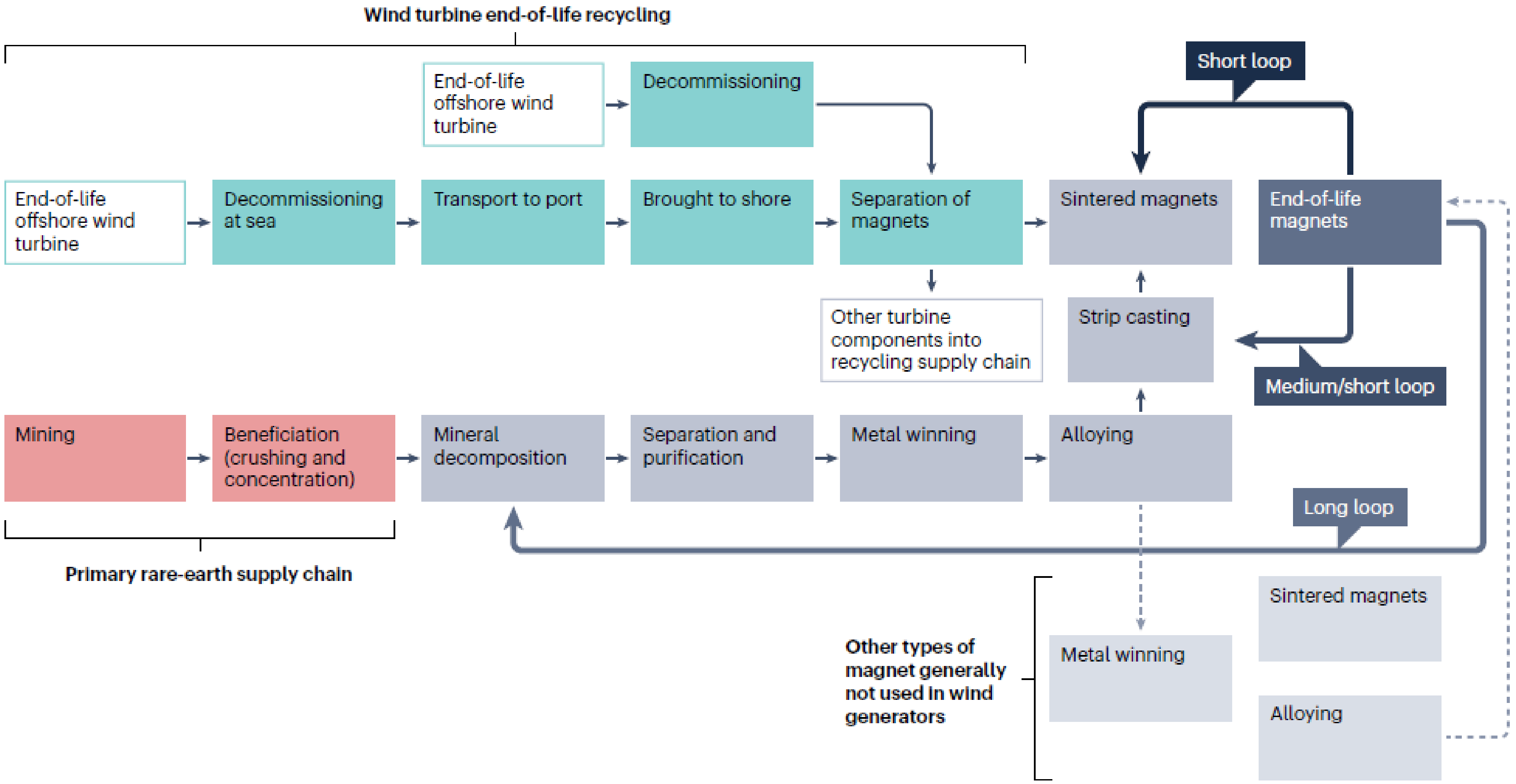
A full list of affiliations appears at the end of the paper. e-mail: f.meng@sheffield.ac.uk; zhanglixiao@bnu.edu.cn

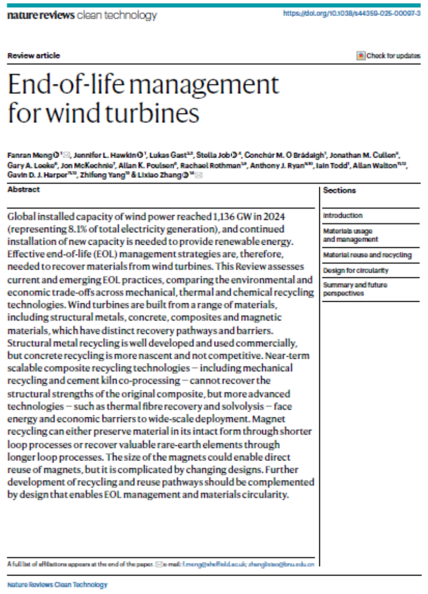
Recycling options for separated NdFeB magnets from wind turbines

End-of-life management for wind turbines

Fanran Meng[1], Jennifer L. Hawkin[1], Lukas Gast[2,3], Stella Job[4], Conchúr M. Ó Brádaigh[1], Jonathan M. Cullen[5], Gary A. Leeke[6], Jon McKechnie[7], Allan K. Poulsen[8], Rachael Rothman[1,9], Anthony J. Ryan[9,10], Iain Todd[1], Allan Walton[11,12], Gavin D. J. Harper[11,12], Zhifeng Yang[13] & Lixiao Zhang[14]

nature reviews clean technology




nature reviews clean technology https://doi.org/10.1038/s44359-025-00097-3

Review article

End-of-life management for wind turbines

Fanran Meng[1], Jennifer L. Hawkin[1], Lukas Gast[2,3], Stella Job[4], Conchúr M. Ó Brádaigh[1], Jonathan M. Cullen[5], Gary A. Leeke[6], Jon McKechnie[7], Allan K. Poulsen[8], Rachael Rothman[1,9], Anthony J. Ryan[9,10], Iain Todd[1], Allan Walton[11,12], Gavin D. J. Harper[11,12], Zhifeng Yang[13] & Lixiao Zhang[14]

Abstract

Global installed capacity of wind power reached 1,136 GW in 2024 (representing 8.1% of total electricity generation), and continued installation of new capacity is needed to provide renewable energy. Effective end-of-life (EOL) management strategies are, therefore, needed to recover materials from wind turbines. This Review assesses current and emerging EOL practices, comparing the environmental and economic trade-offs across mechanical, thermal and chemical recycling technologies. Wind turbines are built from a range of materials, including structural metals, concrete, composites and magnetic materials, which have distinct recovery pathways and barriers. Structural metal recycling is well developed and used commercially, but concrete recycling is more nascent and not competitive. Near-term scalable composite recycling technologies – including mechanical recycling and cement kiln co-processing – cannot recover the structural strengths of the original composite, but more advanced technologies – such as thermal fibre recovery and solvolysis – face energy and economic barriers to wide-scale deployment. Magnet recycling can either preserve material in its intact form through shorter loop processes or recover valuable rare-earth elements through longer loop processes. The size of the magnets could enable direct reuse of magnets, but it is complicated by changing designs. Further development of recycling and reuse pathways should be complemented by design that enables EOL management and materials circularity.

A full list of affiliations appears at the end of the paper. e-mail: f.meng@sheffield.ac.uk; zhanglixiao@bnu.edu.cn

Dr. Gavin D. J. Harper gavin.wales g.d.j.harper@bham.ac.uk

RESCu-M2 | The UK's National Centre for Robotics, AI, Automation and Smart Machine Enabled Circular Manufacturing and Material Recovery

RESCu-M²

TECHNOLOGY
ROADMAP

Forward view of the RESCu-M² research programme, Q3 2026 onwards

University of Birmingham · University of Brighton · Loughborough University · University of Strathclyde · The University Of Sheffield · Leeds · mtc · Durham University · UKRI Engineering and Physical Sciences Research Council

Flagship Demonstrators · Roadmap

Energy

Wind & solar value retention; turbine blade end-of-life; energy storage adjacencies.

Use-case freeze → Demonstrator build → Field trial

Medical Devices

Circular processing of MedTech; diabetic-waste stream (insulin pens, glucometers).

Stakeholder mapping → Pilot process design → Pilot demonstration

Electric Drives & Powertrains

EV motors, magnets, drives. Pilot with ZF Automotive on separation of motor components.

Pilot baseline (manual) → Pilot build & readiness → Trials & reporting

Large Structures

High-value, low-volume assets where Re-X preserves embedded value.

Asset selection → Inspection-rig integration → Integrated demonstrator

Please get in touch:

g.d.j.harper@bham.ac.uk

@gavindjharper

https://www.linkedin.com/in/gavindjharper/

gavin.wales

UNIVERSITY OF BIRMINGHAM
Birmingham Business School

BIRMINGHAM CENTRE FOR STRATEGIC ELEMENTS AND CRITICAL MATERIALS

IfM Industrial Resilience Research Group

UNIVERSITY OF CAMBRIDGE