In partnership with

UK Critical Minerals Recycling and Midstream Processing Capability Assessment

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UK Critical minerals recycling and midstream processing capability assessment

Research report

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Executive Summary

A secure supply of critical minerals is vital for the UK's economic growth and security, industrial strategy, and clean energy transition. UK government will publish a new Critical Minerals Strategy this year, helping to secure our supply of critical minerals for the long term and refining our approach to optimising our domestic production. This capability assessment relates to the opportunities for optimising UK domestic capability and identifying areas for collaboration.

The Department for Business and Trade (DBT) has commissioned Frazer-Nash Consultancy (Frazer-Nash) in partnership with the Critical Minerals Association (CMA) and the Materials Processing Institute (MPI) to carry out an assessment of the UK's capability in midstream processing, and the recycling and recovery of critical minerals.

The critical minerals supply chain faces unprecedented challenges as a result of increasing demand for critical mineral rich technologies such as wind turbines, solar panels and electric vehicles—which is largely driven by the Government's commitment to transition towards a net zero economy. Presently, the UK is reliant on an international supply chain to supply the majority of critical minerals it requires. Moreover, this international supply chain is dominated by a handful of countries including China and Russia, increasing concerns about supply chain security. Furthermore, the UK's limited comparative capability to produce critical minerals domestically may constrain its capacity to influence global markets. This creates a situation where the UK is heavily dependent on imported materials to meet its net zero ambitions and energy security requirements. As a result, the UK government must act to secure supply chains and deliver economic security to the country.

Scope

This report focusses on the midstream and recycling sectors of the value chain. Consideration is also given to mining and exploration because of the associated opportunities for future processing and recycling.

- **Midstream processing -** any post-mining processing where value is added/materials are upgraded from their virgin mined state.
- **Recycling and recovery –** the recycling of end-of-life products and technologies and recovery and re-use of critical minerals from non-traditional sources, such as mining and manufacturing waste.

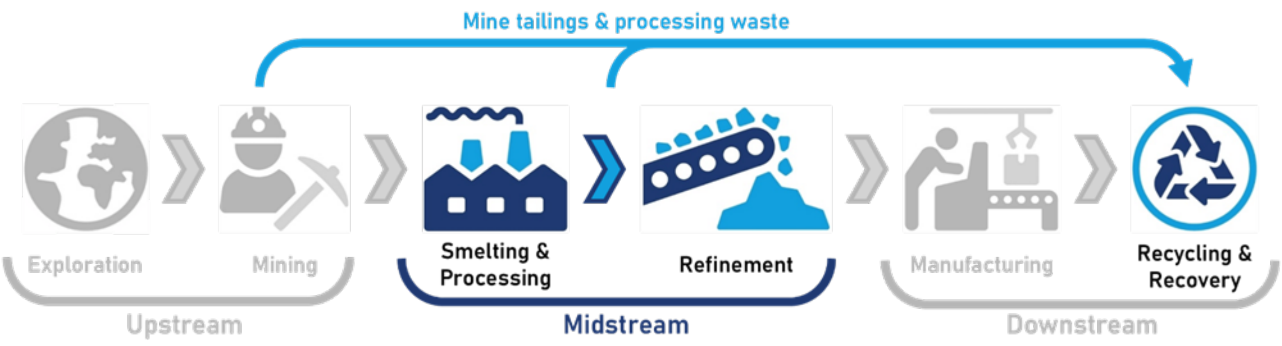

Figure 1 - An overview of the critical minerals value chain. This study will focus on the midstream area of the value chain, and recycling and recovery

This study covers the minerals classified as critical by the Critical Minerals Intelligence Centre (CMIC) in 2024 [1]. Critical minerals are the minerals and metals with the greatest economic importance and the highest risk of supply disruption to the UK. The most recent (2024) list of critical minerals is presented in Table 1.

Table 1 - CIMC's list of critical minerals

Aluminium (Al)	Graphite (natural)	Magnesite ($MgCO_3$)	Rare earth elements (REEs)	Tellurium (Te)
Antimony (Sb)	Hafnium (Hf)	Magnesium (Mg)	Rhenium (Rh)	Tin (Sn)
Bismuth (Bi)	Helium (He)	Manganese (Mn)	Rhodium (Rh)	Titanium (Ti)
Borates	Indium (In)	Nickel (Ni)	Ruthenium (Ru)	Tungsten (W)
Cobalt (Co)	Iridium (Ir)	Niobium (Nb)	Silicon (Si)	Vanadium (V)
Gallium (Ga)	Iron (Fe)	Phosphorus (P)	Sodium (Na) (compounds)	Zinc (Zn)
Germanium (Ge)	Lithium (Li)	Platinum (Pt)	Tantalum (Ta)	

Research Questions

This report provides an assessment of the UK's current technical capability to refine and recycle critical minerals, the risks and challenges facing the industry, and opportunities to grow the sector. The study quantifies the volume and value of critical minerals the UK could process or recycle using different potential policy interventions and quantifies the associated economic benefit of each activity. The key research questions addressed in this study are:

2025

- **Current capability**
  - What is the UK's existing capability base?
  - Which waste streams does the UK currently produce?
  - What is the UK's competitive advantage compared to other countries?
- **Barriers to growth**
  - What are the barriers to the maturity of mineral recovery and re-use from priority waste streams?
  - What are the barriers to midstream processing?
- **Future developments**
  - What policies are required to support the growth of UK critical minerals recycling and recovery, and midstream processing?
  - What is the pipeline of future projects?
  - What is the potential value and volume of UK processing in future scenarios?
  - What is the economic impact of developing mineral recovery and midstream processing capabilities in the UK?

Approach

Frazer-Nash, in partnership with CMA and MPI, adopted a mixed-methods approach comprising the following stages:

- **Literature review** – The review explores the current level of knowledge and understanding, from a UK perspective, of the critical minerals landscape, including existing work by MPI and CMA. Key works and publications have been assessed from various sources, including industrial representative bodies, government organisations and academic institutions.
- **Stakeholder interviews** – Frazer-Nash and CMA carried out 31 semi-structured research interviews with a range of senior stakeholders from industry, academia, and government. Interviews were analysed using thematic analysis to assess the UK's current capability, barriers and future opportunities.
- **Policy development and assessment** – Policy recommendations have been developed using the Frazer-Nash Policy Development Framework and HM Treasury Green Book guidance. Evidence supporting the recommendations came from the insights gathered during rapid evidence assessment and stakeholder interviews. The development cycle included workshops and roundtable events to gain feedback from industry and government stakeholders. Policies have been prioritised using a weightings framework, developed in consultation with DBT and wider government stakeholders.
- **Economic modelling –** Frazer-Nash have used data from the British Geological Survey (BGS) to create an autoregressive integrated moving average (ARIMA) forecasting model which forecasts UK critical mineral production and imports through to 2035. Forecasted revenues from UK production are combined with economic multipliers based on the UK input-output tables to estimate the direct, indirect, and induced economic impact of critical mineral production in the UK. This modelling has been used to estimate the impact of the four highest priority policies.

Drawing on the evidence collected, a set of policy recommendations were developed for DBT to consider. These recommendations address a series of problems, and use various measures designed to help the critical minerals sector reach its potential and provide economic security to the UK.

Key Findings

Findings highlight the UK's current capability, key barriers to industry growth, and future opportunities across the critical minerals value chain. These findings are based on published industry reports and scientific literature, and stakeholder engagement with government policy advisors, business leaders, and academics.

	2025 Current Capability	Barriers to growth	Future
Mining	• No mining in operation. • Plans and pilot stages for lithium, tin, tungsten, nickel, copper, cobalt, REEs and zinc, some of which could see production by 2030.	• Critical minerals' extraction is limited by unexplored geological potential in the UK. • Public perception limits interest, investment and skills uptake. • High capital, labour and energy costs in UK. • Long time to return on investment. • Planning permission for mining sites, related to land ownership, social and environmental.	• BGS / CMIC have identified potential areas for mining prospectivity. Additional research is required. • Novel technologies and innovations can improve efficiency and reduce environmental impact.
Midstream Processing	• Several exemplary cases for refining in the UK adopting an import/export model. • Global reputation for refining PGMs, REEs, aluminium and nickel. • Active in refining/production of zirconium, magnesium, copper, titanium, iron, silicon. • Little capability in natural graphite processing.	• Negative perceptions, despite advances in 'clean' processing and manufacturing technologies. • High capital, energy and labour costs within the processing industry. • Limited mining in the UK means midstream opportunities currently rely on imports. • Planning and permitting for new industrial operations – anticipated to be linked with negative environmental and social perceptions.	• Potential for midstream growth with growing domestic mining activity. • Opportunity to grow service to international markets seeking alternative supply chains. • Plans to develop midstream processing capability for zinc, lithium, tin, tungsten.
Recycling	• Strong capability in recycling product-based materials in key industries: - Iron and steel: iron, zinc. - Platinum group metals (PGMs): platinum, rhodium, iridium, ruthenium, palladium, nickel. - Rare earth elements: REEs, cobalt, nickel, aluminium, silicon. - Li-ion batteries: lithium, nickel, cobalt, manganese, iron. • Pilot stage initiatives in germanium, graphite and phosphorus • Not currently recycled in the UK: bismuth, borates, gallium, germanium, helium, hafnium, indium, sodium, rhenium, antimony, tantalum, tellurium.	• High capital, energy and labour costs force re-melting and casting of shredded iron and aluminium overseas. • Planning and permitting restrictions of industrial sites, including the unclear or unfavourable classification and segregation of waste streams, which can reduce material being recycled and adds to waste disposal charges. • Unclear ownership and responsibility of waste management. • Limited historic investment. • Process limitations and difficulties with growing technology to a commercial scale. • Proprietary designs and lack of standardisation make disassembly of electronic technology for recycling more difficult.	• Expected market growth in battery recycling. • Renewable infrastructure opportunities. • Exploiting 'urban mining' including electronic devices from the general public.

Recovery

▸ Ongoing research in identifying size of opportunity in recovering waste-based sources such as manufacturing and mining waste. ▸ UK midstream sector is active in critical mineral recovery from imported slags and fly ash.	▸ Unclear ownership of waste, including historic mine tailings. ▸ Economic viability and technical challenges in recovering small concentrations of critical minerals from mining and manufacturing waste.	▸ Opportunity for recovery of critical minerals from historic mine tailings and from future mining and manufacturing waste streams. ▸ Establish centralised circular economy and expand recovery opportunities.

Problems to address by government intervention

The UK is largely dependent on international trade to satisfy raw material demand. Whilst recycling can reduce dependence on mined materials and thus deter economic coercion, in many cases, the economics of recovering and recycling critical minerals in the UK are currently uncompetitive. Intervention to develop the capabilities of targeted processing and recycling of the UK's critical minerals is needed to effectively reduce dependency on overseas supply and the associated inherent uncertainties and risks.

Findings from research and stakeholder interviews have identified four key problem statements that policies should address.

The key barriers to the growth of the UK critical minerals can be defined in four problem statements:

- UK energy costs are too high for production of the UK critical minerals to be competitive with the rest of the world.
- The UK critical minerals industry struggles to access sufficient finance to scale its operations.
- There is a negative perception of mining and midstream processing which deters investment and talent.
- Difficulty accessing waste streams means there is not a secure supply of waste to UK operations.

Initial testing of potential policy actions

Policy recommendations have been developed using the Frazer-Nash Policy Development Framework and HM Treasury Green Book guidance. Evidence supporting the recommendations came from the insights gathered during rapid evidence assessment and stakeholder interviews. As part of the Policy Development Framework, potential policy recommendations were tested with the Critical Minerals government cross departmental working group and with industry and academic members of the Critical Minerals Association. Comments and feedback have been incorporated throughout this report, in particular the following points have shaped the recommendations.

- **Funding to support access to finance:** Funding the development of pilot capabilities to move technology readiness levels and develop skills was considered of key value. Funding could be focussed on developing midstream and upscaling capabilities, where these areas are in strong need of investment.
- **Streamlining planning and permitting processes:** Several companies noted how other countries support businesses through planning and permitting processes. The emerging suggestion is for centralised support where businesses can engage with a customer representative to help them through the processes and liaise with corresponding organisations on the companies' behalf. The recommendation for planning and permitting support is focused on providing centralised support with further consideration needed to develop the extent of support and how this differs from existing activities.
- **Classification of waste:** It was noted that to enhance recycling efforts, it's crucial to accurately characterise waste streams containing critical minerals. This process needs to extend beyond simple waste classification. For instance, in the case of Waste Electrical and Electronic Equipment (WEEE), there are several data gaps in the current system.

These gaps make it difficult to track and manage WEEE effectively. Specifically, there is a lack of accurate assessments of WEEE flows, especially regarding what happens to WEEE that isn't recorded as collected and recycled according to mass-based targets. Therefore, the recommendation for considering waste classifications focusses on research to understand what is needed to be changed and the implications for change, with opportunities to engage with other areas of government to avoid adverse effects.

- **Targets and restrictions:** Imposing production targets or restrictions such as a cap on export of waste material could be argued as a policy to promote the development of UK capabilities. However, the majority of companies felt this would disturb the operation of a free market and ultimately reduce competitiveness of their operations, as companies with operations overseas would then be constrained in exporting to these destinations. The main barrier is that the UK currently does not have a robust recycling capability to handle the waste. In 2024 the EU set non-binding benchmarks specifying 25% of annual consumption of specific critical minerals should be produced via recycling activities by 2030 [2]. Additional targets for processing, mining and dependencies on a singular country were also placed, all with the aim of ensuring a secure, resilient and sustainable supply chain. Recommendations to achieve these benchmarks included the promotion of waste collection, circular design and the substitution of critical minerals within products [2].

  Due to stakeholder concerns, targets or restrictions do not form part of the recommendations at this time, however, considerations to overcome barriers to strengthen and diversify critical mineral supply chains to reduce the reliance on exports was explored in this report.

Prioritising potential policy actions

This report proposes a list of nine policy recommendations designed to address the above problem statements. We have prioritised the most impactful of these based on the potential benefits. Each policy was scored one (low) to five (high) according to the below criteria:

- **Economic impact (weight – 25%)** – Potential of the policy to increase critical mineral volumes, values, gross value added, and jobs.
- **Security of supply (weight – 22.5%)** – Ability of the policy to reduce supply chain risks and threats associated with international trade.
- **Capability (weight – 20%)** – Ability of the policy to improve the effectiveness and competitiveness of UK midstream processing and recycling and recovery.
- **Environmental, social and governance (ESG) standards (weight – 17.5%)** – Ability of the policy to overcome risks associated with countries with lower ESG standards.
- **Domestic policy alignment (weight – 15%)** – Extent to which the policy aligns with existing UK policies.
- **Cost assessment** – Based on the capital and resource costs to deliver each action. These are initial rough order of magnitude estimates that require further refinement and are based on similar policies where possible.

The four highest scoring priority policies were carried forward to in-depth economic modelling that forecasts the potential impact of the policies on:

- Critical mineral production in the UK.
- Gross value added (GVA) to the UK economy.
- Employment supported by additional economic activity.

These impacts are compared to the rough order of magnitude cost of undertaking each policy, to estimate the return on investment (ROI). An ROI greater than 1 indicates that the benefits exceed the costs over the lifetime of the policy. The potential economic benefits, and associated ROI, are presented as a range which accounts for uncertainty in future projections. The midpoint of the range is considered the most likely outcome of these estimates.

Policy recommendations

Based on the evidence from stakeholder engagement, published literature, and economic analysis, the recommended potential policy actions are presented by problem statement in Figure 2 and described in turn by priority order.

High energy costs

- **Priority 3**: An extension of existing energy intensive industries scheme to cover critical minerals.
  Potential ROI: 2.01 – 2.47
- Or alternatively, a new energy bill relief scheme tailored to critical minerals.
  Potential ROI: 1.07 - 1.40

Difficulties in accessing finance

- **Priority 2**: Matched grant funding to support and de-risk investment in research and innovation that develops midstream and recycling capability.
  Potential ROI: 2.02 - 2.48

Difficulties accessing waste streams

- **Priority 5**: Amendments to waste classifications.
- **Priority 7**: Publish a critical minerals procurement plan.

Negative public perceptions

- **Priority 8**: Targeted school and university outreach.
- **Priority 9**: Facilitate positive promotion of midstream processing industry.

Cross cutting actions

- **Priority 1**: Centralised support for planning and permitting. **Potential ROI: 0.78 - 2.78**
- **Priority 4**: Centralised support to collaborate with regional clusters. **Potential ROI: 0.72 - 1.43**
- **Priority 6**: Collaborate with international partners to transfer knowledge.

Figure 2 – Potential policy recommendations to address key industry problems

Priority 1 – Centralised support for planning and permitting

Purpose: To enable industry growth by supporting companies through planning and permitting processes.

Rationale: Planning permission can take up to 13-weeks, the need for environmental impact assessments and further considerations of industrial categorisation means planning for critical mineral sites can often take longer [3]. Industry stakeholders felt that a lack of technical understanding on the part of planners led to a slower process and greater costs to business. The impact of a slow planning process means that critical mineral firms may miss out on commercial opportunities or access to markets. Additionally, businesses may be forced to re-locate to overseas where their operations aren't hindered.

Description: Creation of a team of relationship managers located centrally with technical understanding of the industry through experience or training. A relationship manager could be a single point of contact for critical minerals companies focussed on guiding the company through planning and permitting processes across all government and local authority organisations. The potential action could be initiated as a pilot, with one or two relationship managers for future scaling up as needed.

Risks and further research: This action would sit closely with the suggested action to support collaboration with regional clusters. DBT would need to work with Environment Agency, DEFRA, and MHCLG to implement this policy. There could an opportunity to pool resources, however, at this stage it is believed that separate initiatives for planning and permitting would best support the industry.

Potential benefits

- Streamlined planning means that pilot sites can become operational sooner. This results in greater access to markets and increased output for the UK.
- Additional GVA contribution: **£0.7m - £2.5m**
- Additional jobs (for one year) supported: **16 – 54**
- **Potential ROI: 0.78 – 2.78**

Potential costs

- £900,000 to deliver engagement and collaborate with local authorities.
- This is based on 5 full time equivalents over 3 years to help develop the process.

Priority 2 – Funding for innovation in recycling and midstream capability

Purpose: To stimulate growth in the critical minerals supply chain by de-risking investment in innovation projects focussed on developing and diversifying recycling and midstream capability, whilst considering commercialisation.

Rationale: Research and innovation is a competitive strength of the UK and presents an opportunity for growth. However, evidence in this report suggests that access to private finance has been difficult due to limited opportunities and an uncertainty surrounding future demand, particularly midstream activities. Funding is required to develop, demonstrate, and commercialise new technology for use in the critical minerals industry, and to allow industry to enhance knowledge exchange with academia to deliver significant impact.

The existing funding programme, CLIMATES, focusses on the entire supply chain for rare earth elements, in contrast this potential funding programme could focus explicitly on developing recycling and midstream capability across critical minerals key to the UK economy.

The EPSRC Future Manufacturing Research Hubs have demonstrated success in addressing similar challenges; supporting UK manufacturing industries through the commercialisation of early stage research opportunities, whilst explicitly considering the pathway to manufacturing, including production scale up and integration within the wider industrial system. The hubs also take a leadership role in the national research landscape, centralising clusters of knowledge and conducting outreach and driving research excellence in their area. The Manufacturing Hub model could serve as an exemplary case for future funding programmes within the critical minerals industry.

Description: Creation of a new matched funding programme. This programme could be a minimum of £50m over a period of 4 years, as that would allow significant collaborative R&D activity to occur without any additional supporting initiatives. The programme could be strategically targeted on the midstream part of the value chain, for recycled and primary materials. Funded projects could focus on two areas to grow a more resilient UK midstream supply chain for critical minerals:

1. Facilitate the adoption of new innovations in processes, technologies or services by industry.
2. Research on mid and late-stage routes to development, to accelerate the industrialisation and commercialisation of innovative processes, technologies and services.

Risks and further research: It is usually expected that full commercial operations will not be seen for 3 years or more from this type of funding programme. There is a risk that if there is not a clear commercialisation strategy for each project then smaller companies may struggle to access follow-on funding. Therefore, there is a need to further consider more substantial funding to develop pilot capabilities to full operational status and consider funding support for upscaling capabilities, in a similar manner to larger industrial capability programmes. For example, the Automotive Transformation Fund (ATF) is a funding programme created to support large-scale industrialisation, with up to £850 million of funding invested in developing a high-value end-to-end electrified automotive supply chain in the UK. The fund is highlighted as an important mechanism to support green industrial revolution and decarbonisation plans and provides an example of an extension to this policy recommendation for further consideration.

Potential benefits

- Innovation funding provides collaboration opportunities to develop new technologies.
- Commercialising these innovations will deliver improved productivity, greater energy efficiency, and business growth.
- Additional GVA contribution: **£100.8m – £123.8m**
- Additional jobs (for one year) supported: **2,149 – 2,640**
- **Potential ROI: 2.02 – 2.48**

Potential costs

- Minimum of £50m of matched industry funding over 4 years.
- This is a minimum cost that could allow significant business-led R&D activity to occur without any additional supporting initiatives.

Priority 3 – Extension of the Energy Intensive Industries support scheme

Purpose: To actively reduce the cost base for companies in the UK critical mineral supply chain, helping the industry to become more competitive internationally.

Rationale: The UK has the highest electricity costs in Europe, standing at £0.36 per kWh in the second half of 2024 [4]. Stakeholders in this research felt that energy costs were too high for UK industry to be competitive. This is especially true for an energy intensive industry such as critical mineral processing and recycling. High energy costs and uncertainty deter private investment in critical minerals due to reducing the return on investment. Additionally, processes such as re-melting and casting of scrap metal are exported in many cases to countries where energy is cheaper, resulting in business loss, an increase in carbon emissions and additional challenges of the export of material. Action could be considered by introducing a new energy bill or alternatively by extending existing schemes, which is discussed in Section 6.

Description: Under this scheme eligible companies would be able to recover up to 30% of their energy costs. The scheme could be extended to include a larger number of industries, including metal manufacturing, mining, and disposal of waste.

Risks and further research:
It is also worth considering how such a policy would interact with energy use reduction targets, as the cheaper cost could incentivise firms to be less considerate of the energy efficiency of their activities. Incorporating incentives within the scheme to tackle this, or efficiency requirements that funding is contingent on, may be a way to mitigate these concerns. The existing exemption scheme is due to be reviewed in 2026, this includes a review of the qualifying sectors. Eligibility criteria are based on energy use data from 2022, which likely means that sectors such as disposal of waste (which includes several critical mineral recycling firms) would not qualify as an energy intensive industry.

For the EII exemption scheme to be better targeted to critical minerals then the sector eligibility must account for emerging sectors. Without changes to scheme design this potential, this potential action is likely to return benefits to a lesser extent compared to a new scheme. Therefore, there is a need for further consideration of which alternative action may be more feasible to implement.

Potential benefits:

- Energy relief payments will reduce the burden of energy costs on industry. This improves competitiveness of UK firms, resulting in business growth, and higher output.
- This action could benefit industry to a lesser extent than a new scheme but is potentially more feasible to implement.
- Additional GVA contribution: **£787m - £967m**
- Additional jobs (for one year) supported: **18,000 – 22,000**
- **Potential ROI: 2.01 – 2.47**

Potential costs:

- £390 million over the scheme.
- Based on covering 30% of the energy costs of companies producing mineral products.

Priority 4 – Centralised team to support collaboration with regional clusters

Purpose: To facilitate industrial symbiosis via exploiting waste from one organisation as feedstock in another, as well as providing services and labour pools for similar industries, streamlining transportation, supply chains and green energy development.

Rationale: Collaboration between the critical minerals industry and existing regional developments such as freeports, industrial clusters, and innovation parks would provide commercial opportunities to the critical minerals industry and capitalise on a perceived strength of the UK. Stakeholders felt there was an opportunity for industrial symbiosis through locating critical minerals companies close to their customer base. As well as locating recyclers close to their waste streams. For example, establishing a recycling site close to a wind farm to capitalise on the supply opportunity.

Critical minerals companies should benefit from the advantages of local green energy scheme, net zero hubs, and industrial clusters. Collaboration with regional developments can leverage development corporations to help streamline planning, as well as integrating critical minerals into local economic plans which will stimulate regional circular economy activity and allow for targeted regional activity.

Potential clusters to consider collaboration with include South Wales and Tees Valley Industrial Clusters, both of which benefit from deep port access which is a UK advantage. A regional hub could be established in the Southwest to support mining activities.

Description: Creation of a team of 5 relationship managers located centrally. A relationship manager could be a single point of contact for critical minerals companies focussed on guiding the company through government and local authority processes and identifying funding opportunities. Their responsibility could include collaborating with target clusters and the associated local authorities to support critical minerals companies take best advantage of opportunities such as local green energy scheme, net zero hubs, and industrial clusters. The potential action could be initiated as a pilot, with one or two relationship managers for future scaling up as needed.

Risks and further research: This action would sit closely with the suggested action to support planning and permitting. DBT would need to work with other government departments including MHCLG, local authorities, and regional cluster partners to implement this policy. This could provide opportunities to pool resources, however, at this stage it is believed that separate initiatives for planning and permitting would best support the industry.

For this policy to be successful engagement must be targeted to ensure that the right opportunities are pursued. In the first instance engagement could build on existing relationships the DBT critical minerals team has with regional development, as well as aligning to sectors with the highest critical minerals demand (e.g. renewable energy and automotive).

Potential benefits:

- Location near to customers and waste suppliers provides potential greater access to linked supply chains and funding opportunities. Shared energy resources for closely situated businesses.
- Industrial symbiosis via exploiting waste from one organisation as feedstock in another.
- Additional GVA contribution: **£0.6m – £1.3m**
- Additional jobs (for one year) supported: **14-28**
- **Potential ROI: 0.72 – 1.43**

Potential costs:

- £900,000 to deliver engagement and collaboration with all identified parties.
- This is based on a team of 5 full time equivalents over 3 years.

Priority 5 – Amendments to waste classifications

Purpose: To facilitate a greater volume of available critical mineral rich waste through more accurate identification.

Rationale: The current waste classifications have been identified by recycling stakeholders to be a barrier to expanding recycling in the UK. The current classification of materials during upstream processes means some useful minerals appear downstream as waste, this leads to an underrepresentation of supply to recycling firms. This results in smaller waste streams going to UK recycling firms. In essence, these materials are not all waste. Many critical minerals are not currently covered by waste frameworks, such as The Waste Framework Directive. Therefore, a full review of classifications could ensure greater coverage and support greater access materials for recycling.

Description: A review of waste classifications of waste and scrap for secondary sources of critical materials for import, export and transportation purposes. Whilst this report highlights the example of lithium in WEEE, the review of classifications should be broader and in line with the UK recycling aspirations. DBT would need to work with Environment Agency, DEFRA to review regulations.

Risks and further research: Further research is needed to identify which materials and classifications could be classified differently for the industry to benefit, avoiding unintended consequence of inadvertently making trade of waste more difficult. The implications for other sectors will need to be considered alongside the frequency of future reviews. Further research could consider the inclusion of critical minerals traceability, to enable safe and efficient dismantling and recycling as well as enabling proof of minimum recycled content in down-stream products that are placed on the UK marketplace.

Potential benefits	Potential costs
▸ Amendments to waste classifications will make critical mineral waste easier to recycle. This means a greater proportion of waste is recycled in the UK.	▸ £360,000 to conduct investigation and engagement with all identified parties. ▸ This is based on a team of 2 full time equivalents over 3 years.

Priority 6 – International collaboration

Purpose: To provide wider opportunities to build capability, attract talent, and collaborate on research projects in both midstream processing and recycling. This would provide access to skills, commercialisation opportunities, and access to finance.

Rationale: Securing critical mineral supply chains is an active policy space for multiple countries, who are all working to expand their domestic capability. Stakeholders expressed that international collaboration would provide an opportunity to build capability, attract talent, and collaborate on research projects.

Description: Build on existing partnerships with friendly nations and make new ones. These partnerships should focus on knowledge transfer and demonstrating UK capability, providing opportunities for UK companies to collaborate internationally. This allows for greater learning as well as export potential. Potential collaborations indicated in this research include:

- With Western/EU countries to establish 'greener' and high ESG supply chains. Many companies are looking for opportunities to move away from Chinese or Russian supplied minerals and their processing industries.
- While Australia and Canada are leading in extraction of critical minerals in the Western world, with the USA following, little has been done to set up an alternative midstream, resulting in many critical minerals extracted in the Western world being shipped to China for refining. Therefore, there are opportunities to work with Australia and Canada to supply midstream services.
- Canada has strengths in the classification, segregation and recycling of WEEE which provides opportunities to partner with Canadian companies to establish their operations in the UK.
- Similarly, Canadian companies have expertise in operating plants for EV battery recycle and minor metal recovery. With the right incentives, they could be persuaded to establish midstream operations in the UK, or to cooperate with UK partners.

Risks and further research: International collaboration must focus on demonstrating UK capability and facilitating knowledge sharing between countries. This requires targeted engagement to understand mutual benefits of partnerships to boost UK capability.

Whilst this research has identified possible areas of interest for collaboration, further research could explore the feasibility and prioritise potential actions.

Potential benefits	Potential costs
International collaboration provides more opportunities for knowledge transfer and research. This will improve UK capability and drive business growth.	Total cost of £900,000 over 5 years. This includes 3 FTE per year.

Priority 7 – Government procurement plan

Purpose: To provide certainty of forward demand for government procured critical minerals.

Rationale: The security of waste streams is hampered by an unclear end-of-life responsibility, and uncertainty relating to product demand. Recycling stakeholders felt that unclear end-of-life responsibility created disputes of who is responsible for decommissioning and recycling of offshore infrastructure. These disputes create delays to recycling and reduce opportunities for UK industry.

Description: Government to publish a critical mineral procurement plan. This will detail the volumes of critical minerals due to be used in future public infrastructure and clearly designate end-of-life responsibility. The plan would need to detail demand specifics such as what minerals, grade, form, and the product being made.

This plan should cover major public infrastructure projects covering energy, defence, and civil developments. For example, HS2, GB Energy, Thames Tideway Tunnel, Hinkley Point C, and Lower Thames crossing. As well as track current and future public infrastructure (e.g. wind turbines) that are approaching end of life.

This procurement plan will provide a view of public sector demand for critical minerals which will provide demand certainty to the recycling sector. In addition, clearly designating end-of-life responsibility will help to secure the supply of waste as recycling arrangements have much clearer accountability.

Risks and further research: A procurement plan will likely require continual maintenance. Careful consideration is needed to create a reliable source of future demands, that can be relied upon by industry. Further research could consider the extent to which a plan feeds into future procurement contracts. Options to overcome this risk include publishing an updated procurement plan each year or including public sector procurement in the criticality assessment as part of the economic vulnerability calculation.

Potential benefits

- A critical mineral procurement plan will provide certainty on mineral demand. This can improve investor confidence and stimulate investment.
- Designating clear end of life responsibility provides clearer quantity for different waste streams will increase investment in recycling. This is because returns on investment are clearer.

Potential costs

- Total cost of £300,000 (5 FTE) over 1 year to produce the plan.

Priority 8 – Targeted school and university outreach

Purpose: To address issues of a negative perception of midstream processing as well as addressing skills gaps.

Rationale: The Institute of Materials, Minerals, and Mining (IOM3) express a growing skills gap in critical minerals, including mineral processing, and metallurgical skills [5]. There appears to be some strengths in highly qualified R&D or PhD level scientists in laboratory research but are not encouraged to seek roles in large scale processing. This is in part due to a negative perception of midstream processing, as well as an apparent reduction in academic opportunities through changes in higher educational opportunities within the field. A more positive perception of the long-term future and security of the industry could encourage current students to enter the roles in this area.

Description: Government could facilitate collaboration between academia and industry to deliver targeted school and university outreach in areas with local critical minerals capability to promote the sector and training opportunities in parallel to the development of regional critical minerals clusters.

Risks and further research: School outreach will only produce benefits in the long-term, with limited immediate benefits realisation. To expedite some of the benefits engagement should be focused on regions with mining heritage or existing critical minerals capability. This helps to support jobs and training in the local community where opportunities can be acted upon much easier. Further research could identify target schools, universities and courses.

There are several existing outreach programmes across different industries. There is potential to consider partnering with existing advanced manufacturing, engineering, or STEM outreach programmes. Further work could investigate coordinating with existing government outreach programmes.

Potential benefits	Potential costs
Targeted school outreach will provide a create awareness of the sector amongst younger people. This awareness combined with grater knowledge of training and academic opportunities will attract more workers into the sector. This will improve skill levels in the long term.	£300,000 (1 FTE) for 5 years to coordinate the school outreach.

Priority 9 – Facilitate positive promotion of the midstream processing industry

Purpose: To change public attitudes, increase awareness of the importance of the critical minerals sector, and to encourage key skills into the sector.

Rationale: All midstream industry stakeholders felt that there was a negative perception of the industry. There is a perception that the industry is dirty and creates significant negative environmental impacts on local areas, this is in part driven by a perception of water, air, and soil pollution. This has made it difficult to attract talent.

Description: Government to coordinate collaboration between midstream processing companies and industry bodies to develop target marketing campaigns that promote a positive image of the sector. Campaigns could focus on popular areas of interest including environmental impact, use of new technologies, and the positive impact on other industries (e.g. automotive, aerospace, and renewable energy).

Risks and further research: This potential action places government in a facilitation and coordination role, not to directly fund marketing campaigns. Therefore, further research could consider the appetite for industry and industry bodies to support such initiatives.

Potential benefits

- Advertising the capability and benefits of midstream processing will increase the visibility of the sector. This could improve public perception and in turn help to attract workers and investment in the long term.

Potential costs

- £90,000 to facilitate and coordinate industry level advertising campaigns to convey key messages over a continuous period.
- This would require some government time of approximately 0.5 FTE over 3 years.

Next Steps

Informed by literature and stakeholder engagement, the recommendations presented in this report suggest areas of focus to inform and future policy development. All recommendation will require further research and consideration as part of development, the suggested next steps include:

- **Relief for operating costs, beyond energy:** Several companies in the supply chain don't own mining assets and operate mainly as net importers to the UK. These companies still have a high cost base, through other inputs such as high labour costs, but would potential not benefit from energy cost relate support. There is an opportunity to consider shaping energy relief schemes to include a broader range of operating costs.
- **Greater level of funding to bring capabilities to operational level:** Funding the development of pilot capabilities to move technology readiness levels and develop skills was considered of key value. Further research could consider greater funding levels and focus on higher technology readiness levels.
- **Identifying waste classification amendments:** Further research is needed to identify which materials and classifications could be amended for the industry to benefit, avoiding unintended consequence of inadvertently making trade of waste more difficult. The implications for other sectors will need to be considered alongside the frequency of future reviews.
- **Traceability:** Further research could consider the inclusion of critical minerals traceability, to enable safe and efficient dismantling and recycling as well as enabling proof of minimum recycled content in down-stream products that are placed on the UK marketplace.
- **Coordinating with existing STEM outreach programmes:** Further work could investigate coordinating with existing government outreach programmes.
- **Appetite to fund marketing campaigns:** The recommendation to undertake targeted marketing campaigns places government in a facilitation and coordination role, not to directly fund marketing campaigns. Therefore, further research could consider the appetite for industry and industry bodies to support such initiatives.
- **Prioritise international collaboration opportunities:** Focus on demonstrating UK capability and facilitating knowledge sharing between countries. This requires targeted engagement to understand mutual benefits of partnerships to boost UK capability. Whilst this research has identified possible areas of interest for collaboration, further research could explore the feasibility and prioritise potential actions.
- **Focus on particular minerals:** The evidence gathered in this report provided arguments for either a focus on expanding UK industries that currently exist (section 2) combined with developing international collaboration, or alternatively, diversifying the UK's capability and entering new markets (section 4). No clear prioritisation of critical minerals emerged from this evidence, presenting an opportunity for further research in the following areas:
  - The UK has strong capability in rare earth element and PGM refinement and recovery, however these are relatively small scale. Further research could consider investment into the circular economy and subsequent up-scaling of these industries.
  - The current UK capabilities for processing Li-ion batteries is not internationally competitive but there are plans to significantly expand infrastructure in the coming years. The key limitation in this area is the capability for separating the black mass, which is currently exported. Further research could consider developing a sovereign capability to refine black mass.
  - Iron alloy and ferrous scrap recycling is quite effective in the UK, but a significant amount of this waste is exported. It's important to investigate whether there is additional capacity in the UK's steel and iron recycling facilities (such as electric arc furnaces) to recycle more of this waste domestically and reduce exports.

Contents

Tables

Figures

1 Introduction

The Department for Business and Trade (DBT) has commissioned Frazer-Nash Consultancy, in partnership with the Materials Processing Institute (MPI) and the Critical Minerals Association (CMA) to carry out a capability assessment of the UK's critical mineral industry and provide recommendations to inform future policy development. This report assesses the UK's capability in critical mineral midstream processing, and recycling. This research builds on the UK's critical minerals strategy, published in 2022, to identify opportunities for the UK to expand its critical mineral processing and recycling capability to deliver economic security and growth to UK supply chains.

Fraser-Nash has undertaken a mixed methods review of the UK's existing capability, the barriers to growth, and opportunities for future development. This assessment has utilised qualitative thematic analysis, and quantitative econometric analysis to produce a set of policy recommendations for the UK to overcome the pressing challenges for the critical minerals industry. The policy recommendations put forward in this report, section 6, are designed to improve the competitiveness of the UK's critical minerals industry and capitalise on the existing strengths of the UK supply chain to provide supply chain resilience and economic security to the UK.

The research questions to be addressed in this study are displayed in Figure 3.

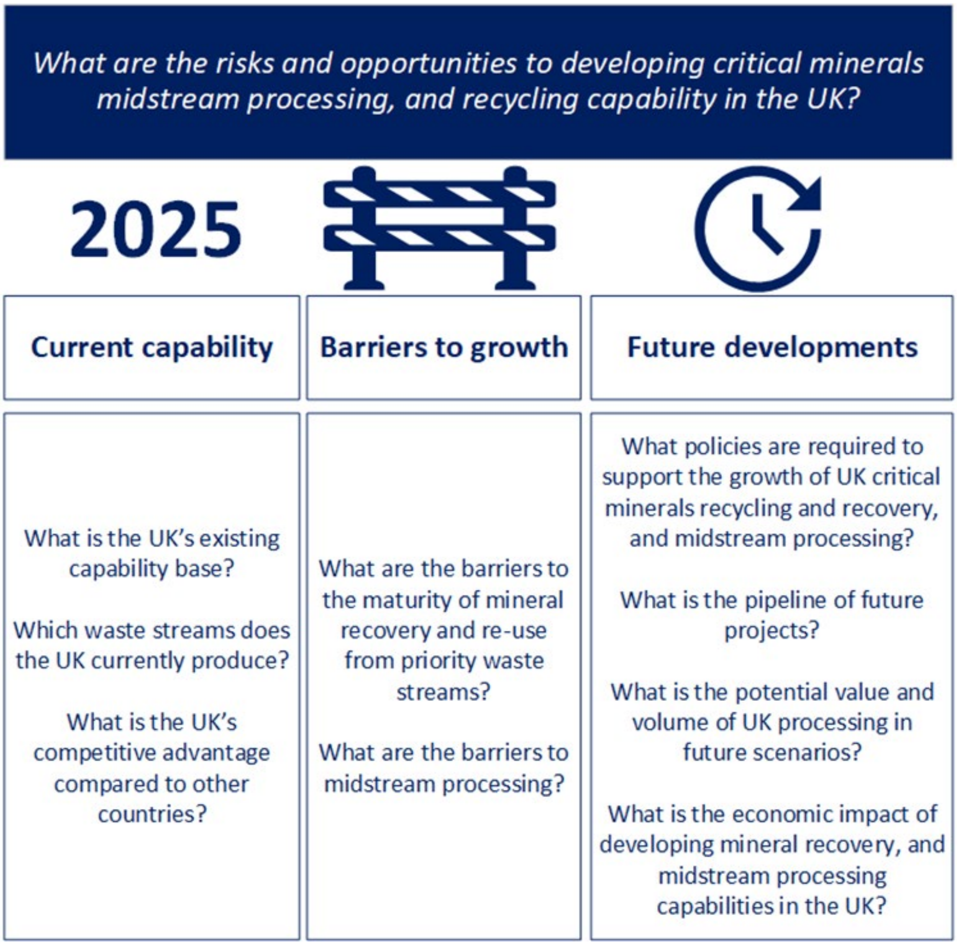

Figure 3 - The research questions cover the UK's current capability, barriers to growth, and future opportunities

The aim of this capability assessment is to define the UK's current position, and outline opportunities for development. This is solidified by a set of policy recommendations and econometric modelling which evaluates the benefits and risks of those opportunities.

1.1 Scope and definitions

Figure 4 visualises the critical minerals value chain. This report focuses the UK's midstream processing and recycling capabilities which are defined below:

- **Midstream processing -** Any post-mining processing where value is added/materials are upgraded from their virgin mined state.
- **Recycling and recovery -** The recovery and re-use of critical minerals from non-traditional sources, such as mining waste, and end of life technologies.

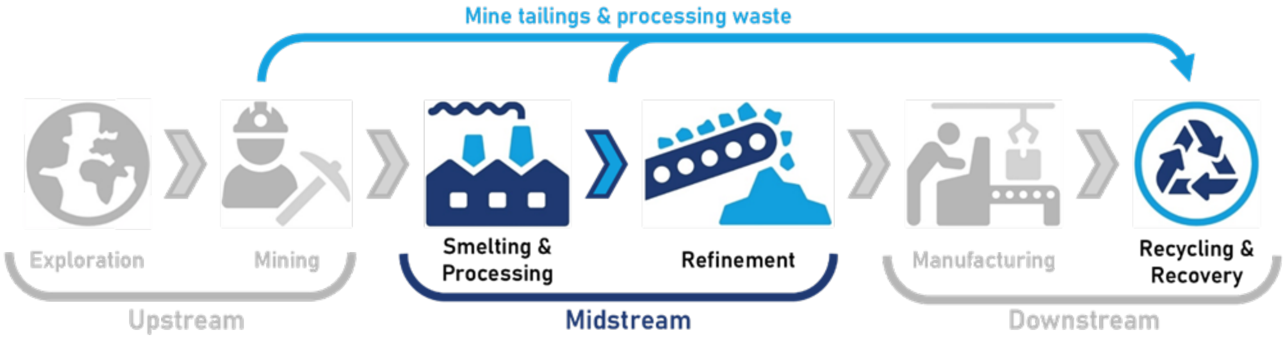

Figure 4 - An overview of the critical minerals value chain. This capability assessment will focus on midstream areas of the value chain, and recycling and recovery

This study focusses on the midstream aspect of the value chain and recycling, however, consideration is given to mining and exploration because of the associated opportunities for future processing and recycling. Expansions in mining will increase the potential volume and midstream processing as well as recycling capacity from mine tailings.

Whilst it is noted that manufacturing is out of scope for this study, any future work should consider the circular economy impacts and standardisation of manufacturing, design for repair, design for end of life and re-designing of end products. In particular, future research should include a focus on battery and wind turbine construction alongside the context of EU regulations for minimum recycled content. Such research could also include a focus on what is required to encourage firms to more fully include recycling and circular economy principles within end-product design. This leads to more sustainable products with less dependency on primary critical minerals. This forms part of a future potential demand assessment for critical minerals. Redesign and re-manufacture of end products can reduce critical mineral import demand. There is a fundamental link between end product demand and raw material demand which requires further research.

1.2 Minerals deemed as critical in the UK

The UK's Critical Mineral Strategy defines critical minerals based on their high economic vulnerability and high global supply risk. The UK's Critical Minerals Intelligence Centre (CMIC) has co-authored a criticality assessment report with the British Geological Survey (BGS), defining the minerals and metals with greatest economic importance and the highest risk of supply disruption as critical minerals to the UK [1]. Criticality is assessed by the following priorities:

- Economic importance based on UK consumption
- GVA contribution
- Import reliance
- Risk of supply disruption, based on production concentration and recycling rates.

Updated in 2024, the list comprises 34 critical minerals, which includes the removal of palladium and the addition of 17 minerals, since 2021. A comparison of all minerals considered during the study is shown in Figure 4. Those with a criticality score of greater than four (based on its UK economic vulnerability and global supply risk) are considered critical. Table 1 provides a list of UK critical minerals. Annex A.1 contains a full list of each mineral's criticality score and the global industries for which it is used.

Table 1 - CMIC's list of critical minerals

Aluminium (Al)	Graphite (natural)	Magnesite ($MgCO_3$)	Rare earth elements (REEs)	Tellurium (Te)
Antimony (Sb)	Hafnium (Hf)	Magnesium (Mg)	Rhenium (Rh)	Tin (Sn)
Bismuth (Bi)	Helium (He)	Manganese (Mn)	Rhodium (Rh)	Titanium (Ti)
Borates	Indium (In)	Nickel (Ni)	Ruthenium (Ru)	Tungsten (W)
Cobalt (Co)	Iridium (Ir)	Niobium (Nb)	Silicon (Si)	Vanadium (V)
Gallium (Ga)	Iron (Fe)	Phosphorus (P)	Sodium (Na) (compounds)	Zinc (Zn)
Germanium (Ge)	Lithium (Li)	Platinum (Pt)	Tantalum (Ta)	

Top 5 most critical minerals (by CMIC criticality score):

1 Niobium (Nb)
2 Cobalt (Co)
3 Rare earth elements (REEs)
4 Germanium (Ge)
5 Phosphorus (P)

Top 5 minerals by UK consumption (£s spent):

1 Lithium (Li)
2 Iron (Fe)
3 Aluminium (Al)
4 Silicon (Si)
5 Zinc (Zn)

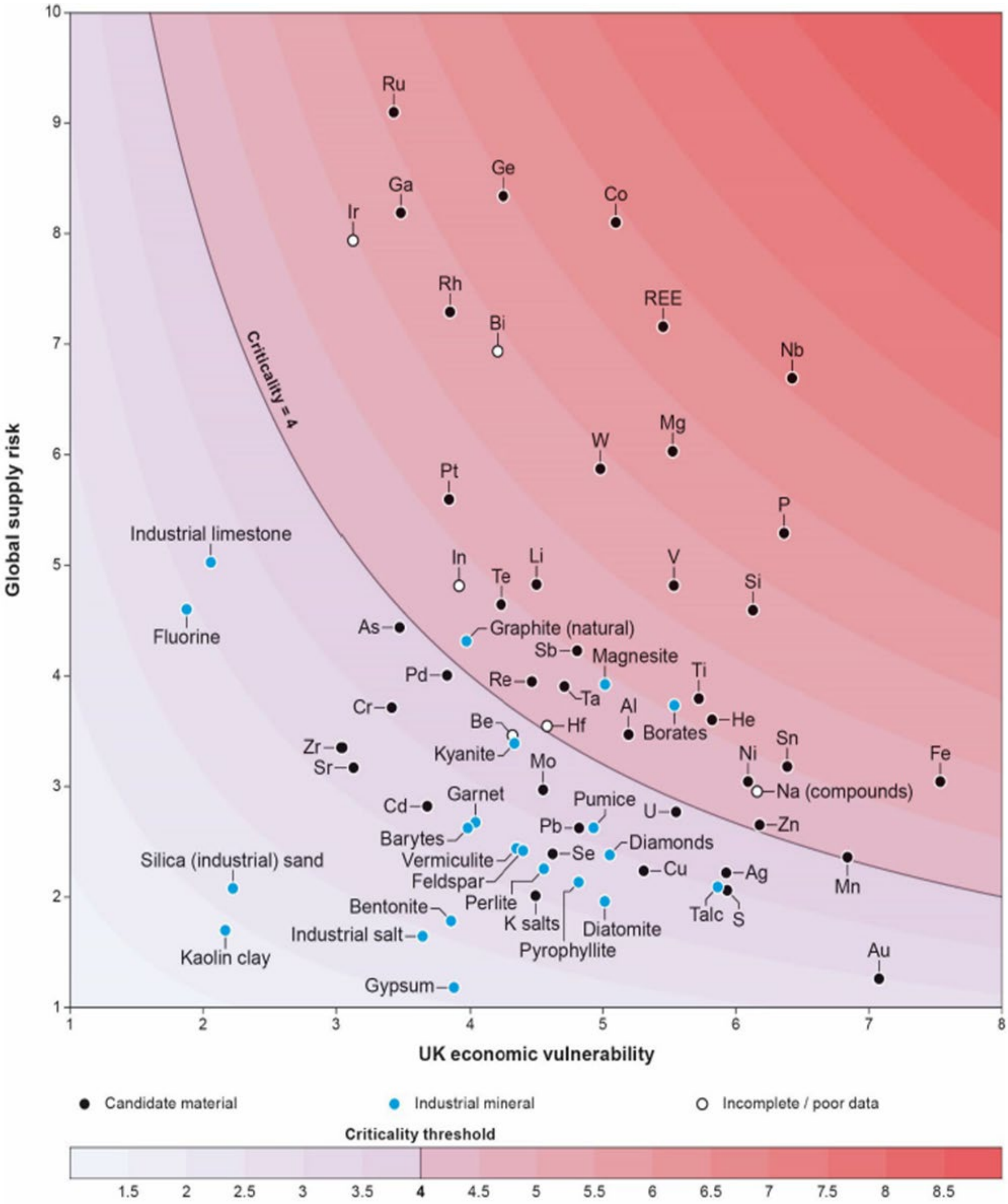

Figure 5 - Criticality graph of each assessed mineral, based on the UK's economic vulnerability (x-axis) and global supply risk (y-axis) [1]

1.3 Challenges facing the UK critical minerals industry

This research has found that the challenge facing the UK critical minerals industry is in part due to:

- Increasing demand for critical mineral rich technologies such as wind turbines, solar panels and electric vehicles—which is largely driven by the transition towards a net zero economy.
- The international supply chain is dominated by a small number of countries including China and Russia, increasing concerns about supply chain security.
- The UK does not currently have sufficient production capacity to keep up with demand.

As a result, the UK is dependent on global supply chains for crticial minerals to meet net zero ambitions.

A drive towards providing consumers with greener, environmentally friendly alternatives has resulted in a rapid uptake of electric vehicles and renewable energy sources such as wind and solar. According to the Society of Motor Manufacturers and Traders (SMMT), a total of 314,687 battery electric vehicles were registered in the UK in 2023, higher than the numbers registered in 2021 and 2022 combined and creating the second largest electric vehicle (EV) market in Europe [6]. Similarly, the National Energy System Operator (NESO) has reported that 51% of the UK's electricity generation in 2023 came from renewable sources, up from 2% in 1991 and 14.6% in 2013 [7]. The increased demand for net zero technology creates increased demand for critical minerals. This is shown in Figure 6 which indicates global demand increasing up to 2040, as well as the proportion of this demand that is driven by net zero technologies. In addition, UK net zero transition policies place a strong emphasis on mineral dependent end products which will lead to increasing demand for minerals from strongly concentrated sources.

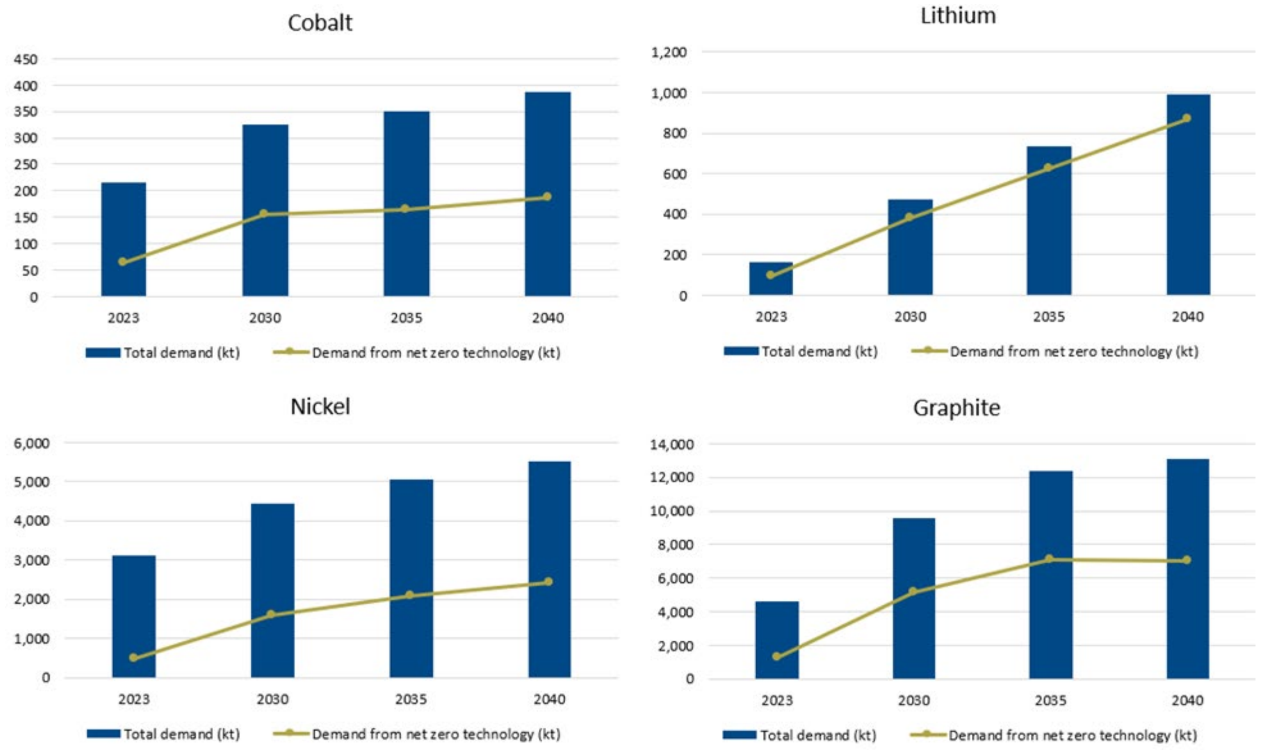

Figure 6 - Global demand forecast for cobalt, lithium, nickel and graphite. The gold line depicts the mineral demand from net zero technologies (e.g. Battery electric vehicles, solar panels, wind turbines etc). Source: International Energy Authority [8]

The UK is heavily reliant on imported critical minerals because it does not have large reserves of naturally occurring minerals, when compared to the rest of the world, as well as declining mining output in recent decades.

The UK currently has limited capability to produce the minerals contained in Figure 6 and Figure 7. These have been selected as key minerals of the UK critical mineral list included in the IEA market outlook:

- **Cobalt:** The UK currently has no mine production of cobalt, although exploration is underway. Aberdeen Minerals, for example, is active in the exploration of cobalt and nickel. Previous UK production of cobalt has come as a by-product of copper, lead, and zinc mining [9].
- **Lithium:** The UK has begun exploring the potential for lithium production and refining in Cornwall, and the North and North East of England are exploring recovery of lithium from brines, as well as refining. These sites are all still at pilot and/or planning stage and are not yet commercially active [10].
- **Nickel:** Nickel has traditionally been produced in small quantities in the UK, with little mining opportunity. There is nickel refining capability in Wales, being carried out by Vale nickel refinery. In 2022 the UK produced 33,000 tonnes of nickel [11], this is approximately 1% of global nickel production [8].
- **Graphite:** There is currently little domestic production of graphite in the UK [12]. The UK relies on imported graphite for manufacturing. Further research is required on graphite exploration in the UK, however the current understanding suggests that known deposits are unlikely to be commercially viable and only one UK producer generates synthetic graphite.

As a result, the UK is dependent on a geographically concentrated market where key players are able to influence prices. The International Energy Authority (IEA) forecast this geographical dominance to continue [8]. For example, lithium demand is due to increase by 30% by 2030 due to a rise in EVs. In addition, 95% of battery grade graphite is predicted to be concentrated to China by 2030, as well as 58% of battery grade lithium. Forecasted global supply and the share of production controlled by the top three global suppliers is shown in Figure 7. This creates significant economic risk to the UK and threatens the UK's economic stability and net zero leadership ambitions.

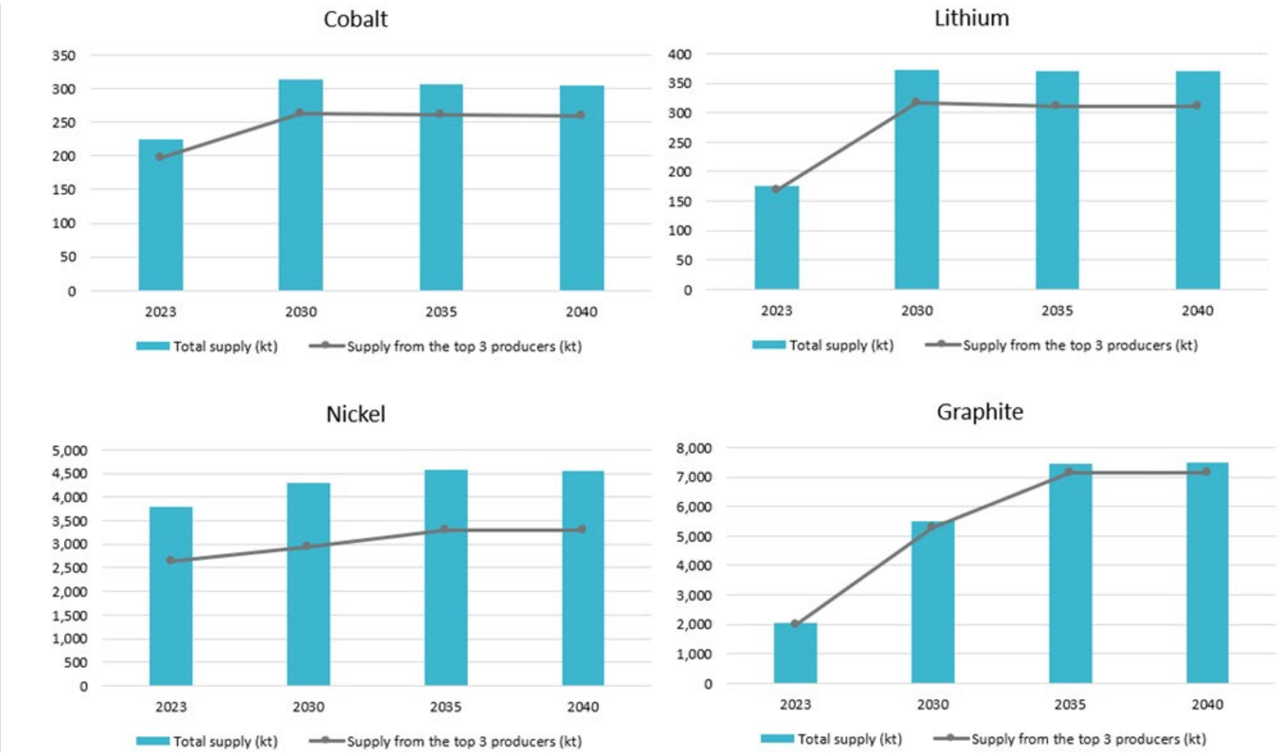

Figure 7 - Global supply forecast of cobalt, lithium, nickel, and graphite. The grey line indicates the proportion of global supply provided by the top three producers which is due to remain high. Source: International Energy Authority [13]

1.4 Stages of mineral production

1.4.1 Exploration and mining

The scope of this review includes midstream processing, recovery and recycling, however relevant aspects of the upstream processes such as exploration and mining of critical minerals will be also highlighted due to their intrinsic link to midstream operations and recovery, and their importance within the UK critical minerals landscape. Often, mining and extraction facilities are paired with on-site processing, which acts as one of the first midstream processes, and mining waste can also act as a feedstock for recovery. Understanding the UK's current and future mining capacity will therefore expose the potential for any domestic downstream opportunities.

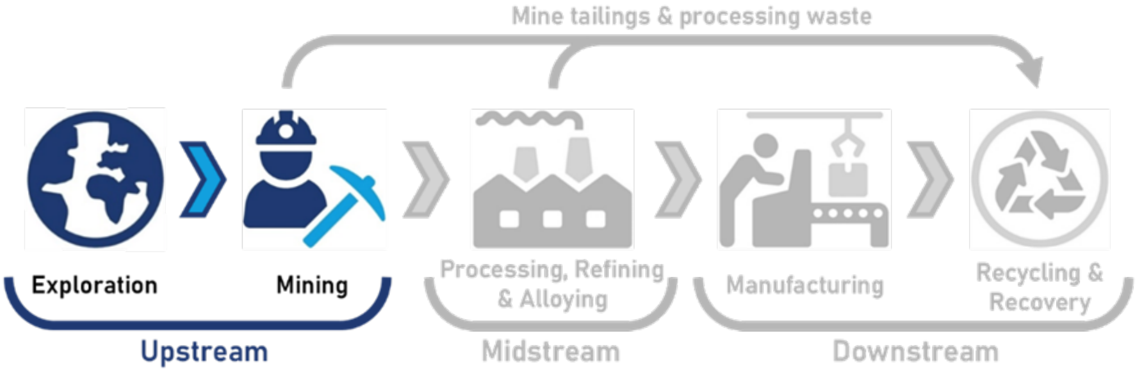

Figure 8 - Position of extraction and onsite processing within the materials and minerals lifecycle

Raw elements are rarely found in a pure state; instead, ores are removed from the Earth through mining processes which are stable compounds of elements, usually oxides, carbonates and hydroxides. In addition, some elements can only be extracted as co-products, or as by-products of mining primary elements – this is often referred to as 'companionality' [14]. For example, 60% of cobalt is obtained as a co-product of copper mines and 95% of gallium is obtained from zinc mines [15]. This is the case for most of the critical raw materials listed in the UK Criticality Assessment (2024) [1], whereby many are recovered as by- and co-products from ore-forming minerals. This is an important consideration in the exploration of new mines and also to understand the unlocked potential in alternative critical mineral sources such as mining waste and tailings, which will be discussed in section 4.

1.4.2 Midstream processing

Midstream processing of critical minerals typically spans any post-mining processes where value is added to mined virgin materials to the point of them being manufacturing-ready, as shown in Figure 9. When referring to solid, mined materials (as opposed to materials mined from geothermal waters), midstream processes include the extraction of minerals from their ores, from primary mineral processing to concentrates, through to smelting and refining, and later, additive processes such as alloying.

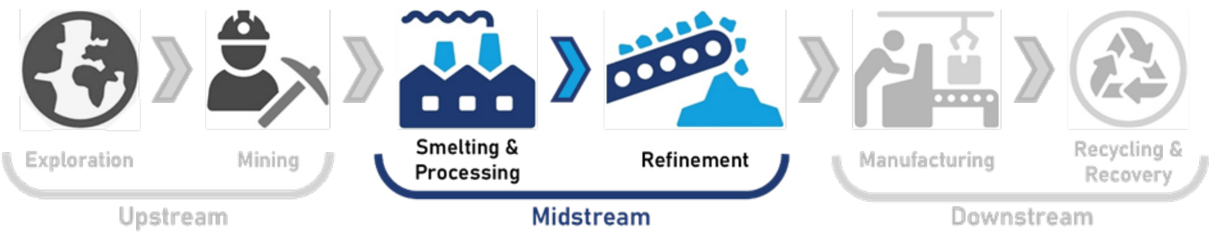

Figure 9 - Position of midstream processing within the materials and minerals lifecycle

Primary mineral processes are normally located within the mining area and consist of comminution, reducing the particle size of the ore through crushing and milling, followed by separation and concentration, using methods such as magnetic, gravity, flotation or chemical leaching [16]. During extractive processes such as smelting, materials are generally heated to extreme temperatures and a chemical reducing agent is added to extract a base metal from its ore/oxide. Refining is a similar, but often takes place subsequently, which utilises chemical reduction to increase the purity of the extracted mineral. Refining often takes place via processes such as hydro- and pyrometallurgy. This highlights the link that exists between midstream processing and recycling, whereby extractive processes are inherently similar to one another, given the parallel requirement to improve the purity of a critical material, no matter the source. In terms of capability, some operators will be able to refine ores, secondary materials such as mining waste and processed recycled materials, such as black mass from batteries, utilising the same technologies. Many consider recycling as a midstream process [1], however, this section will focus on the midstream processing/refining of primary feedstock such as ores and concentrates, whereas section 1.4.3 will specifically cover the processing of recycled products and recovery of minerals from waste. Finally, the alloying process is where additional elements are added, or minerals are combined to obtain a material with a desired chemical composition in readiness for component manufacture.

1.4.3 Recycling and recovery

The recycling and recovery stage is described as 'downstream' of the critical mineral lifecycle, where materials become available for re-use. An efficient recycling and recovery industry should take advantage of end of life, faulty and unused products, ensuring that as many critical minerals as possible are extracted and re-used in the production of new materials. As shown below, the midstream provides the re-entry point for recycled materials, without which, domestic recycling in restricted.

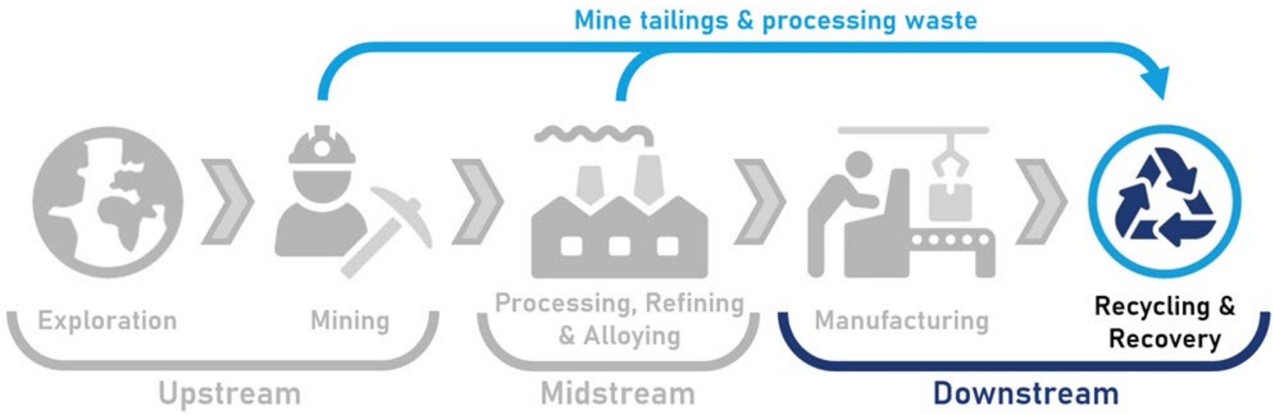

Figure 10 - Position of the recycling and recovery process within the materials and minerals lifecycle

Recycling is the processing of end-of-life (EOL), faulty, or unused products which allows their constituent parts to be separated and used for another purpose. Recycling can greatly reduce energy consumption compared to smelting from an element's natural ore state. A good example of this is aluminium which uses approximately 95% less energy during recycling compared to its primary extraction, significantly cutting emissions and cost [17].

Recovery refers to the processing of secondary waste and un-used manufacturing materials, which also includes sources from historic mining processes that were less efficient at the time. This can include traces of REEs from mine tailings [18], waste off-cut material from manufacturing processes and of byproducts during refining, alloying or processing such as slags.

1.5 Approach

- **Literature review** – The review explores the current level of knowledge and understanding, from a UK perspective, of the critical minerals landscape, including existing work by MPI and CMA. Key works and publications have been assessed from various sources, including industrial representative bodies, government organisations and academic institutions. A full list of references considered during the literature review can be found in the bibliography.

- **Stakeholder interviews** – Frazer-Nash and CMA carried out 31 semi-structured research interviews with a range of senior stakeholders from industry, academia, and government. Interviews were analysed using thematic analysis to assess the UK's current capability, barriers and future opportunities. This is explained in greater detail in Annex 3.

- **Policy development and assessment** – Policy recommendations have been developed using the Frazer-Nash Policy Development Framework and HM Treasury Green Book guidance. Evidence supporting the recommendations came from the insights gathered during rapid evidence assessment and stakeholder interviews. The development cycle included workshops and roundtable events to gain feedback from industry and government stakeholders. Policies have been prioritised using a weightings framework, developed in consultation with DBT and wider government stakeholders. This process is described in more detail in Annex 4.

- **Economic modelling –** Frazer-Nash have used data from the British Geological Survey (BGS) to create an autoregressive integrated moving average (ARIMA) forecasting model which forecasts UK critical mineral production and imports through to 2035. The forecasted revenues from UK production are combined with economic multipliers based on the UK input-output tables to estimate the direct, indirect, and induced economic impact of critical mineral production in the UK. This modelling has been used to estimate the impact of the four highest priority policies. Annex 5 provides a full breakdown of the economic modelling approach and robustness checks.

1.6 Report structure

The structure of this report will follow the research questions set out in Figure 2. This will outline the current capability, barriers, the potential future state, and the recommended policies yielded by this research for the UK to reach its potential. Sections 2 to 4 consider each value chain component in turn with analysis on mining, midstream processing, and recycling and recovery.

- **Section 2**: The UK's current and planned capability in critical mineral mining, midstream processing, and recycling and recovery.
- **Section 3**: The barriers facing the UK critical minerals industry.
- **Section 4**: Opportunities for growth and developments in the critical minerals sector.
- **Section 5**: Discusses industry employment and skills shortages.
- **Section 6**: Potential government intervention to address barriers.
- **Section 7**: The potential economic impact of government intervention on the UK economy.
- **Section 8**: Concluding statement and next steps.

2 The UK's current and planned capability

This section provides an overview of the UK's current midstream processing and recycling capability. This includes detail on the current processes, strengths, weaknesses, and opportunities for the industry. As well as planned sites which aim to boost capacity. A summary of the UK's current capability and the stakeholder views on UK strengths is provided below.

Overview of the UK's current capability

- The UK has a strong heritage in mining but is not currently active in production-level mining of critical minerals. There are however eight new mining project sites which reports suggest could have successful outcomes. To date, three of the eight planned mining sites have progressed to the pilot stage. Additional prospective sites have also been identified but are subject to meeting the necessary geological criteria to progress further.
- The UK has a well-established midstream processing sector processing both ore/concentrate minerals, as well as recycled products and recovered waste. There are exemplary case studies and examples of successful UK-based small to medium sized enterprises who import minerals for processing and then export high-value materials and products.
- The UK has a well-established capability for iron and aluminium recycling—however many UK recycling operations are still at pilot stage. Notably, there are opportunities for the UK to expand its recycling capacity of lithium, PGMs, and REEs, as well as increasing the capacity of processing waste from coal fly ash and mine tailings. Presently, the industry notes that regulatory barriers exist which inhibits the supply of waste into the UK recycling industry.

Stakeholder opinion – REEs capability

- **Research and innovation:** *"I do think that we have some excellent innovation projects going on in UK universities and within companies in the UK"* – Industry stakeholder
- **Environmental, social, and governance (ESG) standards:** It was highlighted by many stakeholders across industry, academia, and Government that the high ESG standards championed by the UK are considered as pillars that support a positive critical minerals industry. Having a green ambition and businesses being accountable offers a competitive advantage and import of irresponsibly produced materials should be discouraged or restricted.
- **International reputation:** There was a consensus that the UK still has a strong commercial influence, skill base, and reputation.

2.1 The UK's current and planned mining capability

Historically, the UK has a strong mining and processing heritage, including the mining of tin and tungsten in Devon and Cornwall, copper and iron in Wales and iron in Northern Ireland and Yorkshire. Zinc, lead and fluorspar have also seen extensive mining activity across the UK. The UK still has capability to mine coal and non-critical industrial minerals such as polyhalite, silica sands, and barytes [18]. However, of the 34 minerals listed as critical in the CMIC UK 2024 Criticality Assessment, none are currently being mined at production level in the UK. The UK's transition to a service-based economy has gradually led to the closure of many mines, with little active mining remaining in the UK. [19]

With the projected global increase in demand for critical minerals, several UK organisations are establishing technologies and developing strengths in knowledge in the field. The Cambourne School of Mines, for example, recently re-launched the UK's only undergraduate degree scheme in Mining Engineering, and a Critical Minerals

Equipment Hub has been formed through the Shared Prosperity Fund to support mining research in the Southwest of England. Companies are already seeking to exploit opportunities within the UK to extract minerals from new and historic mines, and as such, several recent projects have been launched for exploration, for example Aberdeen Minerals (exploring nickel-copper-cobalt deposits) and Helium Resources Limited (testing viability of helium prospects), amongst others. In addition, there are also several cases of reopening, planned and/or pilot mining activities. Planned mining activity and sites currently under construction are shown in Table 2, some of which are existing sites which were operational until recent years.

Table 2 - Planned and pilot mining sites in the UK [19] [20]

Site	Location	Site Planned Processing Capability
Northern Lithium	County Durham, England	**Status:** Planned pilot. **Critical mineral:** Lithium carbonate from geothermal waters, estimated 10,000 tonnes per year. (1,000 tonnes per year during pilot phase)
Cornish Lithium Plc	Trelavour, Cornwall, England	**Status:** Planned. **Critical mineral**: 7,800 tonnes lithium hydroxide per year.
Anglesey Mining plc	Parys Mountain, Wales	**Status:** Planned. **Critical mineral**: Zinc (and copper, lead, gold and silver) 40,000 tonnes of combined zinc/lead to be mined over a 12 year mine life.
Cornwall Resources	Cornwall, England	**Status:** Planned. **Critical mineral**: Tin and tungsten. Technical study indicated a production rate of 600,000 tonnes per year over 12 years.
Cornish Metals Ltd.	South Crofty, Cornwall, England	**Status**: Planned. **Critical mineral**: Tin
Imerys British Lithium	Roche, Cornwall, England	**Status:** Pilot. **Critical minerals**: Estimated 20,800 tonnes per year of lithium carbonate equivalent.
Cornish Lithium Plc	United Downs / Cross Lanes, Cornwall, England	**Status**: Pilot. **Critical mineral**: Direct lithium extraction from geothermal waters. Estimated 500-1,000+ tonnes per year of lithium carbonate.
Tungsten West Plc	Devon, England	**Status:** Under construction. **Critical minerals:** 3,900 tonnes tungsten oxide predicted, as well as 600 tonnes of tin by year 3.

2.2 The UK's current and planned midstream processing capability

In addition to a strong mining heritage, the UK also has an excellent track record in material processing, refining and manufacturing, with many midstream processes having been historically conceptualised and developed in the UK. For the purpose of this report, the UK's current/planned midstream processing capability can be split into three midstream subprocesses; primary mineral processing (e.g. crushing and milling); extractive processing (e.g. smelting and refining) and additive processing (alloying), as shown in Figure 11.

Figure 11 - Breakdown of typical solid critical mineral midstream processes

Given its relative abundance in capability, alloying is not explicitly addressed within the analysis of this report. Alloying, while considered a midstream process, typically takes place as part of integrated material and component manufacturing operations. For example, most metal manufacturers in the UK consist of primary liquid metal processing, followed by casting and subsequent forming (via forging, rolling, machining etc) into finished or pre-finished products. During primary processing, alloys that have normally been sourced or procured, that have been previously refined via extractive processing methods, will combined at extremely high temperatures for melting, and ultimately solidified with the desired chemical composition. There are a few cases, namely in integrated steel steelmaking, where refining of ores takes place, followed immediately by primary processing/alloying and manufacturing. The UK has relevant abundance in metal manufacturing capability, and therefore in alloying, and are active in the manufacture of various steels and alloys that utilise critical minerals as material input.

The open literature was not found to explicitly quantify the number of operations specific to alloying alone, but under the assumption that primary metal manufacturing also constitutes alloying, the strengths in this industry appear to be vast in the UK. [21] provides a list of companies in the UK that are classed as 'Primary Metal Manufacturers', collated by the North American Industry Classification System (NAICS) code, 331, which quantifies the number of primary metal manufacturers as 3,256. Further research needs to be carried out to understand the operational split of these industries, but this initial figure, along with supporting evidence from UK manufacturing associations (such as UK Steel and Make UK), suggest that the UK has a robust and healthy alloying and manufacturing industry.

Furthermore, primary mineral processing and extractive processing is of greater concern to the critical minerals sector due to an overall scarcity in UK capability.

Stakeholder opinion – UK midstream capability

- Stakeholders highlighted that the UK has a strong capability in refining and end-use applications within the midstream aspect of the supply chain. This is evidenced through its industry leading organisations, specialising in processing PGMs and rare earth elements.
- However, many felt the UK is not able to influence global markets and geopolitics. UK strengths are limited to rare earth elements and PGMs.

As previously discussed, primary mineral processes such as crushing and milling typically take place on mine sites. Given that the UK does not have any production-level critical mineral mining activity, there are no current primary plants dedicated to the processing of critical minerals. The UK, however, is no stranger to the use of these processes, having extensive experience through historic metal mining and ongoing activities in the wider UK minerals landscape, where the UK is considered a leader in the high-quality processing of key raw mined materials used predominantly in the construction and transportation sectors [22]. This report does not consider the diversification of existing non-critical mineral facilities for use in critical minerals primary processing, but with the proposed future mining activity in the UK, many businesses have shared their plans for on-site primary mineral processing, as shown in Table 3. Of the seven sites proposed, five discuss plans for on-site primary processing, which will see ores taken to concentrate-level.

Two of the seven sites utilise direct lithium extraction from geothermal waters and therefore do not require solid primary mineral processing.

Where known, Table 3 also highlights other midstream processes planned for each proposed new mining site. Only two have shared intentions for co-locating refining capability on site, suggesting that concentrates may need to undergo further processing offsite, or even internationally, except where direct lithium extraction is used.

Further to operations concerning domestic mining, the UK already has a well-established and successful extractive midstream processing industry, concentrated on the refining of oxides and concentrates that are predominantly imported. The UK is reported to import a variety of materials, including waste materials, re-processing these into higher value materials or products [1].

Table 3 - Planned UK mining activity and associated midstream processing operations (Reproduced from CMA: [23])

Site	Location	Site Planned Processing Capability
Anglesey Mining plc	Parys Mountain, Wales	**Status:** Planned. **Critical mineral:** Zinc Plans for mining and primary mineral processing on site. Processing to include crushing, separation, grinding, cleaning, floatation. Smelter costs have been presented as part of an economic analysis but unclear if this will be part of the project scope [24].
Cornish Lithium Plc	Trelavour, Cornwall, England	**Status:** Planned. **Critical mineral:** Lithium Proposed processing site at TreLith to consist of crushing and milling and processing through a concentrator. Lithium mica concentrate to be further processed via hydrometallurgical plant at TreLith, producing battery grade lithium hydroxide monohydrate. A sulfuric acid production plant is proposed to support the hydrometallurgy facility which will also benefit the UK economy as all sulfuric acid is reported to be currently imported [25].
Cornish Metals Ltd.	South Crofty, Cornwall, England	**Status:** Planned. **Critical mineral:** Tin and tungsten New on-site processing plant proposed. Processing facility to open potential to serve as a central hub to other projects within reasonable transport distance, such as the United Downs and Cross Lanes projects. Downstream opportunities such as smelting and refining prospects will be assessed as the project advances [26].
Weardale Lithium	County Durham, England	**Status:** Planned. **Critical mineral:** Lithium Direct lithium extraction from geothermal water, no solid mineral processing or refining required [27].
Strategic Minerals	Cornwall, England	**Status:** Planned. **Critical mineral:** Tin and tungsten A process plant and infrastructure study as well as an economic assessment have been conducted, showing economic benefits, suggesting future for on-site processing is being considered [28].
Imerys British Lithium	Roche, Cornwall, England	**Status:** Pilot. **Critical mineral:** Lithium Currently producing battery grade lithium carbonate, suggesting mineral processing and lithium refining capability exist [29]. Plan to co-locate beneficiation plant and refinery on quarry site in the future [30].

Cornish Lithium Plc	United Downs/Cross Lanes, Cornwall, England	**Status:** Pilot. **Critical mineral:** Lithium Direct lithium extraction from geothermal waters to create saleable lithium chloride. No solid or further processing required [31].
Tungsten West Plc	Devon, England	**Status:** Under construction**.** **Critical mineral:** Tin and tungsten Mineral processing facility planned to consist of crushing, water-based suspension separation, drying and reduction. Output from reduction kiln to be transported offsite [32]. Further refining of tungsten concentrate scheduled to be exported for refining in Austria or the US.

Of the midstream industries in the UK, there are some exemplary cases by which the sector can follow; Vale nickel refinery in Clydach, South Wales, is one of Europe's largest nickel refineries and one of the longest-running refineries in the world, producing approximately 40,000 tonnes per year of high-purity nickel. The nickel is used in specialist applications such as aerospace nickel alloys, stainless steels, and materials for EVs, as well as other high value applications. Ore is imported from mines in Canada, Japan and Indonesia and is supplied to approximately 280 clients in more than 30 countries worldwide, including Europe, Asia and the USA [33].

Stakeholder opinion – REEs capability

"From a rare earth perspective, I think we have the best midstream capability in Europe and arguably at the moment in North America. (…) unfortunately, it's pretty much [with one] company" – Government stakeholder

Less Common Metals (LCM) are a world leader in the manufacture and supply of complex alloys and metals and are specialists in those based on rare earth elements. They are the only company in the western world producing highly specialised strip cast alloys needed to manufacture the highest performance neodymium iron boron (NdFeB) magnets – the most powerful permanent magnets commercially available. Based in northwest England, LCM are active in supporting the procurement of oxides from sources outside of China where possible and have positioned the UK as one of the only countries in the world outside of China who can convert neodymium oxides to metal. The majority of LCM's customer base is outside the UK, exporting to over 17 countries worldwide, including Europe, the Far East and the USA. The business has demonstrated that customers clearly want to support an alternative supply chain [23]. As shown in Table 4, the UK is also particularly active in the refining of PGMs with world leading facilities, producing alloys for global manufacturers in the automotive, electronics and consumer sectors, making the UK a significant exporter of these materials. These PGM producers are mainly active in refining from secondary sources such as waste and recycled materials, however, and will therefore be discussed in more detail in subsequent sections.

Table 4 - Current UK midstream refining capability (reproduced from [23])

Refinery	Location	Mineral(s)
Vale Europe	Clydach, Wales	Nickel
JBR Recovery*	Midlands	PGMs
Mastermelt Refining Services*	North England	PGMs
Livent Lithium	North England	Lithium
Less Common Metals	Northwest England	REEs
Luxfer Group	North England	Zirconium, magnesium
Phillips 66	Northeast England	Petroleum coke
Johnson Matthey*	London	PGMs
Britannia Refined Metals	Southeast	Copper, nickel, lead

* Source lists PGM producers as 'refineries', but all three producers are mainly active in recycling/recovery of PGM's from secondary sources. ** A by-product from Phillips66 is coke and anode graphite, which is subsequently recycled and used as a natural graphite replacement in electrodes.

In addition to midstream processing associated with new mining activity, and those listed by CMA, additional production activity of critical minerals in the UK is taking place; Alvance British Aluminium, recognised as one of the worlds greenest metal production plants, largely due to being powered by local hydro-generated electricity, is active in aluminium smelting (and is also classed by CMA as a recycler); Elkem are active in the production of silicon powders, Pilamec produce, process and supply a variety of metal powders (ore and recycled) such as silicon, iron, aluminium, titanium; Tronox manufactures titanium dioxide from their international mining operations, and Venator produce various critical mineral-based pigments such as zinc sulfide and titanium dioxide. [23] and [1] also highlight additional planned refineries in the UK, shown in Table 5.

The new projects are mainly focussed on exploiting the UK's position in providing midstream processing for ores and concentrates that are imported from sustainable sources overseas. For example, Tees Valley Lithium (Alkemy) is planning to establish Europe's first and largest lithium hydroxide facility which will utilise a low-carbon electrochemical processing route, powered by renewables. The site aims to exploit a UK-Australia supply chain, importing high value feedstock from Australia and around the world and enabling the production of battery-grade lithium hydroxide and carbonate to supply the UK and Europe. The site will benefit from being located in the Teesside Freeport, benefiting from offshore wind energy, international accessibility, with by-products being sold to neighbouring businesses [34]. Similarly, Peak Rare Earths, Pensana and Green Lithium aim to import materials from overseas while supplying the European (and other) markets. These midstream operators will act as an alternative source to the Chinese supply chain while also enable mining companies to access the European market, rather than shipping their ores to China for processing.

Table 5 - Planned midstream refining capability (reproduced from [23])

Refinery	Location	Mineral(s)	Operational Stage
Tees Valley Lithium (Alkemy)	Northeast England	Lithium	Planned
Peak Rare Earths	Northeast England	REEs	Planned
Pensana	Northeast England	REEs	Planned
Green Lithium	Northeast England	Lithium	Planned
Ionic Technologies*	Northern Ireland	REEs	Pilot

* Source lists Ionic Technologies in Belfast as a planned refinery but the facility will focus on the separation and refining of spent magnets, as opposed to mined ores.

2.3 The UK's current and planned recycling capability

Assessing the capability of the UK's recycling processes is difficult for three main reasons. Firstly, company data relating to recycling efficiency, feedstock and production amounts is considered sensitive and not commonly released into the public domain. As certain waste streams are in some cases restricted to only one main supplier, anonymising any data for the purposes of this report would not be possible. Secondly, the products recovered through recycling are unknown in many cases. For example, a company may recycle lithium-ion batteries, but the exact quantity and type of critical minerals extracted are unknown. Finally, 'recycling' is a term that can be used to describe companies that purely process scrap through deconstruction or shredding of products and send it abroad to be recycled. This is misleading and falsely inflates the UK's opportunity to be self-sufficient.

"As much as 80% of the metal products that are classified as waste are exported from the UK, making us the largest exporter out of the EU" [35]

The UK's recycling capability can be split in to 'closed' and 'open' loop recycling. The former refers to the processing of material to form metal alloys of a similar grade, such as in the steel, ferrous alloy and superalloy industries. Certain critical minerals, such as the presence of tin (Sn) within steel, cannot be removed from the process and are therefore recycled within the same industry. Open recycling is less restrictive and allows materials to be broken down into their constituent critical minerals for use in multiple industries. There is a cross-over with recovery in some processes. For example, as zinc is vapourised during steel smelting in electric arc furnaces, it forms a fine dust which is recovered and sold to be refined. Zinc could therefore be captured under both the recycling and recovery categories.

From an analysis of available literature, it is clear the UK's current production-level recycling capability is limited mainly to five distinct industries which are presented in Figure 12. Additionally, there are several other recyclers and refiners that have the ability to process aluminium (Al), nickel (Ni) and cobalt (Co). Some elements are listed as 'not currently recycled' (in the UK); however, some initiatives have been highlighted on the recovery of phosphorus, including the development of a National Phosphorus Transformation Strategy [36], and an example of recycling germanium has also been reported [37].

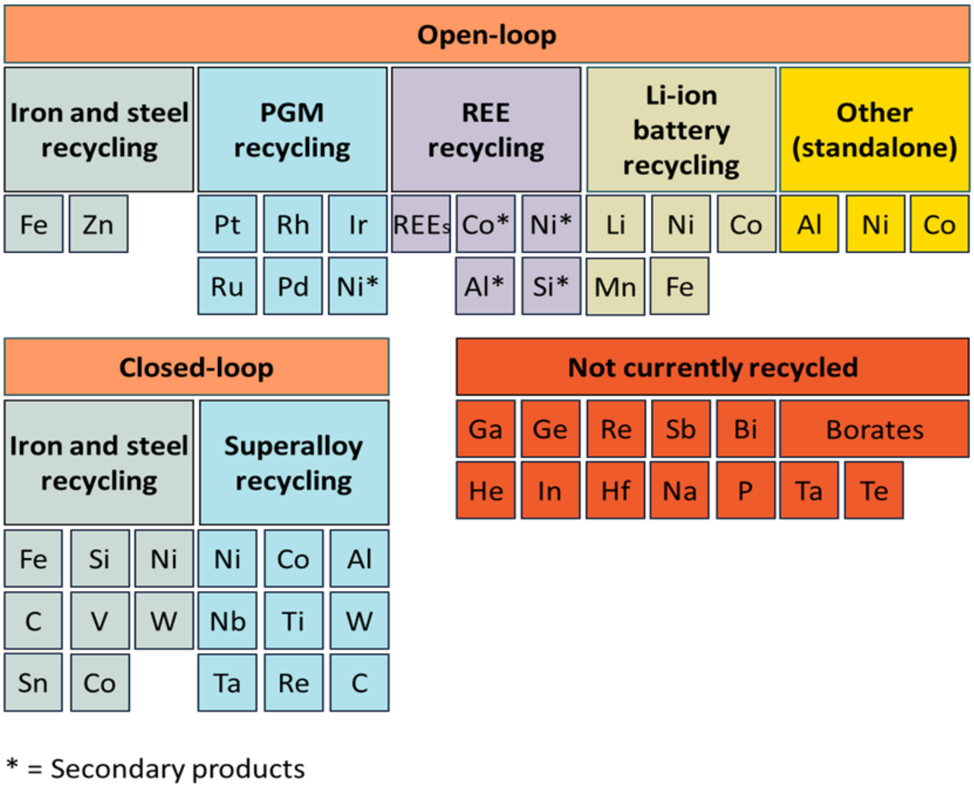

Figure 12 - Critical minerals involved in each recycling process

Data from the British Geological Survey's 2023 Minerals Yearbook shows that the UK exported large amounts of scrap between 2018 and 2022 [38], some of which is summarised in Table 6. The data shows that whilst the UK does have the ability to recycle its own waste from several different waste streams (as presented above), it does not have any advantage on a global scale. Research from the University of Birmingham also found that approximately 80% of metal products in the UK that are classed as waste are exported [35].

Table 6 - Scrap export data for several different critical minerals during 2022, taken from the British Geological Survey's 2023 materials yearbook [38]

Commodity	Mass exported (tonnes)	Value (£)
Iron, steel and ferro-alloy scrap	8,813,525	3,424,051
Nickel scrap	13,782	179,061
PGMs	5,771	969,912
Zinc scrap	7,075	15,022

2.3.1 Lithium-ion batteries

Lithium-ion batteries are used in a wide range of consumer technologies, from personal devices such as smartphones and tablets to electric vehicles (EVs) and hybrid-power public transport. In addition to offering wireless power, batteries have also been key in reducing exhaust pipe emissions within cities and fuelling the drive towards net zero by providing an alternative to fossil fuels. 'Lithium-ion' is a general term used to refer to batteries containing lithium oxide cathodes and includes chemistries such as $LiCoO_2$, $LiMO_2$ and $LiNO_2$ [40].

According to the CMA, two sites currently recycle lithium-ion batteries within the UK with an additional four sites planned, as shown in Table 7[24].

Table 7 - Current and planned lithium-ion battery recycling capability within the UK [23, p. 28]

Site	State	Total Processing (Per annum)
R.S. Bruce Ltd	Operational	2,000 tonnes of batteries to produce 1,000 tonnes of black mass [39]
S.A.R. Metals Ltd	Operational	Unknown
Altilium Metals	Planned	150,000 vehicles
Veolia	Planned	1,000 tonnes
Glencore	Planned	Unknown
Fenix Battery Recycling	Planned	Unknown

Most of the UK's lithium-ion battery recycling capability is at construction or pilot stage. Figure 13, taken from a report by the Faraday Institute [40], shows the current and proposed capability of battery recycling within European countries. The UK presently has very little capability but is expected to be the second-largest battery recycler in Europe with a planned capacity of approximately 95,000 tonnes per annum. There is currently no native cathode manufacturing taking place in the UK, however, and as such, the downstream supply chain of these recycled materials is unclear.

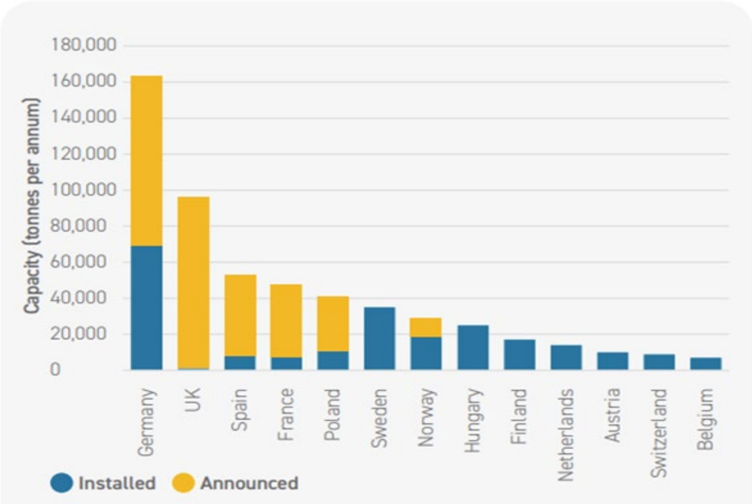

Figure 13 - Current and planned battery recycling capability in Europe, as of 2024 [40]

The lifecycle of battery CRMs is shown in Figure 14. At EOL, batteries are disassembled and shredded. The shredded material can either be refined using pyrometallurgy or separated to produce a high-value granulated material called black mass.

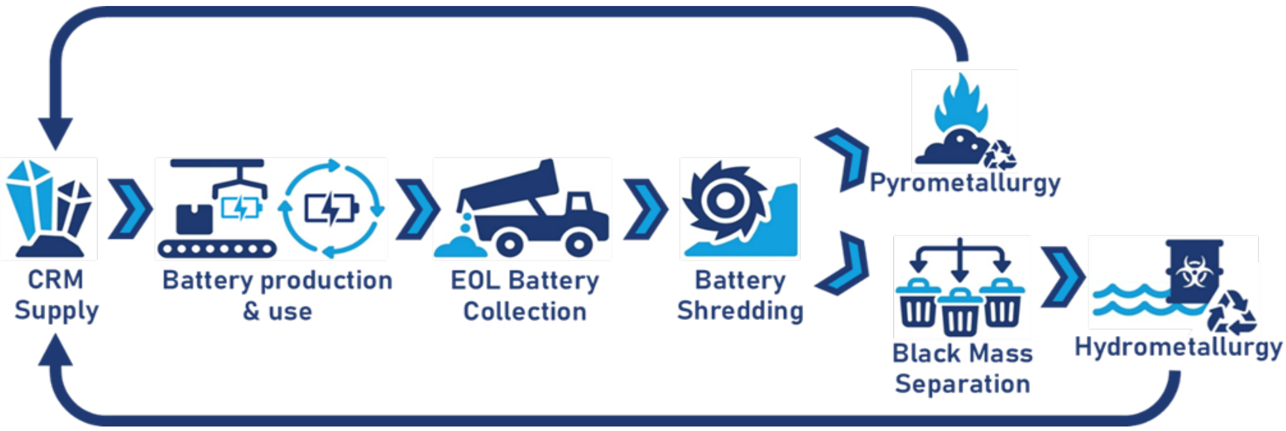

Figure 14 - Battery lifecycle diagram produced using information from The Faraday Institute [40]

The pyrometallurgy process is employed in multiple industries and involves using high temperatures to purify metals [40]. Temperatures of up to 500 °C are used to burn off any remaining volatile electrolytes or solvents before being smelted at over 1400 °C. The process yields cobalt, nickel and copper alloys as well as a lithium and aluminium oxide slag that can be refined further via additional processing. Graphite, however, is usually burnt off and lost during the process. The operation is relatively simple and allows a large processing capacity, although lithium is trapped in the slag resulting in a low recovery rate. Very high energy requirements are amongst some of its disadvantages. Pyrometallurgy is commonly used in some European countries and widely across Japan, South Korea and China.

Black mass consists of shredded battery particles, named due to the dark colour caused by high amounts of carbon. It is separated from other constituents formed from battery shredding and has a typical composition of various critical minerals, as shown in Table 8.

Table 8 -The composition of critical minerals in black mass, taken from Aqua Metals [41]

Critical Mineral	Typical black mass composition
Lithium compounds	2-6%
Cobalt (Co)	5-20%
Nickel (Ni)	5-15%
Copper (Cu)	3-10%
Aluminium (Al)	1-5%
Iron (Fe)	1-5%
Manganese (Mn)	2-10%
Graphite (and copper)	Balance

Black mass is clearly valuable due to its critical mineral content but cannot currently be refined within the UK due to a lack of the commercial hydrometallurgy process capability [40]. There are also no cathode producers within the UK, restricting the domestic market for refined black mass. Hydrometallurgy is a more recent technology, that uses leaching agents such as acids to dissolve each critical mineral, allowing them to be separated and recovered. The process allows a higher recovery rate than pyrometallurgy and is less energy intensive. However, there are environmental and safety concerns regarding the use of very strong acids and the process is generally more complex. Despite this, hydrometallurgy is gaining interest from academic and industrial researchers to attempt a recovery material purity of greater than 99%, which would qualify as battery-grade quality and eliminate the need for further processing requirements. North American company Aqua Metals is currently increasing operations at their 'Sierra ARC' site to reach a recycling rate of 10,000 tonnes of black mass per annum [42].

Currently, all batteries that are 'recycled' within the UK are therefore only processed to produce valuable black mass which is exported for refinement. This includes alkaline batteries, which provide a black mass with greater amounts of magnesium and zinc.

2.3.2 Platinum group metals

According to the CMA, eight sites were found to currently recycle PGMs within the UK, with no pilot or planned sites recorded, as shown in Table 9. There is no publicly available data on the capacity of these sites [23]. In addition to those listed by CMA, it has also been identified that Betts Refining are active in the recycling of materials containing silver, gold, palladium and other PGMs.

Table 9 - Current PGM recycling capability within the UK [23]

Site	State	Site	State
R.S. Bruce Ltd	Operational	Hensel Recycling (UK) Ltd	Operational
S.A.R. Metals Ltd	Operational	Kaug Refinery Services Ltd	Operational
BASF Metals Recycling Ltd	Operational	Platinum Recoveries Ltd	Operational
G.C. Metals Ltd	Operational	Mastermelt Refining Services	Operational

The hydro- and pyro-metallurgy processes often used during recycling are inherently similar to those used in the refinement of some critical minerals due to the parallel requirement to improve the purity of a critical mineral, regardless of the source. As such, there are two additional sites within the UK that are listed as refiners of PGMs within the CMA's report that could also be considered recyclers. These are shown in Table 10.

Table 10 - Current PGM refining capability within the UK [23]

Site	State
Johnson Matthey	Operational
JBR Recovery	Operational

2.3.3 Rare earth elements

Globally, over 43% of REEs are used in the production of permanent magnets which are included in electronic devices and technology, electric motors and wind turbines [1] [45]. Neodymium-iron-boron (NdFeB) magnets are most commonly used, however other REEs used for magnet technology include dysprosium (Dy), thulium (Tm), praseodymium (Pr) and samarium (Sm) [46]. Most recycling of REE material comes from electronic waste and EV components.

According to the CMA, two fully operational sites were found to currently recycle REEs within the UK, as shown in Table 11 [24]. An additional site is in a pilot stage.

Table 11 - Current and planned recycling capability for REEs within the UK [23]

Site	State	Total Processing (Per annum)
Avon Specialty Metals Ltd	Operational	~2,400 tonnes
Less Common Metals	Operational	Unknown
HyProMag Ltd	Pilot	50 tonnes of NdFeB powders

As explained prior, the hydro- and pyro-metallurgy processes often used during recycling are inherently similar to those used in the refinement of some critical minerals due to the parallel requirement to improve the purity of a critical mineral, regardless of the source. As such, there are three additional sites within the UK that are listed as refiners of REEs within the CMA's report that could also be considered recyclers. These are shown in Table 12.

Table 12 - Current and planned refining capability for REEs within the UK [23]. There is no publicly available data on production capacity

Site	State
Ionic Technologies International Ltd	Pilot
Pensana	Planned
Peak Rare Earths	Planned

2.3.4 Steel and ferrous alloys

Oxygen Steelmaking (BOS) vessel during the more prevalent integrated (blast furnace) steelmaking route, or in Electric Arc Furnaces (EAFs), where up to 100% scrap is used. A push towards more sustainable steel making in the UK means EAFs continue to replace integrated steelmaking which will increase the UK's capacity to recycle steel [47].

During electric arc steelmaking, the grades of steel produced are not the same specification or quality as the materials fed into the furnace which means it still needs to undergo secondary processing or alloying to achieve the required product. As well as specific alloying elements, direct reduced iron (DRI) can also be added where speciality grades are required, which is sourced from overseas.

There are four companies which currently recycle steels and ferrous alloys at production capacity within the UK, with another two planning to replace BOS with EAF capability, presented in Table 13. As well as closed-loop recycling of steels and ferrous alloys, iron and zinc can also be extracted during the process to create an open-loop process [48] [49].

Table 13 - Steel recycling in the UK according to a report by UK Steel and Make UK [43]. Estimated Total processing is calculated by the company's steel production capacity multiplied by the recycled material content where direct figures were not available

Producer	Location	Technology	Estimated Total Scrap Processing Capacity (million tonnes Per Annum)	Percentage recycled content used
British Steel	Scunthorpe	BOS	0.6	20% to 25% [44]
British Steel	Scunthorpe & Teesside (planned)	EAF	Unknown	Unknown
Tata Steel	Port Talbot (planned)	EAF	2-2.25 [45]	Unknown
Celsa Steel	Cardiff	EAF	1.08	98%
Liberty Steel	Rotherham	EAF	1.14	95% [46]
Marcegaglia Stainless Sheffield Ltd	Sheffield	EAF	0.43	95%
Sheffield Forgemasters	Sheffield	EAF	0.04	Unknown

2.3.5 Other waste streams

In addition to the specific waste stream identified in previous sections, CMA have identified five current sites in the UK that specialise in the processing of aluminium, nickel and cobalt. These are shown in Table 14. As explained in previous sections, refiners have been included due to the inherent link between the processing methods involved in recycling and refining. Other well established aluminium recyclers identified as part of this research include Novelis Recycling, Bridge Noth Aluminium, Milver Metals and Hydro.

Table 14 – Current recycling and refining capability for aluminium, nickel and cobalt within the UK [23]

Site	Critical Minerals	State		Total Processing (Per Annum)
Alvance British Aluminium Ltd	Aluminium	Operational	Refinery and Recycler	<100,000 tonnes (final product) [47]
Cronimet (GB) Ltd	Nickel, cobalt	Operational	Recycler	Unknown
Vale Europe	Nickel	Operational	Refinery	40,000 tonnes [48]
Avon Speciality Metals	Nickel, cobalt	Operational	Recycler	Unknown
Britannia Refined Metals	Nickel	Operational	Refinery	Unknown

2.4 The UK's current and planned recovery capability

There is currently limited recovery within the UK, with only three recovery routes identified within the UK.

- **Mine tailings**: Which can be defined as the vast amounts of 'waste' that is discarded during mining operations due to low purity or an absence of any material that is deemed to be useful or financially viable by the mine's operators. Particularly the case for historical mines, the technology may also not have been available to extract such small amounts of trace metals from tailings.

- **Alloying and metal processing slag**: Waste oxides and other byproducts that are formed during the manufacture and smelting of alloys. The slags can contain a wide range of critical minerals.
- **Fly ash**: The ash byproduct that is produced and captured during the firing of coal in powerplant processes. Like mine tailings, large stockpiles of fly ash exist all over the UK, dumped after legacy coal-firing operations.

2.4.1 Mine tailings

The recovery of critical minerals from historic mine tailings is already an established process in both Canada and Australia [23] but as of yet, does not have any substantial industry in the UK. However, there is some ongoing research into the processing of mine tailings, which often contain critical minerals such as REEs, iron (Fe), manganese (Mn) and companionality elements that can be found in small amounts during the mining of a major source. UK-based clean technology company Altilium announced in 2023 that they had received over £700,000 of government funding for research into recovery of REEs from mine tailings, in partnership with CPI and Camborne School of Mines [49].

2.4.2 Slag and fly ash

Sheffield Forgemasters sends their steel slag to be used in the aggregate industry [50] and extracts zinc from the dust that is produced by the electric arc furnace process. Liberty Steel also uses their slag the same way but does not specify what their zinc is used for once it is extracted from extraction system dust [46]. Celsa UK collect and process electric arc furnace dust and process it to produce enriched zinc oxide which is used in pharmaceutical, galvanising and animal food industries [51]. Fly ash can also be used to increase the strength and processability of concrete [52]. However, there is little information on the quantities of material recovered by these companies. Research collaborations are also known in this field, integrating waste recovery from foundation and metal industries, for example, an Innovate UK funded project with MPI and Mormair targets the recovery of REE's from coal-fly-ash.

The recycling of steel slags in other countries is summarised in an article by 'recovery Worldwide' [53]. Germany is described as a 'model country' for slag recycling, utilising 8.83 Mt in 2018 for use in cement production, concrete and aggregates.

3 Barriers to growth

This section defines the challenges and barriers facing the critical minerals supply chain. A barrier can be defined as a factor preventing change or contributing to a negative change. Evidence has been reviewed from literature and insight sought from stakeholders, and as such, barriers have been grouped diagrammatically via a PESTEL analysis, which has been used to highlight the key external factors (political, economic, social, technological, environmental, and legal) that affect the sector. Each area of the value chain faces its own unique barriers, discussed in more detail within each subsection. The evidence base typically groups political, social and environmental together and therefore, a similar approach has been followed through the key discussion points.

This section can be summarised into four key problem statements.

The key barriers to the growth of the UK critical minerals can be defined in four problem statements:

- UK energy costs are too high for the UK critical minerals to be competitive with the rest of the world.
- The UK critical minerals industry struggles to access sufficient finance to scale its operations.
- There is a negative perception of mining and midstream processing which deters investment and talent.
- Difficulty accessing waste streams means there is not a secure supply of waste to UK operations.

3.1 Challenges and barriers in UK mining

Several challenges have been identified in the development of the UK mining and midstream industry as shown in Figure 15. Specific research and stakeholder findings relating to mining are listed below.

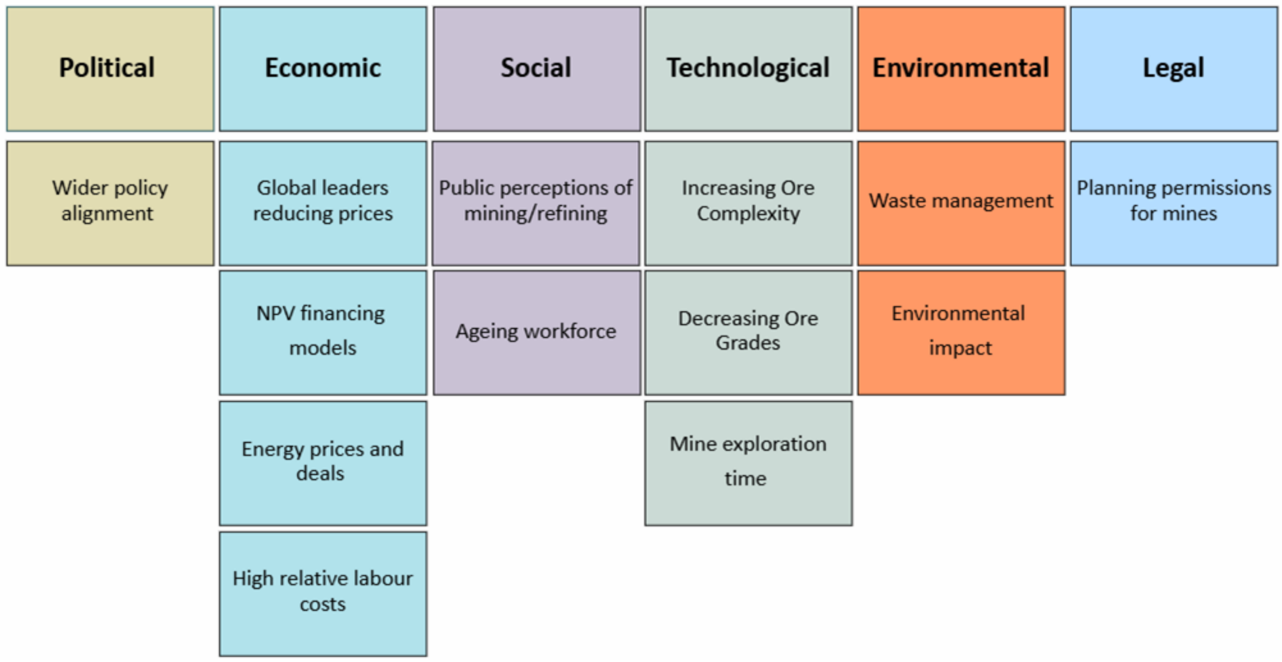

Figure 15 - Political, economic, social, technological, environmental, legal (PESTEL) analysis diagram for challenges and barriers in UK mining and midstream industries

Political, Social and Environmental

- Of ongoing concern to many, including the public, industry and government, is the sustainability and environmental impact of mining. A research briefing published by UK Parliament POST [54] highlights the complex relationship between mining and communities, culture and society and the impact that it can have on the environment, should it not be carried out responsibly. The global industry is taking steps to improve its environmental and social performance; however it has been noted that some metrics are under-reported [55] and that there are inconsistencies across measurement technologies [56]. The UK Government have committed to "ensuring critical mineral mining and processing being carried out to the highest ESG standards as possible" [57], which includes domestic and trading activities. However, the lack of reliability and quality of the data means that confidence in mineral resourcing is currently lacking and in fact, there are very few schemes for certification of metals and products that allow procurement based on better ESG performance [54]. The UK Government have also recognised that UK companies practicing high ESG standards bear additional costs, which place them at a competitive disadvantage [58] and that consumers will likely carry the costs of more responsible mining and mineral processing [54].

Economics

- The variability of metal prices, high capital costs, and the longevity of infrastructure have also proved as barriers to both companies and investors in the mining industry [54], which has also resulted in slower innovation uptake, meaning mining and processing industries are ultimately lagging behind high-tech sectors [59].

- In addition to high costs associated with capital and investment, the cost of energy in the UK remains to be a barrier to most industries. In addition, these industries can contribute to the production of carbon emissions while using an ever-reducing supply of fossil fuels. As the demand for critical materials increases, the energy demands across the entire industry will also increase. Mining is energy-intensive and is reported to consume up to 38% of industrial energy and 15% of electricity in the world, [60] comprising 15-40% of total operating costs to the mining industry [61]. To overcome the operational cost, resource and environmental challenges associated with energy, many industries worldwide are adopting the use of renewable energy technologies in their operations, electrifying mining vehicles and equipment and redesigning sites for improved transportation efficiency. While these offer significant benefits, the financing of the integration of renewables is forecast to be a major barrier to the industry.

Stakeholder opinion – energy costs

- All government and industry stakeholders felt that high energy costs were a significant barrier to the growth of the industry. Because many processes in the critical minerals supply chain are highly energy intensive, the cost, reliability and security of energy in the UK was deemed to be one of the greatest concerns to the sector.
- Furthermore, the cost of energy in the UK is prohibitive to UK-based businesses being competitive in international markets, and is also a major deterrent in attracting investment, restricting development of the industry.

"UK energy prices are a big factor in the economics of sending copper and aluminium and things like that outside the UK to be recycled" – Industry stakeholder

- **Energy costs and recycling:** the cost of energy is still a major consideration and in many cases a barrier to viability for recyclers, especially those utilising pyrometallurgy recovery methods and high temperature refining which is required for some minerals.
- **Energy transition opportunity:** considering the importance of energy costs to the industry, industrial stakeholders were unanimous in their support of an energy transition and network improvements that would grant long term energy security. The pursuit of lower energy costs and increased energy security within the industry presents the opportunity for the critical minerals processing and recycling industry to act as a catalyst in the UK's transition to renewable energy generation which in-turn reduces the reliance on imported fossil fuels.

Technological

- To understand the full potential prospects for mining in the UK, an extensive amount of research and analysis is required. Some new projects will be discussed in the subsequent section in greater detail given their potential to pose new opportunity, however, in relation to the exploration of new mines, the British Geological Survey strongly recommends that more geoscientific data be captured across the UK in terms of critical minerals, as much of the country remains underexplored. The addition of high resolution geological, geochemical and geophysical data is therefore required which would underpin a successful exploration and mining sector [62].
- As shown in Table 2, the UK is largely focussed on lithium, tin and tungsten extraction. However, it is important to consider all possible raw minerals in the UK to achieve full value mining, especially should the UK wish to secure a broad supply of minerals in the future. Moreover, further work is also required in understanding the extraction of gallium, germanium, indium, molybdenum, bismuth and tellurium from many deposit types in the UK [62]. These minerals are typically mined as by-products and co-products and their deportment in UK deposit types is not well understood and requires more geoscientific data to enable more specific targeting of mineral deposits. Additional understanding would be especially valuable for materials that are considered most critical by CMIC, such as germanium.
- Whilst mining is less prevalent in the UK compared with many other countries, there are plans to restart tin, tungsten and lithium mines in England, as well as exploration of nickel, cobalt and platinum reserves in Scotland [62]. The CMIC has suggested further in-depth surveys to explore mining opportunities of nickel, which could be beneficial and provide a more reliable estimation of the UK's capability [63]. Current studies have identified a high concentration of nickel and cobalt, but these would have to be mined as a by-product. Where strong mining opportunities have been identified in the UK via initial surveys, in either high value, volume or criticality, further exploration should be considered, where a domestic midstream industry and demand exist for those materials.

Legal

- One of the greatest barriers to accessing mining opportunities in the UK is the location of prospective sites. These may be on private land or in areas protected as conservation areas or heritage sites, meaning that planning permission would be inherently challenging [1].

Stakeholder opinion – the planning process

- A third of industrial stakeholders expressed concerns with the UK planning permission process, relevant to mining and midstream operations. While the rigour of these processes is regarded as a positive—because it contributes to the creation of a green and ethical supply chain—the efficiency and capacity of planning in the UK is seen as extremely prohibitive and deters investment and growth in the sector. Stakeholders cited long delays in waiting for decisions, as well as the need in some cases to employ external consultants to support businesses and local authorities in navigating the planning process.
- There is also a perception among some commentators that there is a lack of technical understanding and skills within planning and governance departments, which can stall planning processes. These concerns were mainly voiced by businesses operating at production-scale, rather than pilot-scale, with some stakeholders indicating they had not yet engaged with planning bodies.

3.2 Challenges and barriers in UK midstream processing

As discussed, the UK has an established midstream processing industry that has demonstrated successful outcomes thus far. There are, however, challenges associated with developing a midstream capability, especially when referring to the midstream processing of ores and concentrates. Many of the challenges associated with midstream processing are synonymous to those reported in mining, as highlighted in Figure 15, which shows the PESTEL analysis of both the mining and midstream industries. Some of these shared barriers include energy cost and secure supply of energy, cost of infrastructure, economic feasibility, public perception, ESG, planning and site location. Additional points relevant to midstream are discussed below.

Political, Social and Environmental

- The supply of materials to a UK midstream processing industry could pose a challenge as well as an opportunity. Since the UK does not have significant primary ore reserves, it must secure its feedstock from a wider pool of sources. Nevertheless, the UK currently does not have the midstream capability or capacity to support its own planned mining activity and therefore should be developed to support the supply chain of mined materials.

  In terms of ores and concentrates, as well as serving the domestic mining industry, a successful midstream industry could bolster its supply from imported materials (the security of recycled feedstock will be discussed in subsequent sections). While the established and planned UK businesses have successfully secured their supply chains, new projects must typically take place as joint ventures/partnerships with suppliers and customers, to ensure a secure supply and demand prior to capital investment and to ensure economic viability. This is a key determinant for midstream operators [23].
- Risks associated with importing raw materials also include international competition, export controls by supplier countries and logistics. The UK midstream processing industry would also need to ensure that their raw materials are ESG compliant throughout the supply chain [23].

Stakeholder opinion – perception of midstream processing

- All mining and midstream stakeholders shared the concern that the processing and manufacturing industry has a poor image among the public. Interviewees felt that the public held misconceived perceptions of the industry—specifically regarding environmental concerns—despite progresses in waste capture technologies and clean energy in recent years.
- It was also expressed by industry stakeholders that there were similar negative perceptions of the industry within some government departments, which they believed had influenced strategy and funding. It is feared that this perception is likely to also influence the next generation of workforce.
- Coupling this negative perception with a decline in the size of manufacturing and heavy industry has led to long-term viability question. It is also felt among midstream stakeholders that the negative perception makes it more difficult to make investment cases and attract talent.

"We don't typically recruit from UK universities because they don't want to work in this industry as such because I guess it's perceived as being a dirty industry" – Industry stakeholders

Stakeholder opinion – Opportunities for collaboration

- **Industrial clusters and freeports:** midstream stakeholders felt that the sector has strong support from freeports and combined authorities, and that regional bodies [in some areas] are taking the necessary action to exploit opportunities. Building on the theme of collaboration, seven industry stakeholders echoed a similar sentiment regarding the opportunity to create industrial symbiosis by geographically grouping industry.
- By strategically and geographically clustering organisations, it is possible to streamline transportation, planning, energy and resources and create local regions of industrial circularity, while also increasing the prosperity of these areas. Clusters where mining operations offer onsite refining were particularly favoured by stakeholders and many also supported clusters that offered good transport links and freeports.

"So, the whole Freeport thing, the chemicals clusters, the unitary councils, all of that, that works. It's good, very, very good. Teesside's a good example of it" – Industry stakeholder

- **Domestic and international collaboration:** all industry interviewees felt there were strategic benefits from partnering with allies, domestic processers and developing relationships with domestic, European and international partners. This would enable greater access to funding and allow for knowledge transfer.

"It does seem like there is quite a lot happening between academia and industry which builds on all the strengths in terms of UK's R&D research and higher education facilities as well" – Government stakeholder

Economics

Access to finance – stakeholder opinion

- Approximately half (11 out of the 21) of industry stakeholders interviewed expressed they had challenges accessing public and private finance. In general, stakeholders felt that private investors' risk aversion, coupled with a wider negative perception of mining and midstream processing has made investment in the industry less attractive than other industries. In addition, early technology readiness level (TRL) innovations are research intensive and can span extensive time periods, which can result in long commercialisation timelines—further decreasing the industry's attractiveness as an investment opportunity.

"Unless the banks are willing to support UK businesses in development, then all of this fantastic technology and innovation that's going to be developed in the UK is going to fall into the hands of foreign investors." – Industry stakeholder

"Anything to do with mining and mineral processing is really, really, hard to raise finance for. People just don't want to be involved with mining" - Industry stakeholder

- **Finance opportunity:** Approximately one third of stakeholder commentators felt that the UK has a strong finance sector that should be used to support the minerals and mining sector. Interviewees mentioned the impressive strength of the financial market with emphasis on the London Metal Exchange. As a result, there was consensus that there is an opportunity to leverage the London financial markets to support UK based projects through either de-risking investments or raising finance.

"In London, we've got the London Metals Exchange, and we've got the London Bullion Markets Association, we've got the London Platinum and Palladium markets. We have that central role in global metals trade, where certainly a lot of that kind of commodities exchange happens" - Industry stakeholder

Technology

- Further to energy-related challenges and the adoption of renewables, during downstream processes, heat requirements vary from low to extremely high temperatures. In addition, the energy required for refining ores during midstream processing is reported to be much higher than recycling the equivalent material [64]. For example, recycling steel requires approximately 25% of the energy required to produce steel from iron ore. However, this does not consider the energy associated with the full lifecycle of the material. Renewables have been reported to be suitable for low to medium temperature requirements, but the high temperature demands of technologies such as refining via pyrometallurgy processes remain a challenge [65]. As with the mining industry, it is anticipated that financing the integration of renewable energy will also be a barrier.

3.3 Challenges and barriers in UK recycling and recovery

A number of barriers have been identified which could prevent or delay the UK's future recycling and recovery capability. These have been summarised in Figure 16.

Political	Economic	Social	Technological	Environmental	Legal
Change in policy for managing different waste streams	Large costs for infrastructure	Human health and landscape damage from mine tailings	Physicalities of collecting waste	Potential use of greenbelt land for infrastructure	Ownership of mine tailings can be unknown
	Workforce and collection of waste will be expensive	H&S considerations e.g. the use of toxic acids	Control of waste quality and identification of mineral content	Highly toxic acids can be used which present an environmental risk	Ownership of EOL infrastructure and components (e.g. wind turbines/solar)
	Incentives for the public to recycle their technology		Scaling of infrastructure with growing demand		Building and planning of infrastructure
	Changes in policy will be expensive and time-consuming		Variety of critical minerals and different processes used		

Figure 16 - PESTEL analysis diagram of the barriers to recycling and recovery development within the UK

Political, Social and Environmental

- The need for recycling and refinery infrastructure to be built in close proximity to waste streams and built-up areas mean that greenbelt land is often designated for the projects. This can lead to a rise in noise and light pollution and opposition from local communities [66] [67] [68].
- Strong acids typically used in recycling processes such as hydrometallurgy can be highly damaging to human health and the environment when not handled properly [40] [69] [70].
- Identifying the type, source, ownership and value of the various waste streams available is a broad challenge, as well as their alignment with UK policy and in relation to industry handling of these waste streams. Some of the challenges and barriers identified include the following:
  - The classification and handling of waste across the UK is complex and does not support its use as future critical mineral feedstock; both from secondary sources such as mining/manufacturing operations, and from end-of-life recyclable products.
  - In many cases the ownership of historic mine tailings is unknown or unclear.
  - The quantity and contents of waste deposits from UK-based manufacturing and mining is not currently well understood but is anticipated to pose opportunity, based on initial findings and the international import market, as exemplified by research carried out by Rheinmetall BAE Systems Land and the University of Sheffield [71]. Further research and analysis is required to understand the magnitude of the opportunity in the UK, specifically addressing the quantities and composition of wastes generated by UK manufacturing and mining industries [23].
  - There are many health and environmental risks associated with the collection of tailings including pollution of rivers, groundwater and crops, dangerous stability of tailing dams and the flammable nature of dust and gas emitted from tailings [72].

- The UK government stipulates that supermarkets and 'big shops' that sell over 32 kg of batteries per year must provide a free of charge collection point for the recycling of batteries, a scheme which led to 17,675 tonnes of batteries being collected and recycled in 2019 [73] [74]. However, the lithium-ion batteries, most commonly used in personal technology are often integrated and cannot be taken out of their devices which makes recycling much more difficult. These devices cannot be collected via the scheme and have to be disposed of as electrical waste which presents far less opportunities for consumers. The removal of lithium-ion batteries is a requirement in the EU, which could be echoed in the UK.

- Consumers can be reluctant or unable to recycle personal devices, as well as other high value waste, especially where no doorstep collection exists. An Ipsos Mori survey found 37% of consumers had concerns over personal data on devices, whilst 29% said they didn't know where to recycle old technology devices [75].

- Waste electrical and electronic equipment (WEEE) typically contains very small critical mineral quantities in each device and are inherently difficult to recycle, contributing to low global recycling rates of just approximately 20% [76]. Lithium-ion batteries found in personal devices are often incorrectly recycled in WEEE as they are not separated from any other electrical waste during recycling, meaning that waste is often sent to landfill, creating lost opportunity [23] [75]. Furthermore, the UK is reported to illegally export approximately 45% of its WEEE outside of the European Union, also impacting the opportunity to domestically recycle [77].

Stakeholder opinion – waste classification

- It was voiced by stakeholders that accurate assessments of waste flows, such as WEEE, are lacking. Several data gaps exist, particularly around projected versus actual recycling, type and composition breakdowns of waste to understand the recycling of specific critical minerals, and data to support the scale of waste, and specific materials, that is available to exploit. A reformed waste system would require data to be collected at sufficient granularity to be able to map and track critical mineral flows, including data on the type and complexity of recycling and specific material compositions.

"Accurate characterisation of critical mineral containing waste streams will be key to increasing recycling, but this will likely need to go beyond waste classification."

Stakeholder opinion – waste streams in the UK

- All recycling stakeholders expressed different views on opportunities to exploit waste streams in the UK.
- **Offshoring:** A mixed opinion was voiced on the potential of reducing the offshoring of waste or imposing an export cap on waste materials. Some stakeholders agreed that there was an opportunity for the UK to reduce offshoring waste, if the UK had a successful recycling and midstream capability, or that it would incentivise the growth of a domestic midstream/recycling industry. Opportunity in the demand for recycled materials was highlighted in the UK, especially in the use of future gigafactories where it has been reported that by 2035, 40% of gigafactories material could be supplied through domestic recycling routes. Several recyclers felt there was an opportunity for finding a route to make landfill waste commercially viable and all recyclers agreed with improving waste classifications and mandating end of life responsibility.
- On the other hand, a differing view on waste export was voiced, where implementing a policy to reduce export would disturb the operation of a free market, and many UK-based companies would not be able to exploit their own international operations. Some industries are also seeking to grow international recycling facilities and supply chains, which would be hindered by an export cap. It was also noted that some countries offer a 'buy-back' on critical mineral-rich products such as batteries – this was recognised as a high value export route, but also an opportunity to adopt a similar ethos in the UK, giving industries a second opportunity to exploit the value chain.
- **Mining waste:** six of ten industry stakeholders emphasised the wealth of opportunities to make up the critical mineral supply gap through recovery from mining, manufacturing and industrial waste. This may include mine tailings, slag heaps, fly ash, sinter fines amongst others. As well as identifying isolated waste sources, this opportunity links well with industrial cluster models, where industrial symbiosis and circularity can exist locally, with a recycling and recovery facility that handles the waste of local industries.
- **Export refined and recycled material:** as well as exploiting domestic waste streams, development of a successful recycling and recovery industry could present opportunities to recover or import waste from other parts of the world, thus accessing a greater volume and greater diversity of waste streams. Industry stakeholders highlighted the opportunity to import, while some also emphasised the export potential of recycled and refined materials to other countries.

Economics

- Data provided by The Financial Times and BloombergNEF shows that the UK has the highest electricity prices in the world for business and industrial users. This is likely to significantly impact the ability of UK-based business to expand their capabilities and could also be classed as completely prohibitive for high-energy scrap remelting [78].
- The previous development of recycling processes has shown there are significant costs involved in sector research and setting up infrastructure and transport systems. Notable examples are a £1.2 billion transformation from blast furnace to electric arc at Tata Steel's Port Talbot site and investments for battery recycling technology by Altilium and Recyclus [79] [80] [81].
- There are large costs associated with the transportation of batteries due to hazardous waste classifications [40]

Legal

- Challenges may be brought against companies wanting to expand their infrastructure which can hinder growth.
- The ownership of a large proportion of the UK's wind turbines by the Crown Estate means there are difficulties with identifying ownership of the infrastructure at EOL.

Stakeholder opinion – end of life responsibility

"We were talking about wind turbines and what happens to wind turbines at the end of the life, and who owns the magnet in a wind turbine. And it wasn't clear who owned the magnet, who had the responsibility of disposing of it, that nobody actually seemed to own it, realise it had a value" – Government stakeholder

4 Future opportunities and developments

This section describes the key opportunities and developments that the UK should capitalise to realise its potential in midstream processing, and recycling and recovery. This includes increased exploration, increased research activity, and building on existing capability in PGMs and rare earth elements. The outputs of this section have been combined with the key barriers to define a set of policy recommendations.

Key future opportunities for industry growth:

- **International collaboration and alignment** - industry stakeholders felt that the UK should work alongside international partners such as the EU to secure critical mineral supply. This potentially includes integration, adoption, or alignment with the newly introduced EU critical minerals act to reduce any regulatory barriers to trade, as well as reduce any uncertainty. Following the UK's exit from the EU, the UK is responsible for introducing any legislation governing critical minerals. Furthermore, industry stakeholders believed that the UK could use its influence in international relations and strength in innovation to get more involved in multi-national policy. Stakeholders also felt there was an opportunity to facilitate knowledge transfer with other developed economies to help overcome common issues.
- **Action on energy prices** - government stakeholders commented that a clear way to increase competitiveness would be to have a policy to reduce energy prices, especially for midstream and recycling industries. Industry stakeholders also suggested that action should be taken on energy prices and suggested measures such as subsidies, or the use of guaranteed prices to reduce the burden on the industry. Others suggested larger scale reform to tax or finance structures to overcome wider cost increases across the economy. Another industry stakeholder suggested support in the form of tax credits for critical minerals industries, across operating costs (not just for energy), akin to the US Advanced Manufacturing Production Credit. A softer policy measure might be to include critical minerals within wider energy and industrial strategies to ensure that UK energy capacity and costs support a growing critical mineral industry.
- **Clear direction and investment** - all government stakeholders acknowledged there was a need to attract more funding and investment. Some industry stakeholders felt this was an area where the UK is less competitive compared to other countries. Industry stakeholders also felt that innovation funding should be provided throughout the production cycle, rather than only supporting low technology readiness levels (TRL) technologies. This would require additional support, finance and exploitation of opportunities for commercialisation, pilots, and scale-up to ensure that the strength of UK innovation is translated into capability.

Stakeholder opinion – visions for the future

"I think we could lead the world, certainly in rare earths" – Government stakeholder

"There's a real opportunity to leapfrog the Chinese by capitalising on our chemical parks, bringing in a high value product and then using our offshore wind" – Industry stakeholder

"We could effectively become a leader in Europe for reprocessing, recycling, and primary production of some critical minerals" – Industry stakeholder

4.1 Future opportunities for growth in UK mining

As well as the planned and pilot projects discussed, the BGS, in partnership with the CMIC, have conducted extensive research on the potential for critical raw material prospectivity the UK [62]. The BGS have assessed the UK's geology, demonstrating that prospectivity for individual critical minerals exists across the country. However, a number of key areas have been highlighted for further investigation due to their high density of several different critical minerals, highlighting potential opportunity. These key areas include Gairloch, parts of the central Highlands and Aberdeenshire, mid-County Tyrone, parts of Cumbria, parts of the North Pennines, northwest Wales, Pembrokeshire and southwest England, as shown in Figure 17.

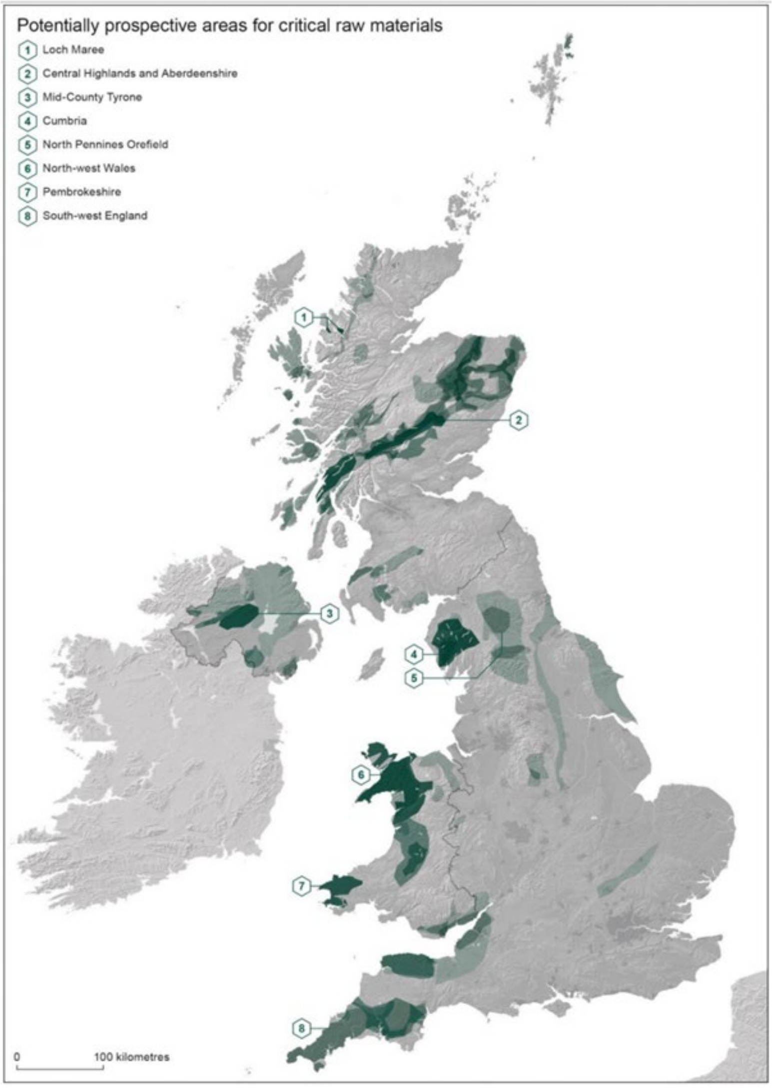

Figure 17 - Potentially prospective areas for critical raw materials in the UK, with darker areas representing a higher density of critical minerals. Source: UK CMIC Potential for Critical Raw Material Prospectivity in the UK, 2023 [62]

The areas highlighted have met geological criteria, however it must be noted that this does not guarantee critical mineral deposits but instead suggests a high potential for deposits to occur. The key regions listed (darker regions in Figure 17) have been mined historically or are currently being explored. Additional considerations are also noted, highlighting that even in regions where the geology is considered as prospective, much more detailed investigations are required to allow for full exploration.

A previous report from the University of Birmingham has shown the UK's existing mining industry is based predominantly on financing, insurance, equipment supply and consultancy, as well as research and education, which is exploited by companies around the world [35]. The possibility of leveraging the City of London's position as a hub of global mining finance was raised in the report, which suggested it could be used to develop opportunities and projects to protect the UK's access to a supply of critical minerals.

The challenges and barriers associated with ESG considerations have been discussed, but these can also pose new opportunities as the UK enters a modern era of mining. Innovation and the development of new technologies can be exploited to reduce, and some cases completely avoid, the environmental impacts of mining. It has already been shown that innovation can allow the mining industry to maintain good demand, be competitively priced, improve efficiency and reduce the use of energy, production of emissions and water consumption [54].

By exploiting innovations associated with ESG, an opportunity exists amongst the wider supply chain as more countries seek to procure materials from responsible sources. While this is considered a 'recent trend', investors have felt the pressure to improve ESG performance and due diligence systems around responsible sourcing have begun to enter legislation [54]. Some examples include the US Dodd-Frank Act, the 2021 EU Conflict Mineral Regulation, the United Nations Sustainable Development Goals and the UK Carbon Border Adjustment Mechanism. While many of these systems are still restricted in scope, they are indicative of the trajectory of the industry and the associated supply chain, introducing new opportunities for the UK. This is also explored in greater detail in relation to midstream processing.

> *"For metals used in specific technologies (such as lithium in batteries), rapid decarbonisation of the world's economies will lead to unprecedented increases in demand that cannot be met by anything other than dramatically increased mining"* – UK Parliament Post – Mining and the Sustainability of Metals [54].

Mining activities are considered essential to meet the increased demands of modern technologies, and should the UK seek to re-initiate its mining operations, an opportunity exists in setting a global example in 'resource stewardship'. Mining alone cannot be completely sustainable, since once it is extracted, it cannot be returned to source. However, there is expansive opportunity for efficient management of resources throughout their lifecycle. Concepts underpinned by a circular economy should be adopted and integrated with mining activity and implemented across the life of products, such that any mining operations feed sustainable products that use materials efficiently and can be repaired, reused or recycled [54]. In addition, practicing the sustainable management of mining waste can also lead to opportunities in the recovery of high value materials. Recycling and recovery will be discussed in greater detail in other sections, but the importance of mining to meet demand and the intrinsic link between mining and recycling economies must continue to be considered.

Stakeholder opinion – opportunity for increased exploration

- Midstream stakeholders felt that there should be an increase in exploration activity in the UK. This belief is driven by the UK's endowment in natural resources when compared to the rest of Europe. Stakeholders felt that increasing exploration and domestic mining activities will reduce the need for offshoring, as well as attracting overseas refiners to establish their capability in the UK.
- Linked to this recommendation, stakeholders reflected on the role of planning permission to enable exploration. Some stakeholders advocated for a centralised process for planning across the UK, with suitably qualified and experienced personnel taking ownership of critical minerals related applications. Allowing local authorities to manage local planning matters - whilst seeking input/consultation from centralised critical minerals specialists – was also recommended.
- Additionally, planning teams should support businesses and work with local authorities to prioritise industrial infrastructure and reduce the time that is taken to approve planning were suggested.

4.2 Future opportunities for growth in UK midstream processing

While the UK's domestic critical mineral mining capability may be considered marginal in absolute volumes, relative to many large international mines, several competitive advantages exist in midstream processing. As previously highlighted, the UK is already expanding its production-level midstream processing capability, as well as continuing to invest in research and development in energy and manufacturing technologies, all of which will likely incite new opportunities. The opportunities in midstream are similar to those highlighted for mining, specifically in relation to the exploitation of innovations and clean technologies and supply chains seeking high ESG standards. As with mining, it is possible in the midstream industry to leverage the UK's current strengths in financing, consultancy, research and development, and skills/education.

Of the planned domestic mining projects listed in Table 3, only two have discussed the potential of developing integrated refining facilities. This should be considered a major concern for UK capability but also means that a large opportunity exists in the refining of UK-mined critical minerals which should preferably be carried out in the UK. The CMA [23] also highlights some additional exploration projects that may lead to successful mining including Cornish Tin and Aberdeen Minerals, which would require the refining of tin, nickel, copper, cobalt, and PGMs. Overseas potential has also been identified, supporting the midstream processing of minerals mined in Australia and Canada. As well as processing mined ores and concentrates, it is also possible to exploit secondary or recycled sources as a refining feedstock, strengthening the economic viability of new projects and investment.

It was previously highlighted that securing a supply chain associated with new midstream operations could pose a challenge as well as an opportunity. In terms of opportunity, it is evidently clear that many countries in the West (as well as the rest of the world) are seeking an alternative critical mineral supply chain, to ease their dependence on China. As well as having its own reserves for graphite, REEs and silicon, China's midstream processing industry currently dominates, importing huge quantities of ore for refining and supplying materials domestically, as well as exporting materials internationally. In an effort to de-risk their supply chains, consumer governments are introducing measures to limit over-dependence on a single country, for example the European Union's Critical Raw Materials Act (2024). Additionally, the US established the Minerals Security Partnership (MSP) was introduced in 2022, recognising the need for international cooperation. While these types of initiatives are still in their infancy, they are indicative of the growing need to reduce supply chain vulnerabilities [82]. As such, a great opportunity exists for the UK. By working collaboratively with international partners and forming joint partnerships to develop and secure supply chains, the UK can build upon its manufacturing heritage, its current capabilities and financial sector along with exploiting recent developments in clean energy and freeports to grow a prosperous midstream industry, serving domestic and international markets.

To encourage joint working, international collaborations and supply chain partnerships, the UK Government Critical Imports and Supply Chains Strategy (2024) [83] highlights how states typically respond to challenges and look to exploit opportunities that will influence trade. Examples include limiting supply, increasing legislation, subsidies and implementing other interventions that are seen to strengthen critical industries. Trade protectionism is also discussed and is becoming increasingly apparent in areas of future strategic importance or where competition exists for highly concentrated resources. The strategy also highlights that free trade agreements states can identify and agree to remove tariff and non-tariff barriers to trade and agree joint strategies on measures such as diversification or information sharing. While these disruptions may be considered to exploit opportunity, the implication of any action must be assessed across the supply chain.

The use of freeports and industrial clusters would provide hubs for integrated logistics and facilities for midstream processing operations, beneficial to both domestic and international processing activities. Industrial clusters allow for shared resource management, transportation and shared green energy supplies (such as in the Tees Valley), while freeports offer ease of import/export activities to international partners.

As shown, the UK has some midstream processing capacity for certain materials, but comprehensive supply chain analyses remain complex and limited. The CMIC recommends prioritising detailed research into specific materials and their movement within the UK economy. Data collection, a broader capability where the UK is world-leading, should be evaluated to ensure it effectively supports supply chain tracking. Future efforts should focus on distinguishing and quantifying primary and secondary material flows, as current economic data does not always allow for this. Strengthening secondary flows presents a major opportunity to retain value, enhance resilience, and support a more circular economy [1]. This further work is needed to identify and develop areas where the UK has existing or potential strengths.

Stakeholder opinion – Need for clear strategy and communication to support midstream processing

- Industry stakeholders felt that the UK should clarify its commitment and long-term strategy on mining and midstream processing. This would increase certainty for investors, therefore increasing their confidence and willingness to invest. This links to a wider opportunity of leveraging the UK's strength in mining finance and tertiary services to support the critical minerals industry.
- In addition, future strategy and communication should aim to improve the perception of the midstream industry to increase awareness of investment, career opportunities in midstream processing in the UK, as well as using education as a method to change public opinion on midstream processing.

4.3 Future opportunities for growth in UK recycling

The future potential of the UK's primary recycling capability has been identified using current manufacturing and production data. It is also important to reiterate the link here between recycling and midstream industries and the importance of supporting the growth of both industries to improve recycling rates as midstream is the point of entry of recycled material into the circular economy. A summary is shown in Figure 18.

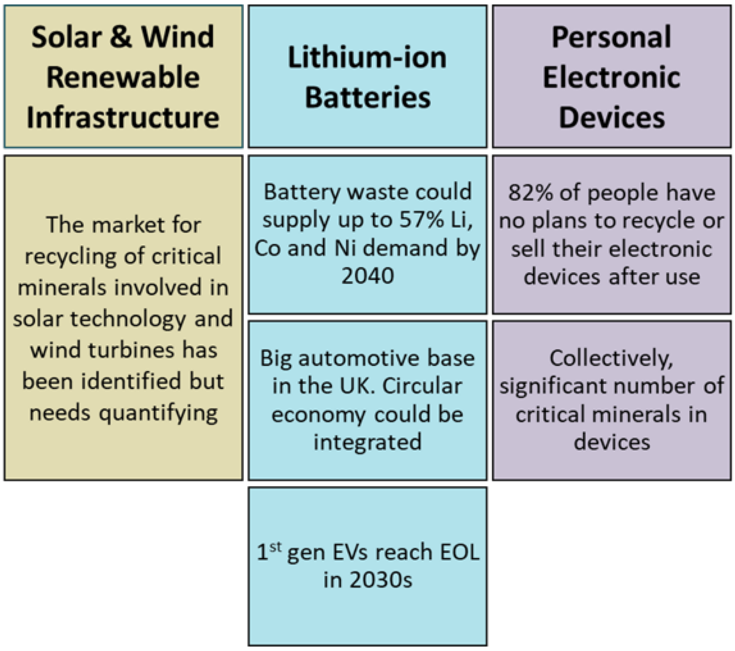

Figure 18 - Potential opportunities for the expansion of recycling within the UK

4.3.1 Solar and wind renewable infrastructure

addition to a rise in the number of EVs, the UK government's push towards net zero has produced a considerable market for so-called 'green energy', leading to significant investment in a range of renewable energy infrastructure. As of February 2025, the UK had 9,188 onshore wind turbines and 2,765 offshore, contributing a yearly average of 82,192,632 MWh to the national grid and removing 35,918,180 tonnes from the country's CO2 burden [90]. In 2019, a report by the Office for National Statistics also stated that both the onshore and offshore wind industries supported over 11,600 jobs [84]. Greenmatch also conducted their own analysis in 2023 which showed the wind power industry had grown to support over 30,000 jobs, contributing £3.5 billion to the UK's GDP and providing a turnover of almost £6 billion [85].

The UK's solar farm capacity has also seen significant growth, rising from 5,488 MW in 2014 to 13,259 MW in 2019. The market is predicted to grow even further, rising from a production of 15 GW in 2023 to 43 GW in 2028 [86]. Additionally, solar panels are rising in popularity with consumers as a popular way to reduce their energy bills with 1.5

million now installed on the roofs of UK homes [87]. However, turbines and solar panels both contain large amounts of critical minerals. A 3 MW-capacity wind turbine requires 2000 kg of REEs and large amounts of steel and aluminium, whilst solar panels contain silicon, indium, gallium and tellurium [75].

With McKinsey & Company projecting a 65-80% growth of the renewable energy industry by 2050, there is a considerable opportunity for the UK to take advantage of renewables in terms of both production and recycling [88]. Wind turbines have a typical lifetime of 20-25 years before EOL is considered, whilst solar panels can last up to 30 years depending on their construction, chemical composition/technology and commercial or domestic use [89] [90]. The first EOL wind turbines have already been decommissioned, whilst solar panel waste will reach 78 million tonnes globally by 2050 [91] [92]. It is important that this market is investigated and quantified further to enable a circular economy to be established within the UK, and that the market is also supported by further research and development to unlock technical barriers in recycling.

The growth of REE recycling potential is shown in Figure 19 taken from a 2023 academic paper published by MDPI [93]. Currently, less than 1% of rare earth elements (REE) are recycled from end-products such as permanent magnets, lighting, batteries, and catalysts with the remainder going to waste [62].

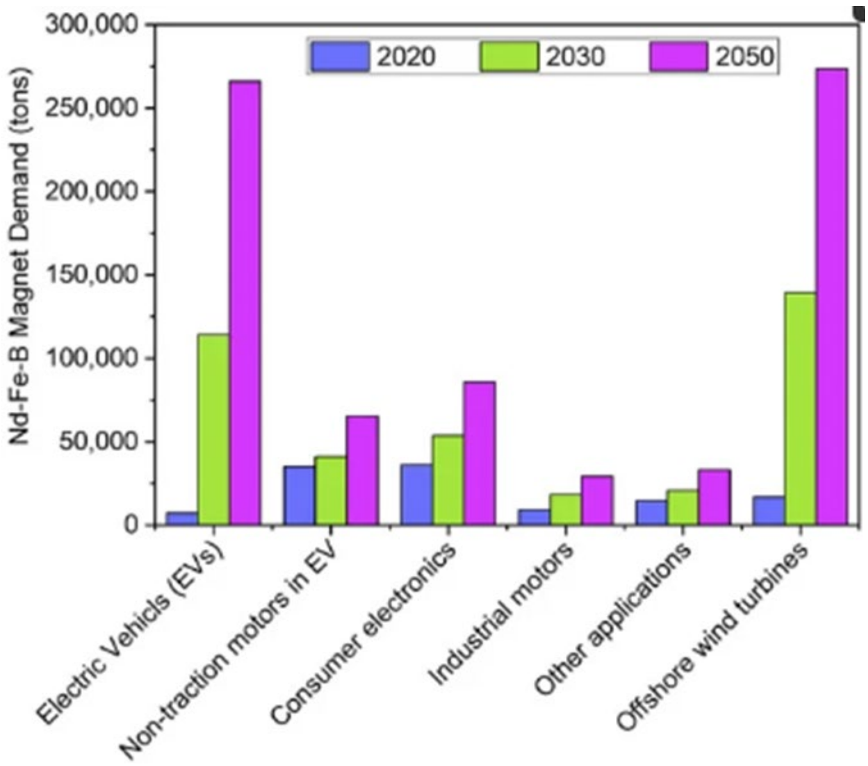

Figure 19 - Comparison on Nd-Fe-B magnet demand (tons) in 2020, 2030 and 2050, across multiple applications. Graph is taken from a MDPI journal publication authored by J. Ormerod [93]

In addition to the UK's largest industries identified above, there is a substantial body of previous and ongoing research that may provide further opportunities for recycling in the UK. A summary is given below.

- A project by the Ministry of Defence, concentrating on the recycling of steel, aluminium and titanium Tornado aircraft parts, is ongoing. It is hoped the findings can lead to an increased accessibility of strategic metals for the UK defence industry and their suppliers [94].

4.3.2 Lithium-ion batteries

A continually expanding market for the use of lithium-ion batteries in the UK and abroad has created a significant opportunity for both the supply of new and refurbished batteries, as well as for their recycling. Vehicles are currently the UK's single most traded good, resulting in a sector worth of more than £94 billion [95]. Over 1.9 million new cars were registered in the UK in 2023, of which 314,687 were fully electric. A further 380,253 contained smaller batteries, known as hybrid electric vehicles. The market shares of both fully electric and hybrid vehicles are expected to rise, with the Government's ban of internal-combustion engine cars being brought forward to 2030 [96]. The Faraday Institution predict that the automotive and EV battery ecosystem could grow by 29% by 2040, needing an additional 50,000 employees and creating 78,000 new jobs in UK-based battery gigafactories and related supply chains [35].

These industries have created a substantial industry for the recycling of lithium-ion batteries, with several sites already being built within the UK to recover the CRMs contained within them. First generation EV batteries are expected to reach end of life in 2030, with an exponential increase in the numbers of retired vehicles after this date [97]. Further, the University of Warwick estimates that there will be 339,000 tonnes of lithium-ion batteries available for recycling per year by 2040, which would generate approximately $1Bn of revenue based on current prices [75].

The Advanced Propulsion Centre has predicted the re-processing of future UK giga factories scrap could produce up to 20,000 tonnes of cathode material which could be used in the production of 100,000 new car batteries [98]. The article also states that by 2040, the batteries recycled from end-of-life vehicles could supply enough cathode material for 60 GWh of new batteries, which is approximately 850,000 vehicles.

- Retaining the key critical minerals contained within UK electric vehicles could supply between 39% and 57% of the demand for lithium, cobalt and nickel by 2040 [40]. However, battery recycling processes (shown in Table 15) vary in complexity and can often prioritise recovery of only certain materials. For example, battery recycling to date has focussed on recovery of materials such as cobalt, nickel, lithium, aluminium and copper but lower-value materials are not recovered. This means the values given for recovery of certain critical minerals may create an 'either/or' situation. It is believed, however, that as recovery efficiencies continue to improve, attention will turn to recovering lower-value materials such as graphite, which is expected to see a surged demand in the future.

Table 15 - Overview of battery recycling processes [40]. Further information on technical processes can be found in annex A.2

Pyrometallurgy	Hydrometallurgy	Direct Recycling (re-conditioning)
• Simple process • Lower recovery rates • Can process mixed waste streams • Less use of strong, toxic acids • Global preference, widely used • Large treatment capacity • Significant emissions, but these can be captured • Energy makes up 45% of costs	• Complex process • Higher recovery rates • Can selectively extract particular metals • Environmental and health risks due to use of strong acids VOCs • Low emissions • Less commonly used • Energy makes up 32% of costs • Shredding and pre-treatment stage produces valuable mixed metal waste called 'black mass'	• Replaces depleted Li and repairs the functional cathode structure • Complex, expensive process • High recovery rate due to re-use • Low environmental impact • Low energy consumption • Skilled manual labour and specialist equipment required • Commercial industry not established

4.3.3 Personal Electronic Devices

Whilst much smaller in size, the consumer's use of battery-based technology such as mobile phones and tablets also create a sizeable resource which due to their relatively low lifetimes and low recycling rates, could be very beneficial to the UK.

- According to Ipsos MORI research included in a report by the CMA, 45% of UK households have up to five unused electronic devices and 82% of those don't have any plans to recycle or sell them [75, p. 2]. Incentivising and encouraging the recycling of such devices could unlock a potential supply of critical minerals.

- As well as battery materials, personal devices such as smart phones, laptops and other electronics with LCD screens contain REE's. While the separation of individual REEs to yield a single element through recycling is inherently difficult in such low volumes, some projects have begun to recycle REEs in the UK, such as in the HyProMag facility in Birmingham [99]. Research to address the recycling of REEs, especially from underutilised sources should continue to be supported.

4.4 Future opportunities for growth in UK recovery

There are numerous opportunities for the growth of critical mineral recovery processes in the UK. These revolve mainly around the extraction of critical minerals from historic waste streams such as mine tailings, alloying slags and historic coal-fired power station ash (Figure 20). There is an additional opportunity raised by the development of a circular economy within the UK. For example, an increase in the use of electric arc furnaces for steel production will require both a greater stockpile of steel scrap, and a larger capacity for extracting critical minerals from the dross/slag that is produced.

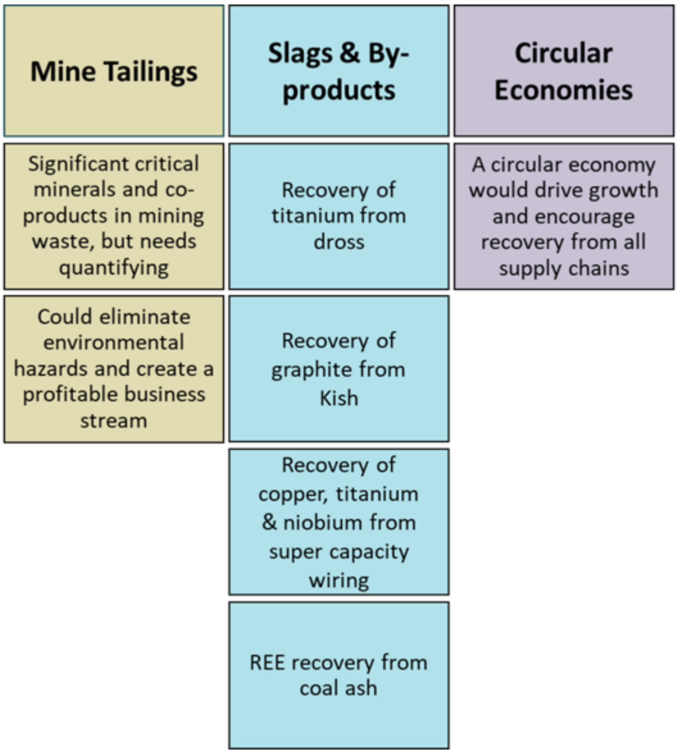

Figure 20 - Graphical representation of future recovery opportunities in the UK

4.4.1 Mine tailings

The UK's extensive mining history of many different metals and non-metallic commodities such as coal means there is a largely unused feedstock of mine tailings around the country that are likely to contain significant amounts of critical minerals. Despite previous research, the recycling opportunity of mine tailings still needs to be quantified, as recommended in reports from the CMA [23]. However, there is enough information available to scope the potential of the mine tailings recycling industry.

Research from 2017 by Crane et. al. found that mine tailings contain significant reserves of critical minerals, based on a study from historic mines in Wales and the southwest of England [100]. The work tested tailing samples from 14 mines for the contents of 18 different elements, of which half are critical minerals. Iron (Fe) and aluminium (Al) were found to be the most abundant in tailing samples, with an average of 8.6 wt.% and 6.0 wt.%, respectively. Whilst other elements varied between samples (as low as 0.001 wt.% for some elements), substantial values of critical minerals have been estimated for some mines due to the sheer volume of tailings available. For example, tailings from Frongoch in Wales are predicted to contain £1.99m worth of zinc (Zn) alone.

As explained in section 1.4.1, companionality plays an important part in mining and can be used to show the level of association between certain minerals or metals which can often be found together (for more information see [14]). This is useful when considering the composition of tailings from previous mining operations within the UK. For example, indium, which is usually mined as a by-product of zinc, is unlikely to have been of interest to mining operations in the early 1900's [14]. However, its application in flat panel screens over recent years (56% of indium use globally [1] has led in part to its position on the UK's list of critical minerals. A high companionality between these two elements indicates a good chance that indium could be found within tailings from zinc mines.

The critical minerals which are therefore most likely to be found in mine tailings of the UK's most historically prosperous mines is presented in Figure 21and includes high probabilities of tellurium (Te) from copper mine tailings as well as germanium (Ge) and indium (In) from zinc mine tailings and REEs from iron mine tailings.

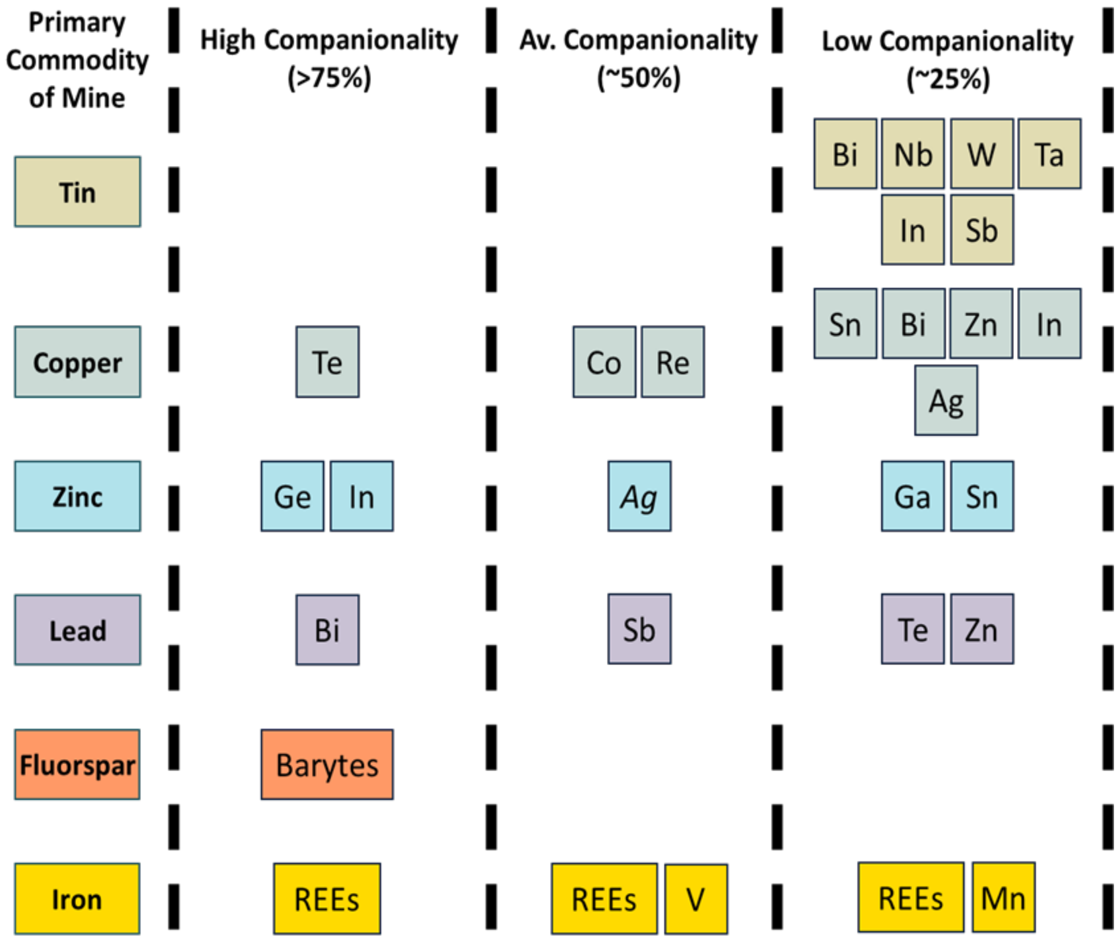

Figure 21 - Schematic showing the most likely companion elements and minerals from the UK's most common legacy mines. Silver (Ag) is not a critical mineral but is shown due to its high value potential [14] [101]

A wider range of CRMs including bismuth (Bi), tantalum (Ta) and antimony (Sb) have a lower but still plausible association with tailings of tin mines, which were historically very prosperous in the southwest of England and may be re-opened in the future [102]. It is important to note that a companionality value of greater than 75% does not refer to the content those tailings may contain. Instead, it is a likelihood that a critical mineral would be found in the same mine and therefore the tailings. Whilst silver (Ag) is not a critical mineral, it has been included as a high-value example of other beneficial metals that could make prospective mine tailings more economically viable to process.

Legacy mine information taken from a report by the British Geological Survey is shown in Table 16 and shows a conservative estimate of the number of legacy mining sites for each commodity. Data is not held to provide an exact number.

Table 16 - Data taken from a 2010 report by the British Geological Survey which shows the minimum number of closed mining sites in the UK by commodity [103]

Commodity	Estimated Number of UK Sites
Iron (mostly ironstone)	1650
Baryte	29
Copper	205
Fluorite	58
Lead	620
Tin	335
Witherite	12
Zinc	5
Other	705

The advantages and disadvantages of processing mine tailings to recovery critical minerals is shown in Table 17.

Table 17 - Advantages and disadvantages of mine tailing processing

Advantages	Disadvantages
▸ Legacy mine tailings can contain higher metal grades due to low metal recovery at the time. ▸ Removal and use of mine tailings would improve landscapes and alleviate the environmental and health hazards currently caused, particularly local water pollution and the possibility of unstable tailings [104] [105]. ▸ Mine water pollution since at least the 1990s. Pollutants of zinc, cadmium, iron, lead and copper [72]. ▸ A new sector would be developed, creating jobs and reinforcing local economies.	▸ In many cases the ownership of mine tailings is unknown or unclear. ▸ There are many health and environmental risks associated with the collection of tailings including pollution of rivers, groundwater and crops, dangerous stability of tailing dams and the flammable nature of dust and gas emitted from tailings [72].

There is a large body of previous research and ongoing projects that are focussed on the recycling of mine tailings and the extraction of materials from mining pollution, much of which is listed in a 2019 report from the EU Commission [106]. Some of these include:

- The UK's Coal Authority is currently working with private company AB Agri to extract iron ochre residue from mine water in their treatment sites, which can be used in the anaerobic digestion industry. This avoids the need to dispose of ochre as a waste material and reduces reliance on imports [107].
- The EU commission's METGROW+ project which was co-ordinated by Finland's VTT Technical Research Centre focussed on researching and developing technologies to extract CRMs from metallurgical waste and low-grade ores.
- Work done as part of the EU commission's EURARE project, which looked to help develop a secure supply of REEs, investigated mine tailings in terms of both environmental impacts and the potential efficiency of extraction of REEs. The processing of red mud, a large-scale industrial waste, was identified as a useful resource of REEs which would also reduce the environmental impact of the metallurgical industry [18].

- The work of academics from Sweden, France and Norway was published in the 'Journal of Cleaner Production' in 2019, which explored the use of acids to separate REEs, tungsten (W), iron (Fe) and copper (Cu) [108].

4.4.2 Slag and fly ash

Whilst the recovery of steel production slags and furnace dust for re-use or further processing is positive (referenced in section 2), the use of steelmaking slags in aggregates may not make the best use of critical minerals. In addition to zinc, it is also possible to recover critical minerals such as iron (Fe), aluminium (Al), cobalt (Co), nickel (Ni), niobium (Nb) and tantalum (Ta) from slags of metallurgical processes and incineration wastes [109]. Additionally, previous research commissioned by MPI has looked at removing Zn from steelmaking by-products so they can be re-used. Currently, steel products containing more than 15% Zn can be recycled via conventional routes and products containing less than 0.3% Zn are recycled back into the steelmaking process. However, there is a difficulty if products have a Zn content between 0.3% and 15%. This work is looking to address this and find a more effective recycling process [110].

A 2023 report by the CMA [23] states that flue dusts from steelmaking (containing zinc and other critical minerals) have been land-filled in the past. Coal waste dumps may contain REEs, something that is currently being evaluated in the USA, and steel slag can also contain vanadium (V) [111]. However, the report states that the exact contents and quantities of critical minerals within these waste streams are not fully understood and encourages further research to determine the size of the opportunity. Previous research from 2018 has shown that significant levels of CRMs can be removed from steel slag using bioleaching (100% Al, 84% Cr, 8% V) [112]. Bioleaching is a hydrometallurgical process that uses microorganisms to solubilise metals through the production of an acid. The process uses low amounts of energy, low capital cost and does not require skilled labour.

Research in 2020 by Riley et. al. analysed data from the Environment Agency, Ordnance Survey, BGS and other published research literature to estimate both the volume and composition of landfilled iron and steel slags across the UK. The research referred to the amount of legacy slag deposits in the UK as 'significant' and identified bulk reuse, ecological enhancement and critical mineral recovery as opportunities. Notable quantifications of the report include at least 49.1 Mt of FeO_2, >0.2 Mt Al_2O_3 and up to 81.1 Mt of NiO present in at least 191.1 Mt of slag available in the UK [113].

Research completed by academics in China in 2019 explored the use of Recovery of vanadium (V) from steel production slags using enhanced acid leaching and found that up to 92% of vanadium could be extracted by the process in optimum conditions [114].

Additional research has looked at the recovery of zinc and iron from sulphide ore smelter slag [115], recovery of silicon (Si), magnesium (Mg), zinc, nickel (Ni) and aluminium (Al) from electric arc furnace slag [116], and aluminium recovery from dross products [117].

As the UK became the first G7 country to stop the use of coal-fired power generation in October 2024, the recovery of critical minerals such as iron, silicon and aluminium oxides in the future is a small opportunity compared to some other countries [118] [119] [120]. However, over 100 million tonnes of legacy waste from coal power production - known as fly ash - could be a valuable source of REEs within the UK [121]. A current project by Mormair and MPI will run until August 2025 and attempt to increase REE recovery through development of high-temperature and chemical processes [122].

There are many other research projects with relevance to the recovery of critical minerals in slags and waste products:

- Extraction of niobium and tantalum compounds from tin process slag [123].
- Recovery of niobium and other precious metals from printed circuit boards using leaching [124].
- A £14m project funded by UKRI, 'ELEMENTAL', is focussed on critical minerals and looking at ways to promote a circular economy. Such research will look at bioleaching (the extraction of metals from waste), bioremediation (the breakdown of contaminants in polluted water and land) and phytomining (extraction of critical minerals from plants that extract them from the soil) [125].

4.4.3 Circular economies

Stakeholder opinion – actions to capitalise on circular economies through recycling and recovery potential

- **Actions to secure the supply of waste:** recycling stakeholders felt that uncertainty surrounding demand for future waste streams represented a significant barrier to developing the industry. This reflects the need to secure waste streams in the UK to ensure that the correct waste reaches the critical mineral recovery and recycling industry.
- Some stakeholders suggested using trade policy to reduce the export of critical mineral-rich waste, as well as attempting to import waste to incentivise the growth of domestic recycling and midstream. Consequently, a greater proportion of the value adding activity happens in the UK, and the UK can process a greater volume of high value waste. This recommendation, as previously highlighted, presented risk in terms of free trade and disruption of international operations.
- Government stakeholders expressed a need for consideration of policy interventions involving security of end-of-life materials, waste management optimisation and a circular economy to keep material within the UK.
- Also critical to circular economy is the potential for manufacturers to re-manufacture their products to make them easier to recycle, this was suggested by two out of four academia respondents. This would require collaboration between recyclers and manufacturers to ensure that mutual needs are understood.
- **Clear regulation and end-of-life responsibility:** Government and industry respondents felt that clear regulation and policy was needed to designate responsibility for end-of-life assets, including the facilitation of recycling through design for disassembly. One stakeholder suggested policy to address a barrier they raised regarding the dispute of ownership of end-of-life equipment, namely offshore wind turbines located on land belonging to the Crown Estate. This would address delays in recycling turbines, which contain large amounts of REEs, and could ensure the material is kept within the UK's recycling process. This links to the wider issue of reversion risk and who is responsible for the decommissioning of offshore assets.

5 Skills and employment

5.1 Previous research

Various works have been carried out highlighting the importance of bridging the skills gap and securing a strong talent pipeline for the critical minerals industry. Key sources of research include a report by the IOM3, titled "The talent gap – critical skills for critical materials" published in 2023 [5] which is supported by significant stakeholder engagement, and the CMA's 2022 report on "A talent pipeline for critical minerals" [126]. Both organisations highlight the growing skills gap facing the critical minerals value chain and that skills in geosciences, mining engineering, mineral processing and metallurgy are in short supply. The IOM3 highlights that while an increase in workforce is required, there is a simultaneous decline the availability of skilled people, namely owed to a large number of industry professionals reaching retirement age with insufficient replenishment of the talent pipeline. Modernising the perception of the industry was found to be essential in attracting new talent, while also sustaining the industry. Furthermore, the IOM3 highlights that with other countries investing in securing their critical mineral supplies, the UK will ultimately be competing in an increasingly challenging and competitive labour market, emphasising the need to act in a timely manner to ensure the security of skills. The CMA presents recommendations to highlight how the UK Government can integrate critical minerals skills through a number of initiatives and actions.

The UK Government's Critical Minerals Strategy [58] has already outlined ambitions to 'review the UK's skills, education and training along the critical minerals value chain and define a critical minerals skills blueprint, recognising the full breadth of skills we need'. The Task and Finish Group on Industry Resilience for Critical Minerals [127] also highlights the need to support UK skills and innovation development in critical minerals midstream and circular economy, particularly to ensure impactful technology scale-up and supply chain resilience; a recommendation which was endorsed by the UK Government [128].

5.2 Stakeholder engagement

As part of the current work, views on skills and employment were captured as part of stakeholder interviews. Respondents shared their perceptions of the state of skills in the UK critical mineral industry, in particular of the quality and quantity of skills, access to education and the matching of skilled workers to jobs in the critical minerals industry. Overall, the output of the interviews echoed the findings of the IOM3 report on the talent gap. A summary of the interview outputs are as follows.

There was a sense amongst industry stakeholders that whilst the UK workforce is generally highly skilled but there are gaps in access to some specific critical mineral skills, as well as a sense of a general shortage of certain specific skills in mineral processing.

- **Skills in engineering** – the majority of industry stakeholders felt that the UK had a strong academic skill base and that this capability is a major competitive strength for the UK. The UK has a strong track record in developing skills in high tech chemical engineering and materials science. However, there was a sense that this capability exists mainly within universities or low TRL research organisations and that skilled graduates tend not to be drawn to industry roles. The need for chemists and chemical engineers in such industrial roles was also raised. Some midstream respondents felt that the perception of the critical minerals industry deters workers from entering the market.

Stakeholder opinion – academic and industrial skills

"So, we're very well equipped for the high value stuff, poorly equipped for the mineral process, basic mineral processing" – Industry stakeholder "We're very well equipped for the high value [skills], but poorly equipped for the mineral process, basic mineral processing" – Industry stakeholder

- **Strong research capability** – Several stakeholders reflected on the high quality of UK academic research as a strength of the industry, supported by UKRI initiatives through EPSRC and Innovate UK. The Knowledge Transfer Partnership was also praised, a scheme that allows employees to work on site in industry whilst receiving academic support from a university. However, employers explained difficulties in being able to complete the application process, as they view the process as lengthy and difficult to meet the criteria for funding. A lack of awareness over the scheme's availability was also expressed. All government stakeholders stated that the UK has a world leading research capability including several spin outs and novel technologies.
- **Skill gaps and weaknesses** - Over half of industrial stakeholders expressed feelings that there is a skills gap or weakness in the UK, particularly in midstream and recycling. This includes a sense that there are limited engineers, materials scientists and coating engineers, chemists and chemical engineers in the areas of mineral processing, industrial instrumentation, battery technology, nano technology formulation science and electrochemistry. Two academic stakeholders voiced concerns of a skills shortage in mining and geology and that this is part of a systematic supply-side problem that isn't limited to just this sector. Educating children at an earlier age by including mining and minerology in the school curriculum was suggested. One stakeholder offered a potential explanation for these skill gaps, noting that the UK has a track record of being at the forefront of training in the highly skilled areas of the supply cain, such as chemical engineering, but is not excelling at training more manual traditional areas of the supply chain, such as mineral processing.
- **Retention of talent in the UK** - One business reported that only one of their engineers over the last 14 years was from a UK-based university, all others were trained overseas. As highlighted by the IOM3, it was felt by stakeholders that with the rise in countries seeking to secure their critical minerals industries, the UK is now competing to retain highly skilled individuals in a domestic sector that has appeared to be shrinking.
- **Access to education –** The number of degrees available which contain education on critical minerals and materials engineering has reduced over recent years. There has been a reduction in critical mineral specific courses in the UK, at both degree and apprenticeship level. Furthermore, three stakeholders expressed the need for investment in academia and a focus on engineering to overcome a general engineering shortage of skills. Concerns were also raised considering recent financial challenges associated with universities, where departments such as chemistry and materials sciences are at risk of closing. Courses such as these were highlighted to provide employers in all sectors a talent pipeline of highly skilled employees, essential to sustained economic growth.

Stakeholder opinion – talent retention in the UK

"No skills, you know, young geologists finishing university, going to Australia or we export our expertise as consultants around the world. We have some of the biggest mining companies based in London. All their operations and all the best geologists are abroad." – Industry stakeholder

"There's a bit of a fear about where the next generation of talent is going to be coming from. Less people are going on materials metallurgy manufacturing type courses" – Industry stakeholder

"We don't typically recruit from UK universities because they don't want to work in this industry as such because I guess it's perceived as being a dirty industry" – Industry stakeholder

- **Perception of the industry –** There was a feeling amongst industry, academic and government stakeholders that employment in the critical minerals industry is hindered by a negative perception of the sector, in terms of environmental impact and sustainability, as well as long term safeguarding and futureproofing of the industry as a whole. It was highlighted that there are a lack of engineering graduates applying for jobs in the midstream processes and mining industry in particular, which are seen as 'dirty' and 'unglamourous'. There is a misconception that industry (mining in particular) is environmentally unfriendly and therefore it is difficult to attract graduates from the UK. This negative perception makes it difficult for the critical minerals industry to attract high quality graduates and boost the skill base of the sector. A lack of high-quality graduates has resulted in UK firms bringing in skilled labour from overseas.

Overall, it can be considered that the skill gaps in the UK are a result of an apparent negative perception of the industry and a lack of access to high education and training. These skill gaps contradict the perception of the UK having a higher skilled workforce. It could be considered that the barriers creating by perception and access means that highly skilled engineers are choosing other sectors over critical minerals. Stakeholders suggested the following opportunities to increasing the UK skill base:

- **Retraining those in other industries** – Retrain other tradespeople in critical mineral skills. There was a sense that a skilled tradesperson could be easily retrained into the skills required for midstream processing. This view was disagreed upon by one stakeholder who felt that upskilling the existing workforce would be challenging. In addition, there was a sense from stakeholders that more apprenticeships are required, or potentially something more attractive than an apprenticeship. This links to a wider sentiment that more on-the-job training could be offered to build up industry experience of young people.
- **International collaboration** – Some industry respondents expressed an opportunity to work alongside international partners to exchange knowledge. This would work for the UK to gain skills from other countries and demonstrate its capability to the rest of the world.

In conclusion, stakeholders felt that the UK has a generally well skilled workforce and strengths in academia, though there is a sense that this is not completely well matched to the needs of the critical minerals industry. This is evident by various perceptions of specific skills gaps in critical minerals such as battery technology and mineral processing. In addition, the UK has a strong research capability and can develop high tech innovations and has strong academic expertise. However, perceptions of the industry and a decline in higher education and training opportunities presents a barrier to the critical minerals industry exploiting the UK's research expertise.

5.3 Addressing the skills gap in midstream and recycling: workshop

The CMA, supported by DBT, hosted a workshop (in February 2025) which brought together stakeholders from across the UK minerals value chain to explore the challenges and opportunities in skills development within the domestic midstream and recycling industries.

The key outputs of the workshop were to discuss and propose solutions to overcome barriers to talent recruitment and retention exploring tangible ways the UK can develop its competitive edge. The session looked to gain insights on best practices, regulatory frameworks and educational or outreach programmes to foster growth within the sector and develop a workforce with the necessary skills to support them.

As part of the workshop, exemplary case studies of outreach and skills training were highlighted, followed by group discussion, which allowed for a number of key recommendations to be formed.

5.3.1 Case studies

Recycling:

- The first case study provided by Bioscope Technologies, a private sector startup using bioprocesses to extract metals from circuit boards and electrical wastes, outlined the concern with the lack of young people within the workforce who were skilled in operational skills and plant design and maintenance.

- It was noted that technical teams working predominantly within lab-based practices and science-based tasks were younger, but didn't necessarily have the transferable skills to support the operational works of the plant through scale up.
- Most of the workforce involved in the building, scale up and operational tasks of the plant are aged 50 and over, creating cause for concern as employees approach retirement age.
- To support young people to pioneer the science involved with the company, Bioscope support many of their technical staff through university via scholarship with the guarantee of a job role at the end of their studies, as well providing educational opportunities to their staff through their affiliation to the company.

- Ionic Technologies, a Northern Ireland based project using chemical processes to recycle rare earth element (REE) magnets, provided a case study on their upskilling programme to train academic scientists in roles within the company to be more competent regarding plant design, operation, health and safety.
  - Many academically trained, technical staff have little experience in plant operation; it thus becomes necessary to implement an operational procedures course to all members of staff.
  - Ionic support PhD students in partnership with Queens University Belfast with projects that develop the company's supply chain, with the opportunity for many to continue work after their studies.
  - A barrier to retention for Ionic is competing with other fields due to salary, security of job roles, and other opportunities given to people in the area.

Midstream:

- Phillips66, the UK's only supplier of sustainable aviation fuel, provided a case study on the development of The Humber Energy Hub - the UK's largest decarbonisation project. It currently employs 600 people within the research centre and aims to provide approximately 1000 apprenticeships per year once operational in 2029.
  - Critical trade skill losses were addressed as a barrier to projects, with an estimated 31% loss in mechanical fitters and platers over the last 10 years, as well as a net 2.2% annual loss of engineers within the field.
  - The Hub requires over 10,000 traders by 2031 when operating at its peak. Concerns that there will be significant gaps in these skills when required causes significant implications to the progress of the project.
  - The Hub is projected to increase the area's population by up to 20,000. This creates an increased demand on local infrastructure, transport and accommodation. Ensuring there is appropriate infrastructure for the estimated workforce is an essential consideration for employee retention.
- Less Common Metals, a manufacturer of complex alloys and metals, provided a case study on their Mine to Magnet workshop in partnership with the Xplore! Science Discovery Centre. This outreach programme has been successfully delivered to 1070 students across 13 counties in the UK.
  - This initiative was funded by Innovate UK and aimed at primary school-aged learners to develop understanding of the supply chain for neodymium-iron-boron (NdFeB) permanent magnets for electric vehicles.
  - The workshop was developed tailored to the National Curriculum and consists of hands-on activities to emulate every stage of the supply chain. It aims to generate interest among young students and encourage pursuit into academic pathways involving geoscience and chemistry for future employment within the industry.

5.3.2 Group discussions

The group discussion yielded barriers to the recruitment and retention of skilled individuals for the critical mineral midstream and recycling workforce. It is currently felt that there is little vision for the goal and future of the industry, thereby making it difficult to fully understand the scale of the problem and implement solutions. There is an urgent need for skills requirements to be mapped out and linked together before the National Curriculum can be adapted to prime young people to fills these gaps.

Similarly, across both groups, it was felt that there should be less persistence and pressure on individuals to follow a university and academic route to train for some of the jobs within the workforce. The ratio of trade and technician roles, to the highly skilled technical roles, require many individuals that would be more appropriately trained through apprenticeships and vocational experiences. These routes to employment could be supported by the ~£1.6bn apprenticeship levy which many felt was not being used to its potential.

However, stakeholders expressed a general concern with the lack of capacity to train up the workforce, in both an apprenticeship and academic capacity. Transferable skills and technical training will therefore be required to train up the workforce and should be prioritised throughout education and training.

It was widely agreed that the regional hub approach to skills development could be very successful based on the case studies provided and ideas given by attendees. This would solve concerns on a regional basis, where skills gaps differ to other parts of the UK. It can evolve through the offer of apprenticeships and employment opportunities through the hubs, as well as provide people with tailored careers advice to allow them to train and work within their regions. Similarly, local hubs could call on academic partners and local educational institutions to provide effective training and outreach exposure from a young age, therefore introducing successful early intervention to target particular roles.

Negative perceptions were highlighted by all groups, but these perceptions varied from previously heard 'dirty industry' concerns. It was highlighted that jobs are unstable, financially vulnerable and hard to make attractive compared to other roles available to people within other fields. Similarly, many of the roles involved within the supply chain are not well known and advertised, and hence the need for a singular point of contact to learn about the industry and roles available is required to aid in recruitment.

5.3.3 Recommendations

The key outputs, captured as potential recommendations for UK Government to adopt, include the following:

1. Setting out a clear vision for the sector in the UK Critical Minerals Strategy, which will allow scope for comprehensive mapping of future skills supply and demand. There is not enough data or quantitative research to understand the skills and jobs needed to fulfil the UK Critical Minerals Strategy. Without this, knowing the direction for addressing the gap is difficult.

2. A UK Government Green Skills Forum to promote this region- and nation-wide.

   a. Creation of a platform that provides a definitive source of information on the industry, clearly advocating for the necessity and positive impact of these skills and employment opportunities, as well as comprehensively listing education and employment prospects in the UK or with UK companies

   b. Clear advocacy in this way can help to address negative public perceptions and draw talent to the sector

   c. Include non-academic pathways to skills such as apprenticeships, vocational programmes and training opportunities for both technical and trade roles required in the field.

3. Regional hubs to foster growth in hotspot areas for industry within the UK.

   a. These can provide local employment opportunities, tailored outreach and training opportunities, and careers advice for young people to develop skills more specific to their region and local prospects.

4. Make adaptations to the National Curriculum from primary school age to include relevant modules related to green skills.

   a. Early intervention is key to fostering growth and interest within the field. Implementing green skills, an understanding of critical minerals, and the extractive, processing and recycling industries can attract talent to the sector and curb negative perceptions.

6 Government intervention

Based on the evidence gathered, the UK government should consider action to overcome the barriers and capitalise on the opportunities for midstream processing, and recycling and recovery to accelerate growth and meet future demand of the industry. Ten potential policy actions for Government to consider have emerged from this research. The policy actions are designed to address the barriers which will help place the UK as a leader in global critical minerals markets. This section outlines the purpose and rationale for each potential action and indicates the next steps for further research needed if the actions are considered by the Government.

High energy costs

- **Priority 3**: An extension of existing energy intensive industries scheme to cover critical minerals.
  Potential ROI: 2.01 – 2.47
- Or alternatively, a new energy bill relief scheme tailored to critical minerals.
  Potential ROI: 1.07 - 1.40

Difficulties in accessing finance

- **Priority 2**: Matched grant funding to support and de-risk investment in research and innovation that develops midstream and recycling capability.
  Potential ROI: 2.02 - 2.48

Difficulties accessing waste streams

- **Priority 5**: Amendments to waste classifications.
- **Priority 7**: Publish a critical minerals procurement plan.

Negative public perceptions

- **Priority 8**: Targeted school and university outreach.
- **Priority 9**: Facilitate positive promotion of midstream processing industry.

Cross cutting actions

- **Priority 1**: Centralised support for planning and permitting. **Potential ROI: 0.78 - 2.78**
- **Priority 4**: Centralised support to collaborate with regional clusters. **Potential ROI: 0.72 - 1.43**
- **Priority 6**: Collaborate with international partners to transfer knowledge.

Figure 22 – Potential policy recommendations to address key industry problems

6.1 Initial testing of potential policy actions

As part of the Frazer-Nash Policy Development Framework, potential policy recommendations were tested with the Critical Minerals government cross departmental working group and with industry and academic members of the Critical Minerals Association. Comments and feedback have been incorporated throughout this report, in particular the following points have shaped the recommendations presented in in this report and offer opportunity for further consideration.

- **Funding to support access to finance:** Funding the development of pilot capabilities to move technology readiness levels and develop skills was considered of key value. Funding could be focussed on developing midstream and upscaling capabilities, where these areas are in strong need of investment.

  Other countries using similar types of grant funding schemes such as, Canada and Australia, have more established critical minerals industries, as well as CM assets and mining opportunities. In comparison, the UK likely requires more funding than funding in other countries and aimed at low and mid technology readiness levels to accelerate the growth of the industry. The recommendation for grant funding is an opportunity to develop this policy as a first step with the possibility to consider greater funding levels and focus on higher move technology readiness levels as needed.

- **Streamlining planning and permitting processes:** Several companies noted how other countries support businesses through planning and permitting processes. The emerging suggestion is for centralised support where businesses can engage with a customer representative to help them through the processes and liaise with corresponding organisations on the companies' behalf. The recommendation for planning and permitting support is focused on providing centralised support with further consideration needed to develop the extent of support and how the this differs from existing activities.

- **Classification of waste:** It was noted that to enhance recycling efforts, it's crucial to accurately characterise waste streams containing critical minerals. This process needs to extend beyond simple waste classification. For instance, in the case of Waste Electrical and Electronic Equipment (WEEE), there are several data gaps in the current system. These gaps make it difficult to track and manage WEEE effectively. Specifically, there is a lack of accurate assessments of WEEE flows, especially regarding what happens to WEEE that isn't recorded as collected and recycled according to mass-based targets. Therefore, the recommendation for considering waste classifications focusses on research to understand what is needed to be changed and the implications for change, with opportunities to engage with other areas of government to avoid adverse effects.

- **Targets and restrictions:** Imposing production targets or restrictions such as a cap on export of waste material could be argued as a policy to promote the development of UK capabilities. However, the majority of companies felt this would disturb the operation of a free market and ultimately reduce competitiveness of their operations. The main barrier being that the UK currently does not have a robust recycling capability to handle the waste. It is deemed more effective to address the reasons why material is exported and not treated in the UK, therefore, targets or restrictions do not form part of the recommendations at this time.

6.2 Prioritising policy actions

To provide an initial indication of priority for future focus, each action has been rated based on cost and potential impact. Annex A.4 provides more detail on how each individual factor has been assessed. Potential impact has been assessed using a weightings framework. Each policy was scored one (low) to five (high) according to the below criteria:

- **Economic impact (weight – 25%)** – Potential of the policy to increase critical mineral volumes, values, gross value added, and jobs.

- **Security of supply (weight – 22.5%)** – Ability of the policy to reduce supply chain risks and threats associated with international trade.

- **Capability (weight – 20%)** – Ability of the policy to improve the effectiveness and competitiveness of UK midstream processing and recycling and recovery.
- **Environmental, social and governance (ESG) standards (weight – 17.5%)** – Ability of the policy to overcome risks associated with countries with lower ESG standards.
- **Domestic policy alignment (weight – 15%)** – Extent to which the policy aligns with existing UK policies.
- **Cost assessment** – Based on the capital and resource costs to deliver each action. These are initial rough order of magnitude estimates that require further refinement and are based on similar policies where possible. Annex A.4 describes the calculation process and associated assumptions.

Table 18 summarises the priority score of each potential policy action based on the above weighed cost and the impact score framework. Each category is scored 1-5, 5 is the maximum value.

Table 18 - The four most impactful policies will be carried forward to economic modelling. Further detail relating to the policy assessment methodology can be found in Annex A.4

Key problems:	Policy	Economic impact	Supply security	Capability	ESG	Policy alignment	Weighted average (max=5)	Rank	Cost
Energy costs	**1.** New energy bill relief scheme tailored to the critical minerals supply chain	4	4	4	4	2	3.70	3	£1.5bn
	2. Extension of the Energy Intensive Industries support scheme	5	4	4	4	2	3.95	3	£900m
Access to finance	**3.** Grant funding for innovation in recycling and midstream capability	5	4	5	4	4	4.45	2	£25m
Accessing waste streams	**4.** Amendments to waste classifications	3	4	3	4	4	3.55	5	£1m
	5. Government procurement plan	2	4	2	4	3	2.95	7	£300k
Negative perception	**6.** Targeted school and university outreach	2	2	2	4	3	2.50	8	£60k
	7. Facilitate positive promotion of the midstream processing industry	1	2	1	4	3	2.05	9	£15k
Cross cutting actions	**8.** Centralised team to support planning and permitting	5	4	5	4	5	4.60	1	£900k
	9. Centralised team to support collaboration with regional clusters	4	3	4	4	5	3.93	4	£900k
	10. International collaboration	2	4	3	5	4	3.48	6	£900k

6.3 Actions to address high energy costs

6.3.1 New energy bill relief scheme tailored to the critical minerals supply chain

Purpose: To actively reduce the cost base for companies in the UK critical mineral supply chain, helping the industry to become more competitive internationally.

Rationale: The UK has the highest electricity costs in Europe, standing at £0.36 per kWh in the second half of 2024 [4]. Stakeholders in this research felt that energy costs were too high for UK industry to be competitive – a recurring theme. This is especially true for an energy intensive industry such as critical mineral processing and recycling. High energy costs and uncertainty deter private investment in critical minerals due to reducing the return on investment. Action could be considered by introducing a new energy bill or alternatively by extending existing schemes, which is discussed in Section 6.

Description: The UK could adopt an energy bill relief scheme specific to the critical minerals sector. Eligibility for the scheme could be based on actual and planned mineral production. This basis for eligibility means the scheme is targeted to mineral producers and recyclers. Under this scheme companies would be able to recover up to 50% of their energy costs. The funding could be contingent on companies receiving ISO50001 certification or committing to reduce electricity consumption relative to profits. This means that there is a longer-term tie in to reduce energy intensity and create longer term reductions in energy costs.

International comparison

- Canada provides tax rebates and subsidies for mining companies who adopt ISO50001, which is a quality standard for mining, requires:
  - Development of an energy plan to identify energy saving targets.
  - Mines must monitor and communicate energy performance
  - Define actions to reduce energy use.
- The EU energy toolbox provides tax relief to energy intensive industries. Similarly, the EU temporary crisis framework, put in place following the start of the war in Ukraine, provides firms who experience a 40% reduction in EBITDA receive a greater degree of support.
- UN emergency intervention meant member states could receive the excess revenues from electricity generation that was not from fossil fuels. To receive this revenue member states must agree to a reducing their energy consumption by 10%.

Policy alignment: The Department for Energy Security and New Zero (DESNZ) has previously delivered the energy intensive industries (EII) exemption scheme, this could be extended under policy 7. This scheme provides energy bill relief for industries deemed as energy intensive. This includes mining and metal manufacture activities but does not include disposal of waste which means recycling is omitted from the scheme.

Ownership of actions:

- **DBT:** Fund and manage the scheme. Consultation with industry to develop scheme details. Legislation might also be needed.
- **CMIC, DBT, and DESNZ:** Collaborate to establish consistent reporting for critical mineral production and energy consumption.
- **Industry bodies:** Engage with industry to advertise the scheme and direct members to the right support.

Potential costs:	**Potential benefits:**
- £1.5 billion over the scheme. - This is based on critical minerals sector electricity consumption data and current prices. The cost of this scheme represents 50% of current electricity costs for the sector.	- Energy relief payments will reduce the burden of energy costs on industry. This improves competitiveness of UK firms, resulting in business growth, and higher output.

Risks and further research: There is a potential unintended consequence that might arise if companies take advantage of energy costs to increase energy consumption, therefore creating negative environmental impacts. A possible mitigation could be a requirement of recipients to make a commitment to energy usage certification or committing to an energy reduction target.

In creating a new scheme, other companies and Government departments focussed on other industry sectors might wish to follow suit, potentially placing more pressure on Government funding.

Several companies in the supply chain don't own mining assets and operate mainly as net importers to the UK. These companies still have a high cost base, through other inputs such as high labour costs, but would potential not benefit from energy cost relate support. There is an opportunity to consider shaping this action to include a broader range of operating costs.

6.3.2 Extension of the Energy Intensive Industries support scheme

Purpose: As immediately above, to actively reduce the cost base for companies in the UK critical mineral supply chain, helping the industry to become more competitive internationally.

Rationale: An alternative to a new bill relief scheme. Extending existing energy schemes could be more straightforward to implement and easier for industry to understand and might avoid additional funding pressures from creating a new scheme.

Description: Under this scheme eligible companies would be able to recover up to 30% of their energy costs. The scheme could be extended to include a larger number of industries, including metal manufacturing, mining, and disposal of waste.

Policy alignment: This policy would be a direct extension of the existing energy intensive industries support schemes scheme. This scheme offers energy bill relief to energy intensive sectors, firms are eligible if their energy bill is 20% of their Earnings before interest, tax, depreciation and amortization (EBITDA).

Ownership of actions:

- **DBT and DESNZ:** Collaborate and legislate for the EII exemption scheme to include a wider variety of sectors, such as disposal of waste.
- **Industry bodies:** Engage with industry to advertise the scheme and direct members to the right support.

Potential costs:	**Potential benefits:**
- £390 million over the scheme. - Based on covering 30% of the energy costs of companies producing mineral products.	- Energy relief payments will reduce the burden of energy costs on industry. This improves competitiveness of UK firms, resulting in business growth, and higher output. - This action could benefit industry to a lesser extent than a new scheme but is potentially more feasible to implement.

Risks and further research:

It is also worth considering how such a policy would interact with energy use reduction targets, as the cheaper cost could incentivise firms to be less considerate of the energy efficiency of their activities. Incorporating incentives within the scheme to tackle this, or efficiency requirements that funding is contingent on, may be a way to mitigate these concerns.

The existing exemption scheme is due to be reviewed in 2026, this includes a review of the qualifying sectors. Eligibility criteria are based on energy use data from 2022, which likely means that sectors such as disposal of waste (which includes several critical mineral recycling firms) would not qualify as an energy intensive industry.

For the EII exemption scheme to be better targeted to critical minerals then the sector eligibility must account for emerging sectors. As a result, this potential action is likely to return benefits to a lesser extent compared to a new scheme. Therefore, there is a need for further consideration of which alternative action may be more feasible to implement.

6.4 Actions to address difficulties accessing finance

6.4.1 Funding for innovation in recycling and midstream capability

Purpose: To stimulate growth in the critical minerals supply chain by de-risking investment in innovation projects focussed on developing and diversifying recycling and midstream capability, whilst considering commercialisation.

Rationale: Research and innovation is a competitive strength of the UK and presents an opportunity for growth. However, evidence in this report suggests that access to private finance has been difficult due to limited opportunities and an uncertainty surrounding future demand, particularly midstream activities. Funding is required to develop, demonstrate, and commercialise new technology for use in the critical minerals industry, and to allow industry to enhance knowledge exchange with academia to deliver significant impact.

The existing funding programme, CLIMATES, focusses on the entire supply chain for rare earth elements. In contrast this potential funding programme, while it could continue to be segregated by material type, it could focus explicitly on developing recycling and midstream capability across critical minerals key to the UK economy.

The EPSRC Future Manufacturing Research Hubs have demonstrated success in addressing similar challenges; supporting UK manufacturing industries through the commercialisation of early stage research opportunities, whilst explicitly considering the pathway to manufacturing, including production scale up and integration within the wider industrial system. The hubs also take a leadership role in the national research landscape, centralising clusters of knowledge and conducting outreach and driving research excellence in their area. The Manufacturing Hub model could serve as an exemplary case for future funding programmes within the critical minerals industry.

Description: Creation of a new matched funding programme. This programme could be a minimum of £50m over a period of 4 years, as that would allow significant collaborative R&D activity to occur without any additional supporting initiatives. The programme could be strategically targeted on the midstream part of the value chain, for recycled and primary materials. Funded projects could focus on two areas to grow a more resilient UK midstream supply chain for critical minerals:

1. Facilitate the adoption of new innovations in processes, technologies or services by industry.
2. Research on mid and late-stage routes to development, to accelerate the industrialisation and commercialisation of innovative processes, technologies and services.

The scheme could also include the opportunity to leverage the finance sector, utilising venture capital reduces the risk to industry and provides a commercialisation route once grant funding ends.

International comparison:

- Canada: The critical minerals research, development, and demonstration programme was launched in 2021 with a CAD 47.7m (c. £26.7m) to support zero critical mineral development. This scheme funds 30 R&D projects and CAD 10.95m for pilot recycling plants [13].
- Australia: The critical minerals development programme provides up to AUD 50m (c.£25.3m) over three years for early and mid-stage projects.
- However, both examples are in the context of a more developed critical minerals supply chain. Thus, far greater funding would be required in the UK to deliver similar impacts.

Policy alignment: Innovate UK funds critical mineral innovations through the CLIMATES programme, a £15m scheme focusing on primary and secondary supply chains [129]. The UK also provides funding through the Canada-UK critical minerals partnership which supports critical minerals SMEs [130].

Ownership of actions:

- **DBT**: Provide government funding and set parameters for the scheme.
- **EPSRC/Innovate UK**: Design the funding and put in place the application and awarding mechanisms.
- **Industry bodies**: Produce an ecosystem map to help members navigate the funding landscape.
- **Finance sector**: Explore investment opportunities and fund high potential projects.

Potential costs	Potential benefits
Minimum of £50m of matched industry funding over 4 years.	Innovation funding provides collaboration opportunities to develop new technologies.
This is a minimum cost that could allow significant business-led R&D activity to occur without any additional supporting initiatives.	Commercialising these innovations will deliver improved productivity, greater energy efficiency, and business growth.

Risks and further research: It is usually expected that full commercial operations will not be seen for 3 years or more from this type of funding programme. There is a risk that if there is not a clear commercialisation strategy for each project then companies may struggle to access follow-on funding.

Therefore, there is a need to further consider more substantial funding to develop pilot capabilities to full operational status and consider funding support for upscaling capabilities, in a similar manner to larger industrial capability programmes. The magnitude and focus of future commercialisation funding is expected to be targeted to specific industries and will require additional research and strategy development. For example, the Automotive Transformation Fund (ATF) is a funding programme created to support large-scale industrialisation, with up to £850 million of funding invested in developing a high-value end-to-end electrified automotive supply chain in the UK. The fund is highlighted as an important mechanism to support green industrial revolution and decarbonisation plans and provides an example of an extension to this policy recommendation for further consideration.

6.5 Actions to address difficulties accessing waste streams

6.5.1 Amendments to waste classifications

Purpose: To facilitate a greater volume of available critical mineral rich waste through more accurate identification.

Rationale: The current UK waste classifications have been identified by recycling stakeholders to be a barrier to expanding recycling in the UK. The current classification of materials during upstream processes means some useful minerals appear downstream as waste, and in some cases, benign waste is being classified as hazardous, leading to much higher landfill charges. This all results in an underrepresentation of supply to recycling firms and smaller waste streams going to UK recycling firms. In essence, these materials are not all waste.

National waste classifications should be updated to maximise critical mineral recovery and should specifically include WEEE and lithium-ion batteries. Legislation facilitating the classification and recycling of EV batteries and drive motors and magnets from wind turbines should be ready by EOL of first generation EVs and wind turbines from around 2030. Clear identification and sorting of scrap should be encouraged, to minimise the dilution of critical mineral content through mixing scrap, therefore maximising recovery [23]. At the end of vehicle or turbine life, component ownership should be established and the asset or components classified and segregated responsibly in readiness for recycling.

Many critical minerals are not currently covered by waste frameworks, such as The Waste Framework Directive. Therefore, a full review of classifications could ensure greater coverage and support greater access materials for recycling.

Description: A review of waste classifications of waste and scrap for secondary sources of critical materials for import, export and transportation purposes. Whilst this report highlights the example of lithium in WEEE, the review of classifications should be broader and in line with the UK recycling aspirations.

International comparison:

- **World bank**: Has produced the “what a waste” global database to record waste generation, composition, collection, and disposal by waste time and locality.
- **EU:** Regulatory changes stating that as of 2031 batteries must contain 16% cobalt, 6% lithium, and 6% nickel from recycled sources.

Policy alignment: Waste classifications are under the remit of the Department for Food and Rural Affairs (DEFRA). DEFRA publishes waste classifications and guidance, this includes waste classification codes for metallic waste (including iron, aluminium, and tin), as well as hazardous waste.

Ownership of actions:

- **DBT, DEFRA, and cabinet office:** Collaborate to amend critical mineral waste classifications to strongly align to critical mineral capability. Creation of supporting database.
- **DEFRA:** Update guidance where necessary.
- **CMIC:** Collaborate with industry and government to establish common data collection and reporting methodology for waste.
- **Industry bodies:** Communicate the changes to members

Potential costs	Potential benefits
▸ £360,000 to conduct investigation and engagement with all identified parties. ▸ This is based on a team of 2 full time equivalents over 3 years.	▸ Amendments to waste classifications will make critical mineral waste easier to recycle. This means a greater proportion of waste is recycled in the UK.

Risks and further research: Further research is needed to identify which materials and classifications could be classified differently for the industry to benefit, avoiding unintended consequence of inadvertently making trade of waste more difficult. The implications for other sectors will need to be considered alongside the frequency of future reviews.

Further research could consider the inclusion of critical minerals traceability, to enable safe and efficient dismantling and recycling as well as enabling proof of minimum recycled content in down-stream products that are placed on the UK marketplace. The EU are already taking proactive steps to adopt such changes in their regulations. For example, from 2030, in Europe, batteries will need to contain a minimum recycled content of 12% cobalt, 4% lithium and 85% lead; these values will be further increased by 2035. Further written evidence has been provided to UK Parliament by the CMA on the topic of waste classification for critical minerals, [75] highlighting the differentiators between UK and EU legislation. This written evidence also provides recommendations for UK legislation amendments should the UK wish to exploit opportunities in recycling and the circular economy.

6.5.2 Government procurement plan

Purpose: To provide certainty of forward demand for government procured critical minerals.

Rationale: The security of waste streams is hampered by an unclear end-of-life responsibility, and uncertainty relating to end product demand. Recycling stakeholders felt that unclear end-of-life responsibility created disputes of who is responsible for decommissioning and recycling of offshore infrastructure. These disputes create delays to recycling and reduce opportunities for UK industry.

Description: Government to publish a critical mineral procurement plan. This will detail the volumes of critical minerals due to be used in future public infrastructure and clearly designate end-of-life responsibility. The plan would need to detail demand specifics such as what minerals, grade, form, and the product being made.

This plan should cover major public infrastructure projects covering energy, defence, and civil developments. For example, HS2, GB Energy, Thames Tideway Tunnel, Hinkley Point C, and Lower Thames crossing. As well as track current and future public infrastructure (e.g. wind turbines) that are approaching end of life.

This procurement plan will provide a view of public sector demand for critical minerals which will provide demand certainty to the recycling sector. In addition, clearly designating end-of-life responsibility will help to secure the supply of waste as recycling arrangements have much clearer accountability.

Policy alignment: The DBT has published a steel procurement plan in 2024 and 2023. This plan laid out the governments steel procurement requirements over the next 10 years. The 2024 plan included steel requirements for HS2, Network Rail, nuclear decommissioning, and defence. The most recent procurement plan includes the volume and value of steel, country of origin and the UK's capability to produce the steel [131].

Ownership of actions:

- **DBT**: Collaborate with wider government to produce the plan.
- **Industry bodies:** Communicate the plan to wider industry and academia.
- **Large industry bodies:** Input into production projects and need for critical minerals into the procurement plan.

- **CMIC:** Establish common reporting for critical mineral quantities in public procurement. As well as working with DBT to forecast future mineral demand for infrastructure projects.

Potential costs	Potential benefits
Total cost of £300,000 (5 FTE) over 1 year to produce the plan.	A critical mineral procurement plan will provide certainty on mineral demand. This can improve investor confidence and stimulate investment. Designating clear end of life responsibility provides clearer quantity for different waste streams will increase investment in recycling. This is because returns on investment are clearer.

Risks and further research: A procurement plan will likely require continual maintenance. Careful consideration is needed to create a reliable source of future demands, that can be relied upon by industry. Further research could consider the extent to which a plan feeds into future procurement contracts.

Options to overcome this risk include publishing an updated procurement plan each year or including public sector procurement in the criticality assessment as part of the economic vulnerability calculation.

6.6 Actions to address negative public perceptions

6.6.1 Targeted school and university outreach

Purpose: To address issues of a negative perception of midstream processing as well as addressing skills gaps.

Rationale: The Institute of Materials, Minerals, and Mining (IOM3) express a growing skills gap in critical minerals, including mineral processing, and metallurgical skills. Engagement with stakeholders suggested a need to address upscaling to plant-level roles as part of education. There appears to be strengths in highly qualified R&D or PhD level scientists in laboratory research but are not encouraged to seek roles in large scale processing.

This is in part due to a negative perception of midstream processing, as well as an apparent reduction in academic opportunities. This results in an ageing workforce in the UK and a shortage of skills overall.

A more positive perception of the long-term future and security of the industry could encourage current students to enter the roles in this area.

Description: Government could facilitate collaboration between academia and industry to deliver targeted school university outreach in areas with local critical minerals capability to promote the sector and training opportunities.

This should include workshops, talks, demonstrations, and innovation challenges to advertise critical minerals to young people. Academia and colleges should focus the outreach on their courses and training opportunities. Materials science should also be included in wider STEM outreach and curriculum to ensure that it is included in wider government outreach. University outreach could help to encourage students already training in materials science, chemical engineering, geology, mining engineering into roles within the sector.

There are several existing outreach programmes across different industries. There is potential to consider partnering with existing advanced manufacturing, engineering, or STEM outreach programmes.

International comparisons:

- **Australia:** University of Adelaide runs school outreach programmes with a series of industry and government partners including BHP, who are a multinational mining company.
- **USA**: Colorado school of mines and West Virginia university deliver global outreach events and workshops across the USA and South America. Success is clearly communicated through a series of case studies.

Policy alignment: CMA and IOM3 already carry out outreach, but there is an opportunity to align this outreach with wider governmental messaging. In addition, the UK runs a green jobs initiative which helps to find young people jobs in the energy sector, this could be extended to incorporate critical minerals recycling.

Ownership of actions:

DBT: With support from the Department for Education, communicate the strategic needs to industry and academia.

DBT and wider government: Advertise events and direct industry to them. Set up a critical minerals trade show.

Industry bodies and academia: Provide the outreach.

Academia and colleges: Advertise their courses within wider STEM events.

Academia: Communicate success through news articles and case studies.

Potential costs	Potential benefits
£300,000 (1 FTE) for 5 years to coordinate the school outreach.	Targeted school outreach will provide a create awareness of the sector amongst younger people. This awareness combined with grater knowledge of training and academic opportunities will attract more workers into the sector. This will improve skill levels in the long term.

Risks and further research: School outreach will only produce benefits in the long-term, with limited immediate benefits realisation. To expedite some of the benefits engagement should be focused on regions with mining heritage or existing critical minerals capability. This helps to support jobs and training in the local community where opportunities can be acted upon much easier. Further research could identify target schools, universities and courses.

Further work could investigate coordinating with existing government outreach programmes.

6.6.2 Facilitate positive promotion of the midstream processing industry

Purpose: To change public attitudes, increase awareness of the importance of the critical minerals sector, and to encourage key skills into the sector.

Rationale: All midstream industry stakeholders felt that there was a negative perception of the industry. There is a perception that the industry is dirty and creates significant negative environmental impacts on local areas, this is in part driven by a perception of water, air, and soil pollution. This has made it difficult to attract talent.

Several companies publish promotional content with this aim (for example Cornish Lithium, CSM, Critical Productions, RSC, and the Natural History Museum). There is a role for government to facilitate industry wide collaboration, between companies and industry bodies.

Description: Government to coordinate collaboration between midstream processing companies and industry bodies to develop target marketing campaigns that promote a positive image of the sector. Campaigns could focus on popular areas of interest including environmental impact, use of new technologies, and the positive impact on other industries (e.g. automotive, aerospace, and renewable energy).

International comparison:

- **Belgium:** The Leuven institute for sustainable metals and minerals has produced documentaries and podcasts about responsible mining.
- **USA:** The university of Texas has produced a short film called "we are miners" to advertise their courses.
- **EU:** The European commission has a responsible mining charter and champions best practice in responsible mining to help address negative perceptions.

Policy alignment: There are several existing example within public sector organisations of targeted marketing campaigns promoting particular industries which focus on the surrounding environment of the sector and job roles. Notable examples include a Department for Education campaign 'Grow Like Only a Teacher Can', aiming to widen the appeal of the profession through showing that, as well as being an exciting, fulfilling career that will enable them to make a meaningful difference. And a Royal Navy campaign 'Made in the Royal Navy', which highlights positive aspects of the job role and environment.

Ownership of actions:

- **DBT:** Coordinate collaboration across the industry.
- **Industry and industry bodies:** Co-create and deliver marketing campaigns.
- **Academia:** Input to marketing materials with case studies and best practice.

Potential costs

- £90,000 to facilitate and coordinate industry level advertising campaigns to convey key messages over a continuous period.
- This would require some government time of approximately 0.5 FTE over 3 years.

Potential benefits

- Advertising the capability and benefits of midstream processing will increase the visibility of the sector. This could improve public perception and in turn help to attract workers and investment in the long term.

Risks and further research: This potential action places government in a facilitation and coordination role, not to directly fund marketing campaigns. Therefore, further research could consider the appetite for industry and industry bodies to support such initiatives.

6.7 Cross cutting actions

6.7.1 Centralised team to support planning and permitting

Purpose: To enable industry growth by supporting companies through planning and permitting processes.

Rationale: Planning permission can take up to 13-weeks, the need for environmental impact assessments means planning for critical mineral sites can often take longer [3]. If a decision is not made then companies can appeal, which again causes delays. Industry stakeholders felt that a lack of technical understanding on the part of planners led to a slower process and greater costs to business. The impact of a slow planning process means that critical mineral firms may miss out on commercial opportunities or access to markets.

Description: Creation of a team of 5 relationship managers located centrally. A relationship manager could be a single point of contact for critical minerals companies, with relevant expertise, focussed on guiding the company through planning and permitting processes across all government and local authority organisations.

The potential action could be initiated as a pilot, with one or two relationship managers for future scaling up as needed.

International comparison:

- **USA:** Primary metal production and refining included as a national critical sector.
- **Europe, Canada, and Australia**: Energy and transport sectors both deemed as national critical infrastructure. These sectors are reliant on minerals.
- **Canada:** Support is offered to companies by a centralised business manager in a critical minerals department
- **Australia:** Critical minerals planning is centralised to work through the local council on companies' behalf, as and 'enabler'.

Policy alignment: The UK already has a list of national critical infrastructure, which encompasses 13 sectors includes energy, chemicals, and water [132]. National critical infrastructure is defined in legislation as infrastructure the loss or compromise of which could have a major detrimental effect on the delivery of essential services and could result in significant economic impacts. Critical minerals developments are necessary to assure the supply of energy and chemical infrastructure and should therefore be deemed as national critical infrastructure.

Ownership of actions:

- **DBT:** Set up relationship managers to connect and engage with government organisations and local authorities. Engage with critical minerals industry to identify companies in need of support.
- **DBT, Environmental Agency, planning inspectorate, MHCLG and local government:** Collaborate to establish a streamlined approach to planning permissions and permitting.
- **Planning inspectorate**: Publish guidance to help industry make planning applications and recruit critical mineral specialists to oversee critical mineral developments.
- **Industry bodies:** Communicate changes and how it effects the industry.

Potential costs	Potential benefits
- £900,000 to deliver engagement and collaborate with local authorities. - This is based on 5 full time equivalents over 3 years to help develop the process.	- Streamlined planning means that pilot sites can become operational sooner. This results in greater access to markets and increased output for the UK.

Risks and further research: This action would sit closely with the suggested action to support collaboration with regional clusters. This could provide opportunities to pool resources, however, at this stage it is believed that separate initiatives for planning and permitting would best support the industry.

6.7.2 Centralised team to support collaboration with regional clusters

Purpose: To facilitate industrial symbiosis via exploiting waste from one organisation as feedstock in another, as well as providing services and labour pools for similar industries, streamlining transportation, supply chains and green energy development.

Rationale: Collaboration between the critical minerals industry and existing regional developments such as freeports, industrial clusters, and innovation parks would provide commercial opportunities to the critical minerals industry and capitalise on a perceived strength of the UK. Stakeholders felt there was an opportunity for industrial symbiosis through locating critical minerals companies close to their customer base. As well as locating recyclers close to their waste streams. For example, establishing a recycling site close to a wind farm to capitalise on the supply opportunity.

Critical minerals companies should benefit from the advantages of local green energy scheme, net zero hubs, and industrial clusters. Collaboration with regional developments can leverage development corporations to help streamline planning, as well as integrating critical minerals into local economic plans which will stimulate regional circular economy activity and allow for targeted regional activity.

Potential clusters to consider collaboration with include, South Wales and Tees Valley Industrial Clusters, both of which benefit from deep port access. A regional hub could be established in South West to support mining activities.

Description: Creation of a team of 5 relationship managers located centrally. A relationship manager could be a single point of contact for critical minerals companies focussed on guiding the company through government and local authority processes and identifying funding opportunities. Their responsibility could include collaborating with target clusters and the associated local authorities to support critical minerals companies take best advantage of opportunities such as local green energy scheme, net zero hubs, and industrial clusters.

The potential action could be initiated as a pilot, with one or two relationship managers for future scaling up as needed.

International comparison:

- Clusternet: The Iberian sustainable mining cluster is involved in the clusternet project which brings together clusters in habitats, renewable energy, mining, and equipment sectors [152].
- Lulea industrial park: Innovation Park in Sweden focusing on the processing of rare earth elements and phosphorus [153]. This is due to be the first innovation park solely focused on critical minerals.

Policy alignment: The UK has established a strong network of innovation catapults and clusters across a range of sectors. Similarly, since 2016 the Cities and Local government devolution act began the process of increased local devolution with the implementation of combined authorities who set local economic plans and strategic direction for their regions. Furthermore, the UK currently has freeports in Plymouth, Humber, and Teesside which provide direct opportunities for critical minerals production. The UK regional development landscape also includes enterprise zones and net zero technology centres.

Ownership of actions:

- **DBT:** Set up relationship managers to connect and engage with existing clusters, catapults, freeports, and local authorities. Engage with critical minerals industry to identify companies in need of support.
- **Local and devolved governments**: Incorporate critical mineral supply chains within local economic plans.
- **Industry bodies**: Publish an ecosystem map to help critical minerals firms to navigate the regional landscape.

- **UK Manufacturing industry:** Explore opportunities to engage with critical mineral suppliers and recyclers

Potential costs:	Potential benefits:
- £900,000 to deliver engagement and collaboration with all identified parties. - This is based on a team of 5 full time equivalents over 3 years.	- Location near to customers and waste suppliers provides potential greater access to linked supply chains and funding opportunities. Shared energy resources for closely situated businesses. - Industrial symbiosis via exploiting waste from one organisation as feedstock in another.

Risks and further research: DBT would need to work with other government departments including MHCLG, local authorities, and regional cluster partners to implement this policy. This action would sit closely with the suggested action to support planning and permitting. This could provide opportunities to pool resources, however, at this stage it is believed that separate initiatives for planning and permitting would best support the industry.

For this policy to be successful engagement must be targeted to ensure that the right opportunities are pursued. In the first instance engagement could build on existing relationships the DBT critical minerals team has with regional development, as well as aligning to sectors with the highest critical minerals demand (e.g. renewable energy and automotive).

6.7.3 International collaboration

Purpose: To provide wider opportunities to build capability, attract talent, and collaborate on research projects in both midstream processing and recycling. This would provide access to skills, commercialisation opportunities, and access to finance.

Rationale: Securing critical mineral supply chains is an active policy space for multiple countries, who are all working to expand their domestic capability. Stakeholders expressed that international collaboration would provide an opportunity to build capability, attract talent, and collaborate on research projects.

Description: Build partnerships with friendly nations. These partnerships should focus on knowledge transfer and demonstrating UK capability, providing opportunities for UK companies to collaborate internationally. This allows for greater learning as well as export potential. Potential collaborations indicated in this research include:

- With Western/EU countries to establish 'greener' and high ESG supply chains. Many companies are looking for opportunities to move away from Chinese or Russian supplied minerals and their processing industries.
- While Australia and Canada are leading in extraction of critical minerals in the Western world, with the USA following, little has been done to set up an alternative midstream, resulting in many critical minerals extracted in the Western world being shipped to China for refining. Therefore, there are opportunities to work with Australia and Canada to supply midstream services.
- Canada has strengths in the classification, segregation and recycling of WEEE which provides opportunities to partner with Canadian companies to establish their operations in the UK.
- Similarly, Canadian companies have expertise in operating plants for EV battery recycle and minor metal recovery. With the right incentives, they could be persuaded to establish midstream operations in the UK, or to cooperate with UK partners.

International comparison:

- **Minerals security partnership:** Collaboration between Australia, Canada, Estonia, Finland, France, Germany, India, Italy, Japan, Norway, the Republic of Korea, Sweden, the United Kingdom, the United States, and the European Union (represented by the European Commission). The aim of the partnership is to secure supply chains.
- **Horizon Europe:** Funding scheme run by the European commission which encourages international collaboration. Horizon 2020 offers funding for circular economy projects.

Policy alignment: The UK is already very actively collaborating with international partners. This includes the UK being a member of the Minerals security partnership. The UK also has in bilateral engagements with India, Canada, and Australia.

Ownership of actions:

- **DBT and FCDO:** Lead on diplomatic missions to build international partnerships.
- **Devolved governments:** Use trade envoys and representatives to promote their nations critical minerals capability overseas and negotiate memorandums of understanding or trade deals.
- **DBT and innovate UK:** Collaborate with international partners to establish joint efforts for R&D with international collaboration.
- **Industry bodies:** Explore opportunities to collaborate with overseas industry bodies to demonstrate UK capability and Publish thought leadership on UK capability and thought leadership from international partners.
- **Industry bodies and investment community:** Produce an ecosystem map and horizon scan to communicate what capabilities exist in other countries.
- **Academia:** Participate in knowledge sharing platforms such as the Critical minerals technical community. Explore opportunities for global outreach and recruitment

Potential costs	Potential benefits
Total cost of £900,000 over 5 years. This includes 3 FTE per year.	International collaboration provides more opportunities for knowledge transfer and research. This will improve UK capability and drive business growth.

Risks and further research: International collaboration must focus on demonstrating UK capability and facilitating knowledge sharing between countries. This requires targeted engagement to understand mutual benefits of partnerships to boost UK capability.

Whilst this research has identified possible areas of interest for collaboration, further research could explore the feasibility and prioritise potential actions.

7 Economic impact of Government intervention

A cost-benefit analysis has been carried out on four shortlisted potential actions. This section provides results of economic modelling to determine which of the highest priority potential actions present the best return on investment from the point of view of the UK government.

To estimate the potential economic benefit of government interventions, econometric estimation is combined with economic impact analysis. The approach makes use of UK mineral production, export, and import data from the British Geological Survey and economic data from the Office for National Statistics. The potential rough order of magnitude cost of implementing each action is estimated by considering the labour cost of administration and comparison to costs of similar policies, full calculations are detailed in Annex A4.2.

The potential additional benefit each policy may have to the industry is presented in terms of estimated additional mineral production, the resulting additional GVA created, and corresponding jobs supported.

Return on investment (ROI) is calculated as the additional GVA contribution divided by ROM cost. An ROI greater than 1 means the benefits exceed the costs. All priority policies are estimated to produce positive returns to the industry from the government intervention. The greatest potential return on investment is seen in a policy to support businesses with planning and permitting processes. Bringing future planned production capability forwards by just a year provides economic value that outweighs the administration costs. The range of ROI presented below a represents the variety of benefits seen for different possible future states, accommodating for uncertainties surrounding successful uptake of interventions.

	Estimated potential return on investment (ROI) of the high priority policies:	**ROI:**
1.	Grant funding for innovation in recycling and midstream capability	2.02 - 2.48
2.	Centralised team to support planning and permitting	0.78 - 2.78
3.	Extension of the existing energy bill relief scheme	2.01 - 2.47
	Or a new energy bill relief scheme tailored to critical minerals	1.07 - 1.40
4.	Centralised team to support collaboration with regional clusters	0.72 - 1.43

7.1 Approach to estimating economic benefits

Model scope: Data are available for UK production, export, and import from the British Geological Survey's 2023 Minerals Yearbook [38]. Economic modelling is constrained by the available data, focussing on the following minerals:

- Aluminium
- Lithium
- Zinc
- Phosphorus
- Titanium
- Tin
- Graphite
- Cobalt
- REEs
- Sodium compounds
- Nickel
- Platinum

Production forecast: UK critical mineral production has been forecasted using an autoregression integrated moving average (ARIMA) model. The forecasting model utilises critical mineral production and import data from the British Geological Survey, as well as control variables including energy prices, multi-factor productivity, and sector level growth. The ARIMA model uses historical variations in the data to forecast forward the likely critical mineral production values. The approach predicts only one period forward at a time to 2035, assuming no previously unseen shocks to the market occur. This provides a likely baseline of future UK production, from which the impact of policy changes is estimated.

Economic impact: Economic multiplier analysis has been used to calculate impacts on the industry gross value added (GVA) and employment generated as a result of new critical mineral production. This approach uses economic multipliers from the ONS input-output tables to generate the direct, indirect, and induced impact of spending from critical minerals production activity.

Additionality: The difference between the forecasted production following the policy intervention and the baseline forecast is considered as additional to the industry. The baseline forecast acts as a counterfactual case where the policy is not implemented. All GVA, production, and employment results are presented as net additional to the critical minerals industry. However, the approach does not consider the possibility that additional resources used may come from other areas of the UK economy.

A full description of the approach is provided in Annex A.5.

7.2 Energy cost relief schemes

Policy description: The proposed policies both address energy costs, though through different mechanisms:

New energy bill relief scheme tailored to the critical minerals supply chain aims to address the high electricity costs faced by the UK's critical minerals sector by introducing an energy bill relief scheme specifically for this industry. The scheme would allow companies to recover up to 70% of their energy costs, with eligibility based on actual and planned mineral production. Funding would be contingent on companies obtaining ISO50001 certification or committing to reduce electricity consumption relative to profits.

Extension of the Energy Intensive Industries support scheme aims to extend the energy intensive industry exemption scheme to cover a greater number of industries, including disposal of waste. This could provide a greater coverage of the critical minerals industry but not as complete as a new scheme.

Potential policy outcomes: The policy is designed to directly allow firms to recoup energy costs, reducing their operational costs overall. Companies could recover up to 30% of their energy costs. This is designed to enhance the competitiveness of UK firms, promote business growth, and increase output, while supporting the retention of critical minerals activities within the UK, and also encouraging long-term reductions in energy intensity.

Economic impact results: Table 19 outlines the estimated costs of the proposed policy to the UK government and the potential increase in UK critical mineral production, along with the associated economic benefits.

Table 19 - Cost benefit analysis of energy cost relief schemes

Policy	Estimated cost	Estimated additional UK mineral production	Estimated cumulative additional GVA by 2035	Job-years supported	ROI
New relief bill	£1.5 billion	5.9m – 7.2m tonnes	£1.6b – £2.1b	36k – 44k	1.07 – 1.4
Extension of EII	£390m	2.0m – 2.5m tonnes	£787m – £967m	18k – 22k	2.01 – 2.47

A new relief bill delivers a higher estimated potential benefit to the industry, due to the increased scope of industries covered by the scheme. This could have an impact of up to £2.1 billion of GVA impact by 2035, supporting up to 44,000 job-years (a job supported for one year), against a cost of £1.5 billion. An extension to the existing scheme could provide up to £967 million in economic benefits by 2035, supporting 22,000 jobs, against a £390 million overall cost. Where a new relief bill can recover up to 70% of energy costs for critical minerals companies, an extending the existing scheme is estimated to recover only up to 30%.

Figure 23 and Figure 24 show the potential forecasted impact on UK mineral production to 2035. The range in estimates are account for potential uncertainties around the uptake of the scheme and associated costs. Figure 25 and Figure 26 show the potential forecasted impact on the economy up to 2035.

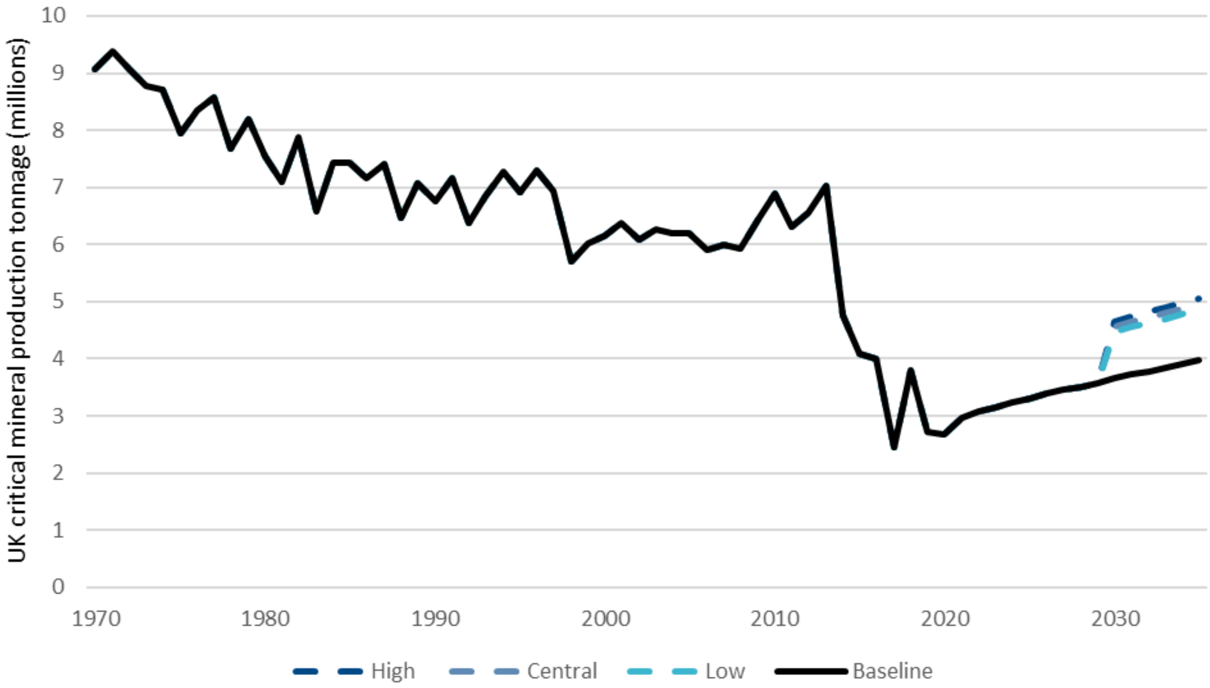

Figure 23 - New energy bill relief scheme UK mineral production impact

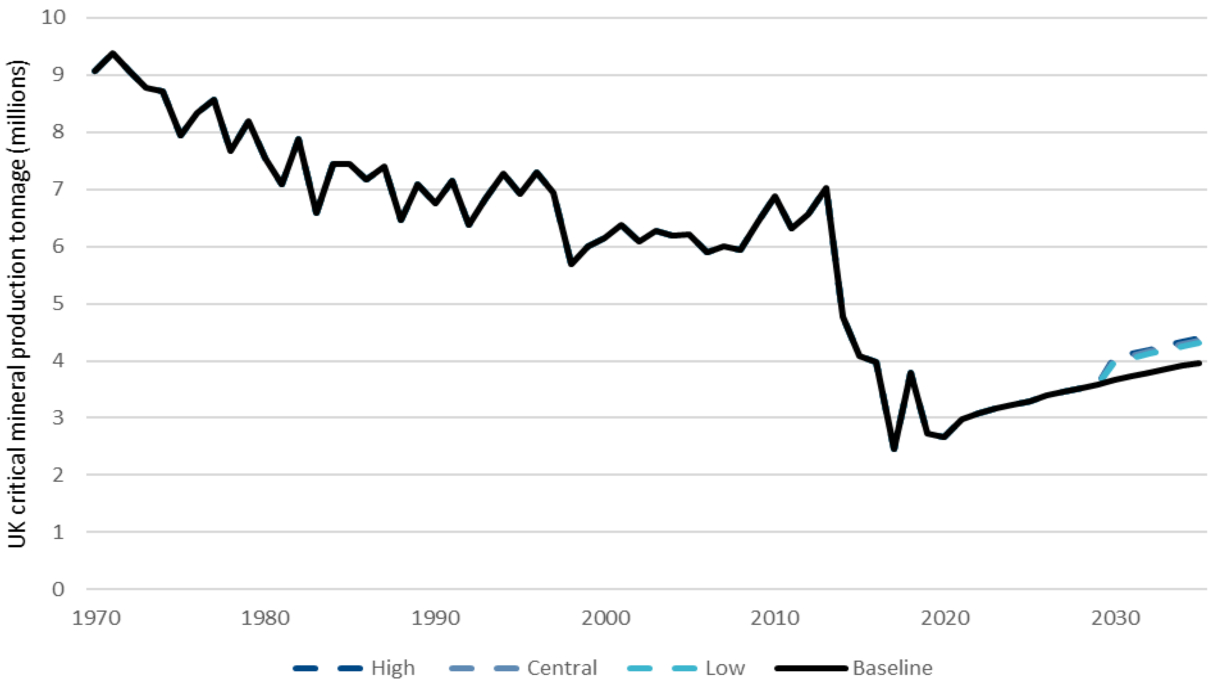

Figure 24 - Extension of the Energy Intensive Industries support scheme UK mineral production impact

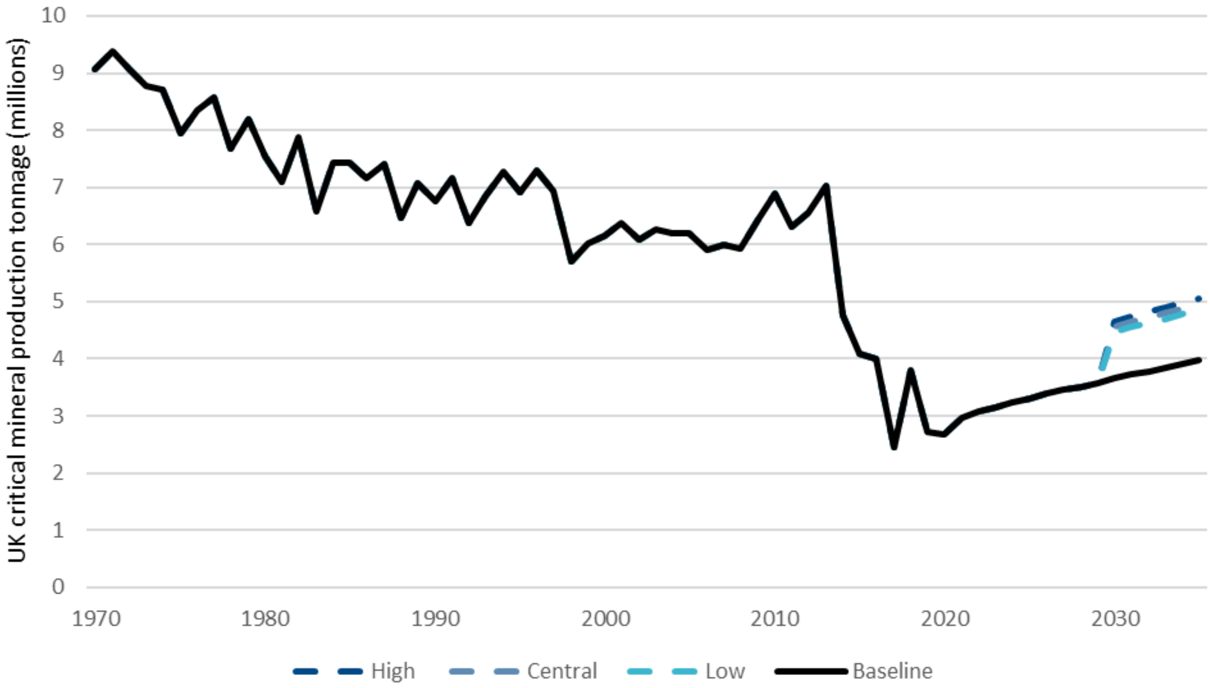

Figure 25 - New energy bill relief scheme UK mineral production impact

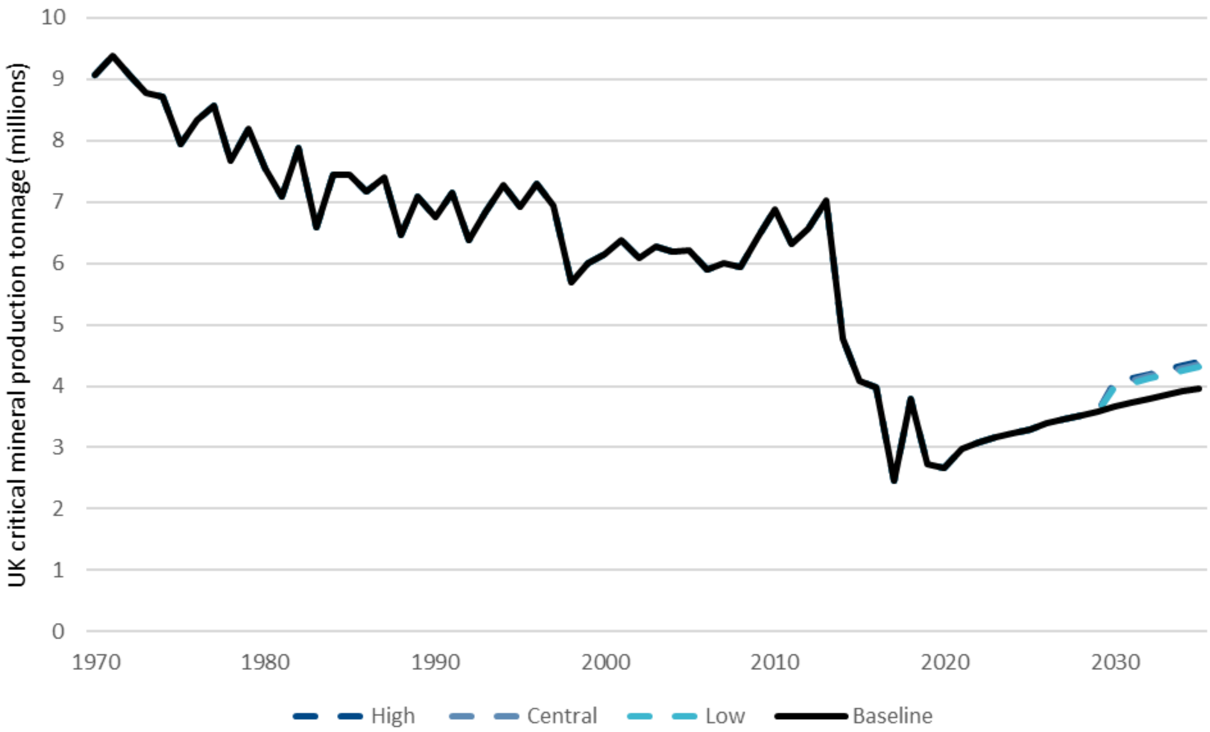

Figure 26 - Extension of the Energy Intensive Industries support scheme UK mineral production impact

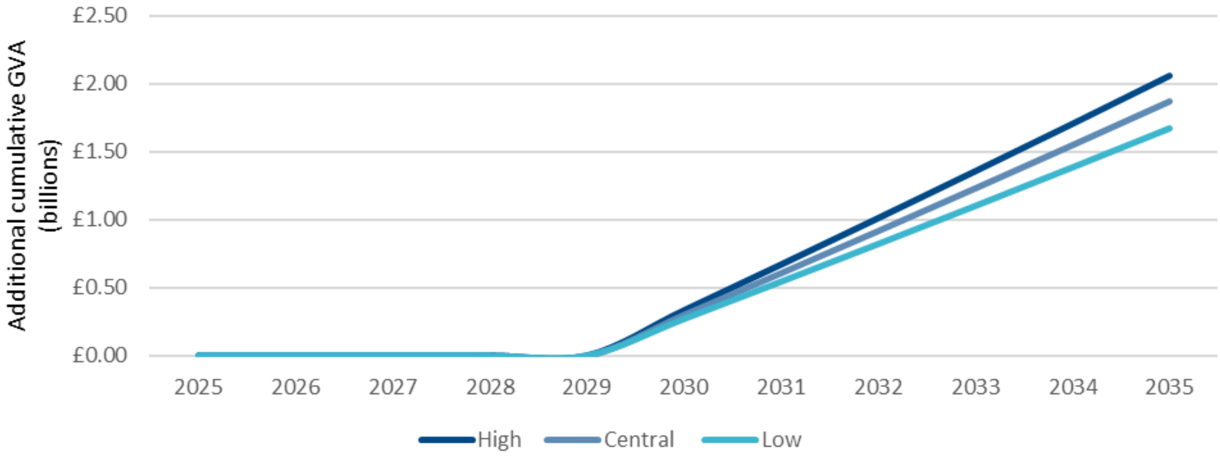

Figure 27 - Additional cumulative GVA generated by a new relief scheme

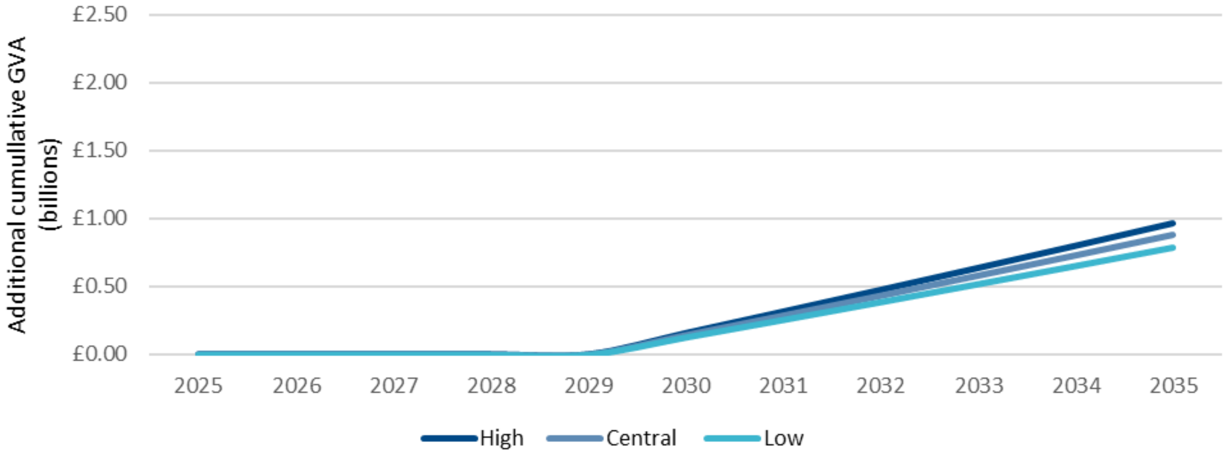

Figure 28 - Additional cumulative GVA generated by extending existing schemes

Whilst a new scheme is estimated to provide a great impact on more energy-intensive minerals, results indicate that extending the existing scheme could potentially provide a greater return on investment. This is because extending the scheme is more likely to include the highest energy uses, broadening the reach of companies with a new bill could include those with lower energy costs.

Recommendation: Both policies can provide a positive return on investment, with an extension of the Energy Intensive Industries support scheme providing a higher ROI. They are both expensive policies but extending the existing scheme may be easier to implement. Both should be explored, in conjunction with policies incentivising innovation and technological advancement to ensure that the saved costs do not mask declines in productivity.

7.3 Grant funding for innovation in recycling and midstream capability

Policy description: Critical minerals focused grant funding aims to assist the development and commercialisation of new technologies and processes in the industry. This addresses an issue many stakeholders face in accessing funding and finance. £50 million of matched industry funding would be made available by DBT and Innovate UK.

Potential policy outcomes: This new funding stream has the potential to drive innovation and technological advancements. This could lead to increased productivity and energy efficiency as new processes are implemented. A 3% decrease in energy prices, and a 12.5 – 35.5% increase in recycling rates was estimated and modelled to inform the economic impact assessment.

Economic impact results: Table 20 outlines the estimated costs of the proposed policy to the UK government and the potential increase in UK critical mineral production, along with the associated economic benefits. Detailed information on the modelling approach is provided in Annex A.5.

Table 20 - Cost benefit analysis of grant funding

Estimated cost	Estimated additional UK mineral production	Estimated cumulative additional GVA by 2035	Job-years supported	ROI
£50 million	307,242 – 377,150 tonnes	£100.8m – £123.8m	2,149 – 2,640	2.02 – 2.48

The size of the funding can be adjusted with relative ease, depending on financial constraints. Due to the positive ROI, any additional funding will produce a greater increase in GVA and number of jobs years. There are additional factors which have not been incorporated into the economic modelling that would improve the ROI from the funding. The primary factor is the positive impact the policy will have on investor confidence and therefore increase private investment in the sector. This will lead to an additional stimulus in GVA, job-years and UK mineral production. Improvements to the effectiveness of the policy can also be made if there is coordination with other funding schemes in related sectors.

Figure 29 shows the additional economic value generated by the policy over time, compared to the baseline where this policy was not implemented. The different impacts of the high, central, and low scenarios are more apparent here, highlighting the difference in economic value even small changes in the quantities of minerals produced can have over time.

These results are primarily driven by production of aluminium, nickel, titanium, and sodium compounds, and the recycling of iron products, platinum, nickel, and zinc. Recycling rates for each were sourced from the CMIC criticality assessment, with a flat percentage increase applied to each mineral's recycling rate. However, in practice, minerals may not experience the same productivity gains from this policy. Minerals with more emerging technologies like lithium would likely see greater increases to the productivity of their recycling activities with innovation funding, than metals like iron and aluminium where processes are well established.

The same is true in terms of energy efficiency, in that more energy-intensive minerals would see a greater benefit from energy efficient technologies.

Recommendation: This policy has potential to provide a positive ROI as a result of improved productivity from new technologies. The scale of benefits will be dependent on how the scheme is implemented and targeted. This may rely on the level of matched funding available, and the proportion of cost contribution required by industry. In addition, the scheme must be carefully designed around areas of existing strength and opportunity in the UK and focus on technologies with clear benefit to industry. Further exploration with relevant stakeholders may help provide clarity on its technological potential, as well as scope the interest in greater investment through matched funding in the UK critical minerals sector.

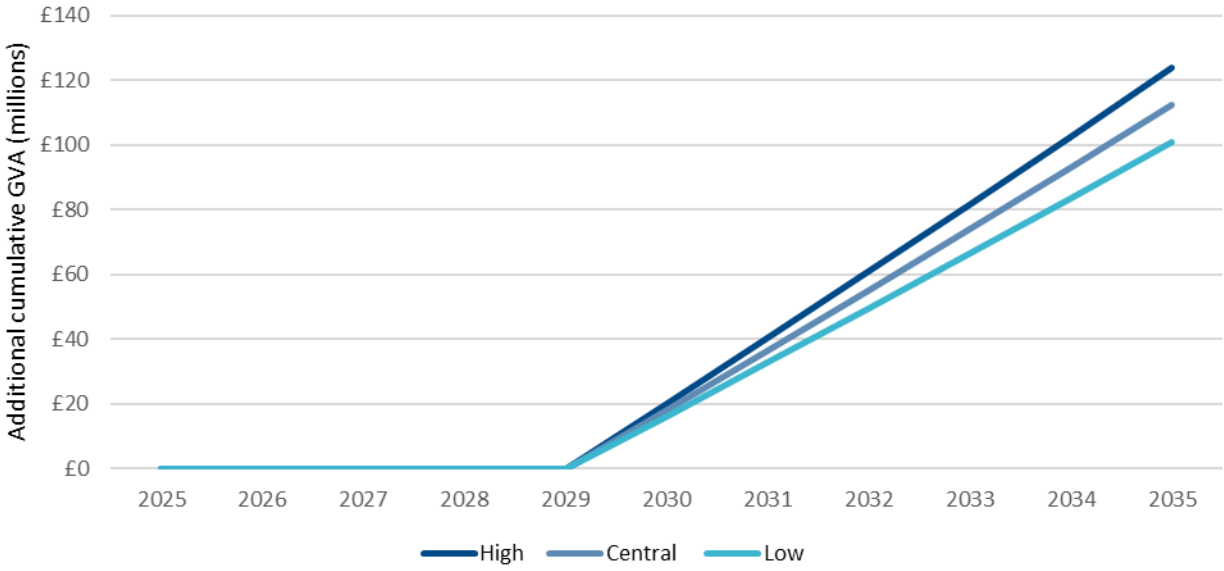

Figure 29 - Additional cumulative GVA generated by 6.3 Grant funding for innovation in recycling and midstream capability

7.4 Centralised team to support collaboration with regional clusters

Policy description: The proposed policy seeks to enhance the commercial opportunities for the critical minerals industry by fostering collaboration with regional developments such as freeports, industrial clusters, and innovation parks. By strategically locating critical minerals companies near their customer base and recyclers close to waste streams, the policy aims to achieve industrial symbiosis, boosting productivity and market access. With an estimated resource cost of £900,000 over three years, the policy aligns with local economic plans and devolution efforts, delivering integration into regional circular economy activities.

Policy outcomes: By fostering collaboration with critical minerals companies and potential customers and suppliers, the industry can increase access to waste streams. This will allow for a greater proportion of output in the UK to be recycled. This will be supported by more aligned commercial opportunities, securing a stable ecosystem of regional hubs, encouraging further efforts to limit waste disposal and or exports. The key impact therefore is an increase in the recycling rate of each critical mineral, modelled as a 50, 75, and 100% increase in recycling rates.

Economic impact results: Table 21 outlines the estimated costs of the proposed policy to the UK government and the potential increase in UK critical mineral production, along with the associated economic benefits. Detailed information on the modelling approach is provided in Annex A.5.

Table 21 - Cost benefit analysis of collaboration with existing development schemes

Estimated cost	Estimated additional UK mineral production	Estimated cumulative additional GVA by 2035	Job-years supported	ROI
£900,000	812,900 – 813,400 tonnes	£645,000 – £1.3m	14 – 28	0.72 – 1.43

The potential impact on UK mineral production is a result of an increased recycling rate applied against UK waste exports, implemented in 2026 with the engagement of critical minerals and waste companies. This increased rate is only applied to a proportion of UK production, resulting in increases in production between 812,900 and 813,400 tonnes. This contributes to a GVA impact between £645,000 and £1.3 million, supporting up to 28 job-years. This GVA impact is illustrated in Figure 28, demonstrating the cumulative GVA generated over the forecasted period compared to the baseline.

The resultant return on investment is then between 0.72 and 1.43, representing a risk that the policy is ineffective. However, an informed, targeted and effective engagement of the appropriate stakeholders may help mitigate this risk. This result also does not account for the reuse of recycled material in the circular economy, and its potential value there, only valuing the waste exports avoided, which are of much lower value than the recycled content. The potential for commercial opportunities between recyclers and consumers is therefore not captured in the economic benefit of this policy.

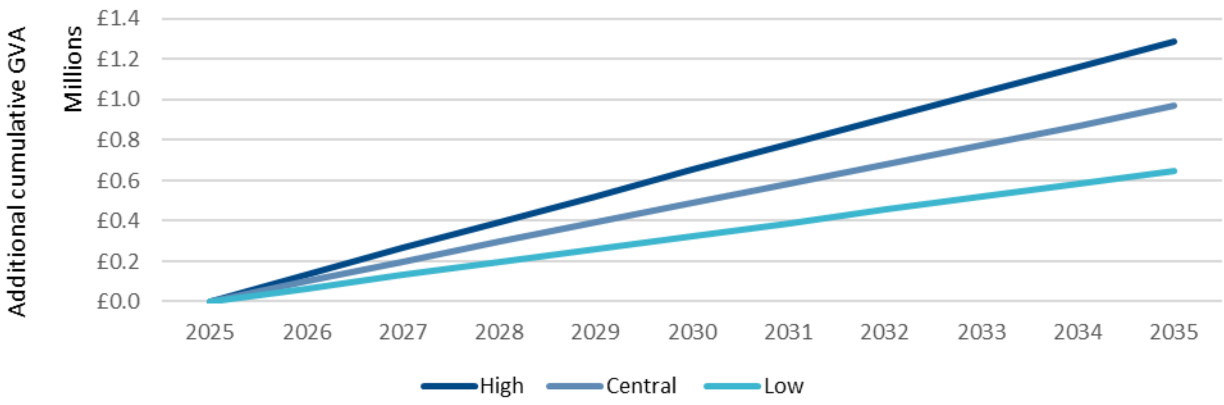

Figure 30 - Additional GVA created by policy 4

Recommendation: Collaboration with existing regional developments and clusters presents an opportunity to develop new commercial relationships between critical minerals companies and potential customers and suppliers, with the impact of increasing recycling rates. This policy can represent value for money, and address difficulties accessing waste streams, however, may not directly address challenges related to energy costs, so should be considered alongside other options. The policy is an opportunity to foster relationships between industry and government, furthering collaboration between sectors and contributing to a holistic approach.

7.5 Centralised team to support planning and permitting

Policy description: The proposed policy aims to streamline the planning and permitting process for critical minerals firms in the UK. The policy addresses concerns from industry stakeholders about the slow planning process, which can hinder market access and business growth.

Potential policy outcomes: By collaborating with local authorities and providing clear guidance, the policy seeks to balance economic security with environmental and community considerations. A streamlined planning process reduces the time lost due to planning delays and contributes towards more informed planning. This allows for critical mineral mining, refining, and recycling operations to be approved sooner, and become operational sooner. Overall, this allows new developments to commercialise quicker and take advantage of new opportunities. The key output of this policy is increased production from new refining and recycling sites.

Economic impact results: Table 22 outlines the estimated costs of the proposed policy to the UK government and the potential increase in UK critical mineral production, along with the associated economic benefits. Detailed information on the modelling approach is provided in Annex A.5.

Table 22 - Cost benefit analysis of streamlined planning

Estimated cost	Estimated additional UK mineral production	Estimated cumulative additional GVA by 2035	Job-years supported	ROI
£900,000	2,519 - 8,400 tonnes	£0.7m - £ 2.5m	16 - 54	0.78 – 2.78

The impact on tonnage is related to planned sites becoming operational sooner than anticipated. As a result, the impact on tonnage is small compared to the other policy options, with the increased in production ranging from 2,519 tonnes to 8,400 tonnes. This contributes to a smaller GVA impact than grant funding and energy price relief, with additional GVA contribution ranging from £0.7m to £2.5m. The ROI ranges from 0.78 – 2.78 this policy representing potential value for money to the UK government. The additional GVA contribution is shown in Figure 31, with the policy beginning in 2028, the graph demonstrates the difference between streamlined planning which allows for larger sites to become operational ahead of schedule. The low scenario represents 30% of planned activity becoming operational, the central represents 70%, and the high represent all planned activity being brought forward to 2028.

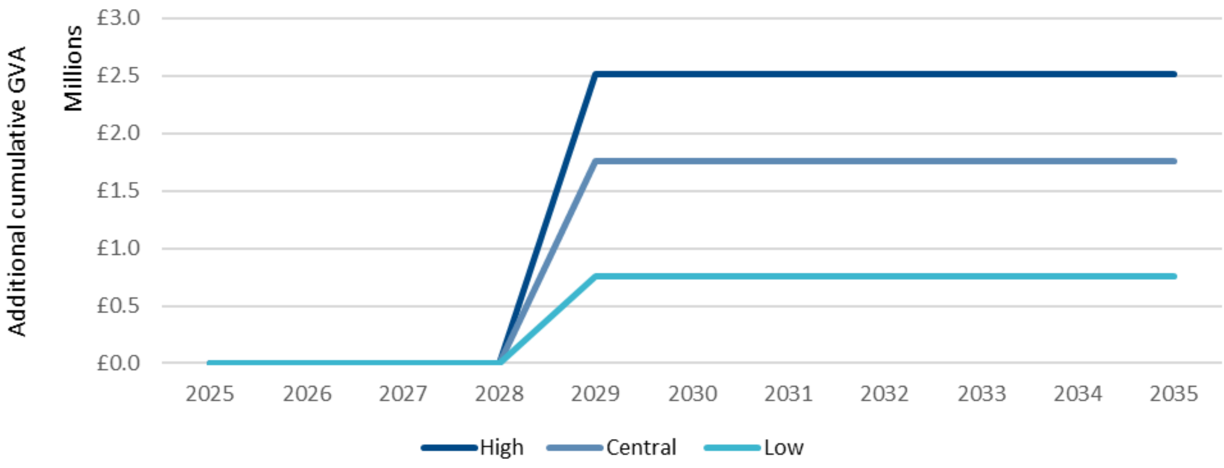

Figure 31 - Additional cumulative GVA generated by Policy 3

Recommendation: Streamlined planning processes and designating critical mineral support allows for the UK to bring new capabilities into operation sooner, as well as allowing quicker scale up of operations. This policy represents good value for money and helps to address some commercialisation challenges. However, this will not overcome challenges around energy costs or accessing finance, so should be considered alongside other policy options. Streamlined planned can help to exploit the innovative capability developed through the UK's strength in research and innovation

8 Concluding statement

This capability assessment has used a mixed methods approach to assess the current capability, barriers to growth, and opportunities for development for the UK's critical mineral midstream processing, and recycling and recovery capabilities. This has utilised a literature review, stakeholder interviews, and econometric modelling to establish a set of 12 policy recommendations to address the key market failures in the critical minerals market.

8.1 Current capability

The literature review has provided an assessment of the UK's current capability in midstream processing and recycling. Overall, the UK has competitive strengths in PGM refining and recycling, as well as REEs refining. However, the UK has limited capability and influence across other critical minerals at present, including lithium, nickel, and cobalt. These capabilities are currently being developed but face barriers including access to finance, energy costs, and planning permissions. The strengths and weakness of the UK's critical minerals industry are summarised below :

UK weaknesses

- The UK's midstream refining capability is more limited outside of platinum and rare earth elements. There are gaps in midstream processing and limited capability for critical minerals relating to battery technology (e.g. nickel, lithium, and cobalt).
- Most UK recycling operations are still at the pilot stage and not yet operational.
- The UK has some of the highest energy costs in Europe, rendering part of the industry as less competitive compared to international companies.
- Access to finance and commercial opportunities means the UK can often not translate innovation into capability.
- The UK lacks mineral processing skills which undermines developing capability.

UK strengths

- The UK has a strong heritage in mining but is not currently active in production-level mining of critical minerals.
- The UK has an excellent reputation for research and development, as well as strengths in higher education institutions.
- World leading and highly competitive capability in platinum, nickel and graphite refining and rare earth elements.
- The tertiary sector and financial markets are a competitive strength for the Uk compared to the rest of the world. There is opportunity to direct this capability towards mining and recycling.

8.2 Barriers to growth

The barriers to growth were principally explored through stakeholder interviews. A barrier represents a contributor to a negative change or a factor that prevents change. The barriers largely fit into the four problem statements expressed below, which impact the economic viability of critical minerals operations, as well as obstructing scalability. Government intervention must seek to overcome these barriers to encourage investment and talent into the sector, as well as support critical minerals firms to commercialise new technology and scale at pace. Addressing these barriers provides opportunities to exploit new technologies and improve global competitiveness. This is required to realise a positive vision of the future where the UK leads in critical minerals processing and recycling.

The key barriers to the growth of the UK critical minerals can be defined in four problem statements:

- UK energy costs are too high for the UK critical minerals to be competitive with the rest of the world.
- The UK critical minerals industry struggles to access sufficient finance to scale its operations.
- There is a negative perception of mining and midstream processing which deters investment and talent.
- Difficulty accessing waste streams means there is not a secure supply of waste to UK operations.

8.3 Policy recommendations to realise a positive future

The barriers outlined above create a series of market failures that prevents the critical minerals industry in the UK from realising its potential. Government intervention is required to improve the competitiveness, viability, and scalability of the critical minerals industry. This report provides a set of policy recommendations to overcome the key barriers to the sector. The four highest priority policies have been carried forward for economic modelling and provide a potential positive return on investment (ROI) for the UK economy.

High energy costs

- **Priority 3**: An extension of existing energy intensive industries scheme to cover critical minerals.
  Potential ROI: 2.01 – 2.47
- Or alternatively, a new energy bill relief scheme tailored to critical minerals.
  Potential ROI: 1.07 - 1.40

Difficulties in accessing finance

- **Priority 2**: Matched grant funding to support and de-risk investment in research and innovation that develops midstream and recycling capability.
  Potential ROI: 2.02 - 2.48

Difficulties accessing waste streams

- **Priority 5:** Amendments to waste classifications.
- **Priority 7:** Publish a critical minerals procurement plan.

Negative public perceptions

- **Priority 8**: Targeted school and university outreach.
- **Priority 9**: Facilitate positive promotion of midstream processing industry.

Cross cutting actions

- **Priority 1**: Centralised support for planning and permitting. **Potential ROI: 0.78 - 2.78**
- **Priority 4**: Centralised support to collaborate with regional clusters. **Potential ROI: 0.72 - 1.43**
- **Priority 6**: Collaborate with international partners to transfer knowledge.

8.4 Next steps

Informed by literature and stakeholder engagement, the recommendations presented in this report suggest areas of focus to inform and future policy development. All recommendation will require further research and consideration as part of development, the suggested next steps include:

- **Relief for operating costs, beyond energy:** Several companies in the supply chain don't own mining assets and operate mainly as net importers to the UK. These companies still have a high cost base, through other inputs such as high labour costs, but would potential not benefit from energy cost relate support. There is an opportunity to consider shaping energy relief schemes to include a broader range of operating costs.
- **Greater level of funding to bring capabilities to operational level:** Funding the development of pilot capabilities to move technology readiness levels and develop skills was considered of key value. Further research could consider greater funding levels and focus on higher technology readiness levels. The Automotive Transformation Fund provides an example of a large industrial programme that could provide the basis for considering the level of funding.
- **Identifying waste classification amendments:** Further research is needed to identify which materials and classifications could be amended for the industry to benefit, avoiding unintended consequence of inadvertently making trade of waste more difficult. The implications for other sectors will need to be considered alongside the frequency of future reviews.
- **Traceability:** Further research could consider the inclusion of critical minerals traceability, to enable safe and efficient dismantling and recycling as well as enabling proof of minimum recycled content in down-stream products that are placed on the UK marketplace.
- **Coordinating with existing STEM outreach programmes:** Further work could investigate coordinating with existing government outreach programmes.
- **Appetite to fund marketing campaigns:** The recommendation to undertake targeted marketing campaigns places government in a facilitation and coordination role, not to directly fund marketing campaigns. Therefore, further research could consider the appetite for industry and industry bodies to support such initiatives.
- **Prioritise international collaboration opportunities:** Focus on demonstrating UK capability and facilitating knowledge sharing between countries. This requires targeted engagement to understand mutual benefits of partnerships to boost UK capability. Whilst this research has identified possible areas of interest for collaboration, further research could explore the feasibility and prioritise potential actions.
- **Focus on particular minerals:** The evidence gathered in this report provided arguments for either a focus on expanding UK industries that currently exist (section 2) combined with developing international collaboration, or alternatively, diversifying the UK's capability and entering new markets (section 4). No clear prioritisation of particular critical minerals emerged from this evidence, presenting an opportunity for further research in the following areas:
  - The UK has strong capability in rare earth element and PGM refinement and recovery; however these are relatively small scale. Further research could consider investment into the circular economy and subsequent up-scaling of these industries.
  - The current UK capabilities for processing Li-ion batteries is not internationally competitive but there are plans to significantly expand infrastructure in the coming years. The key limitation in this area is the capability for separating the black mass, which is currently exported. Further research could consider developing a sovereign capability to refine black mass.
  - Iron alloy and ferrous scrap recycling is effective in the UK but a significant amount of this waste is exported. It's important to investigate whether there is additional capacity in the UK's steel and iron recycling facilities (such as electric arc furnaces) to recycle more of this waste domestically and reduce exports.

Annex A - Support material and methodology

A.1 Table of Critical Minerals

A complete list of the 34 critical minerals, designated by CMIC, is shown Table 23 along with a summary of their main global industry uses. This table shows the criticality score of each mineral, the main end-use applications and the UK consumption index. Source: CMIC

Table 23 - CMIC's list of 34 critical minerals as of 2024 [1]

Mineral	Criticality (higher value = more critical)	Largest Global Industries	UK Consumption (Higher value = higher use)
Aluminium (Al)	4.2	Construction (25%), transportation (23%)	7.1
Antimony (Sb)	4.5	Flame retardants (50%), batteries (35%)	3.7
Bismuth (Bi)	4.5	Chemicals (62%), alloying (28%)	1.9
Borates	4.5	Insulation and ceramics (35%), agriculture (13%)	4.4
Cobalt (Co)	6.4	EV and portable batteries (70%)	5.3
Gallium (Ga)	5.3	Semiconductors and LEDs (88%)	1.0
Germanium (Ge)	6.0	Infrared and fibre optics (50%)	2.1
Hafnium (Hf)	4.1	Superalloys (45%)	1.9
Helium (He)	4.0	MRI scanners (30%), science and cryogenics (14%)	3.7
Indium (In)	5.3	Flat panel displays (56%)	5.8
Iridium (Ir)	4.3	Electrochemical (46%)	1.9
Iron (Fe)	5.0	Steel (98%)	7.6
Lithium (Li)	4.8	EV and portable Batteries (65%)	7.6
Magnesite	4.7	Steel making (57%), agriculture (14%)	4.6
Magnesium (Mg)	4.4	Al alloys and die castings (74%)	3.7
Manganese (Mn)	5.8	Steel (88%)	4.4
Natural graphite (C)	4.0	Batteries (52%), refractories (24%)	5.5
Nickel (Ni)	4.3	Stainless steel (65%), batteries (17%)	6.3
Niobium (Nb)	6.6	Alloying (83%)	4.8
Phosphorus (P)	5.8	Fertilizer (82%)	6.5
Platinum (Pt)	4.6	Automotive (43%), jewellery (18%)	1.0
Rare earth elements (REEs)	6.2	Magnets (44.3%), catalysts (17%)	3.5
Rhenium (Re)	4.2	Superalloys (70%)	1.0
Rhodium (Rh)	5.3	Automotive (88%)	1.0
Ruthenium (Ru)	5.6	Chemical (46%), electrical (29%)	1.0
Silicon (Si)	5.3	Alloying (41%), Silicones and silanes (35%)	6.6
Sodium (Na) compounds	4.3	Chemical synthesis (72%)	5.7
Tantalum (Ta)	4.3	Capacitors (33%), superalloys (22%)	3.3
Tellurium (Te)	4.4	Solar power (40%), thermo-electrics (30%)	1.9
Tin (Sn)	4.5	Solder (48%), chemicals (17%)	5.7
Titanium (Ti)	4.7	Paints (54%), polymers (24%)	6.4

Mineral	Criticality (higher value = more critical)	Largest Global Industries	UK Consumption (Higher value = higher use)
Tungsten (W)	5.4	Tungsten carbide products (65%)	4.6
Vanadium (V)	5.2	Steel (91%)	4.2
Zinc (Zn)	4.0	Steel galvanizing (60%), alloying (13%)	6.6

A.2 Existing technical capability

A.2.1 Approach

Table 24 provides a summary of the UK Critical Raw Materials (CRM) sectors and technology types within them. Also included are indications if the input materials are primary (mined and refined) or secondary (recycled and refined).

The starting point was the CMIC interactive map covering mineral processing, refining, recycling and associated activities [19]. Activities that were on the map but not part of the UK's Critical Raw Materials (CRM) list were excluded, e.g. Gold, Silver, Copper, Lead; unless co-products included a UK identified CRM. Steel production and recycling was not included. Companies needed to be in active production or recycling activities in the UK, even if only semi-processed in the UK. Companies that were found to be out of business were also excluded; however, planned mining was included.

This map was originally accessed on the 16th of January 2025, since then an additional 18 companies were added to the map and have been included. Other companies were identified through business knowledge and interactions with the CMA. A total of 101 companies were reviewed for the summary table of which 82 are included. These companies are not expected to be a complete list of the UK based companies in the areas reviewed, just the ones identified in the time frame of the review.

The companies identified, once found to be in scope of UK CRMs were then investigated based on information available on their website, and if possible, any independent information (e.g. press articles, or knowledge document if defined processes were stated e.g. Hall–Héroult for processing alumina into aluminium).

To differentiate between primary and secondary materials used in the production, there are columns for mining and refining (refining from primary materials), and columns for recycling and R-Refining (refining from secondary materials). If both refining columns are ticked, then it was found that there are some circular economy aspects where the secondary materials are mixed with primary materials to make a new product.

Further columns include final and intermediate products – intermediate products are where the companies reviewed make materials which are then used to make other products, for example ingots, sheet metal. Final products would be items that are a product in themselves or get placed into a large product as a defined part.

All CRM companies identified in the list produce intermediate products, i.e. they provide the input material to go into the manufacturing process to get the final product, they are an example of the manufacturing foundation industry.

The technologies were split into: pyrometallurgy, hydrometallurgy, electrorefining, mechanical and other. These are defined as:

- **Pyrometallurgy** – for this table: thermal treatment, usually by fuels or electrical heating, such as roasting, smelting, refining, calcination, distillation, reheating.
  - Typical advantage of pyrometallurgy are high metal recovery rates and can process large quantities; however,
  - the disadvantages are the high energy consumption and if fossil fuel driven – pollution released into the environment.
- **Hydrometallurgy** – for this table use of solutions to extract and refine metals, such as leaching, precipitation, solution purification, ion exchange, solvent extraction, chemical treatment. When a website stated chemical treatment, this was assumed to be a hydrometallurgical process.
  - Advantages – lower energy consumption (compared to pyrometallurgy), can process low grade ores, can be less air pollution (depending on the chemicals involved).
  - Disadvantages – can produce toxic liquid wastes (maybe toxic gases if the wrong reaction happens), requires large volumes of chemicals and water

- **Electrolytic process** – any process that uses electrolysis, electrorefining or electrowinning to refine, plate or extract metals.
  - Advantages – high purity metals, controlled deposition, selective processing, can be used with low grade ores/wastes.
  - Disadvantages, high energy consumption, harmful chemicals, can be a slow process, anode sludge and waste management.
- **Mechanical** – captures mechanical processing, whether shredding, sorting, crushing, milling, forging, rolling, floatation, gravity separation; this can be energy intensive.
- **Other** – technology that does not fit in the previous sections, e.g. an algae farm for CO2 capture (Vale), hydrogen exposure/decrepitation (Hypromag), direct lithium extraction (lithium mining), atomisation or unidentified, but stated use of 'proprietary technology'.

With regards pyrometallurgy, hydrometallurgy and electrolytic processes, these are not typically used in isolation, the best combination of processes is developed to maximise the process.

Table 24 - Summary of critical minerals industries and technology types

[A] not guaranteed to be a complete list of UK companies. [B] Not all secondary materials are produced by each company in the sector, may not be CRM and can be the main driver. [C] Gold/Silver only included because of byproducts being CRM, this is why mining not included. Also, not every PGM recycler completed gold and silver. Gold/silver recycling/refiners without reference to CRMs were excluded. [D] All PGM processes in the UK are recycling activities from EOL products. [E] Superalloys are metals with unique properties to function in harsh environments, cobalt, nickel, tantalum, zirconium metals have been included in this segment. All refiners found will take secondary raw materials. [F] WEEE recycling and WEEE processors were separated out - lots of WEEE processors employing mechanical separation techniques and then sell the separated materials onwards. [G] This is part of a wider planned mining site at Anglesey, which includes copper, silver, gold and lead, but only zinc is a UK CRM.

Sectors	# Companies Identified [A]	Materials		Areas				Products		Processes					Comments
		Primary	Secondary [B]	Mining	Refining	Recycling	R-refining	Intermediate	Final	Pyrometallurgy	Hydrometallurgy	Electrolytic	Mechanical	Other	
Aluminium smelting	1	Al		☐	☑	☐	☐	☑	☐	☐	☑	☑	☐	☐	future:billet plant & recycling; currently hydro powdered
Al recycling & Alloys	5	Al		☐	☑	☑	☑	☑	☐	☑	☐	☐	☑	☐	operational
Aluminium powders	2	Al		☐	☑	☑	☑	☑	☐	☑	☐	☐	☐	☑	other - atomisation, operational
Gold/Silver [C]	7	Au, Ag	PGM,	☐	☐	☑	☑	☑	☐	☑	☑	☑	☑	☐	all operational
Lead smelter	1	Pb	Zn, Cu, Ni, Ag	☐	☐	☑	☑	☑	☐	☑	☐	☐	☐	☐	operational
Lithium mining	4	Li compounds	Rb, potash, Cs	☑	☑	☐	☐	☑	☐	☐	☑	☐	☑	☑	other-DLE; 2 x pilot; 2 x planned
Lithium refining	4	Li compounds	NaAlSi2O6.H2O	☐	☑	☐	☐	☑	☐	☑	☑	☐	☑	☐	2 x operational; 2 planned
LIBs recycling	7	CAM	Al, Cu	☐	☐	☑	☑	☑	☐	☐	☑	☐	☑	☐	mixed construction/pilot operational
Molybdenum	1	ferromolybdenum		☐	☑	☐	☐	☑	☐	☑	☐	☐	☐	☐	operational
Nickel Refining	1	Ni		☐	☑	☐	☐	☑	☐	☑	☐	☐	☐	☑	other - algae farm; operationl
Nickel/Cobalt mining	1	Ni, Co	Cu	☑	☐	☐	☐	☑	☐	☐	☑	☐	☑	☐	prospecting/pilot
Oil	1	Oil/fuel	anode and graphite coke	☐	☑	☐	☐	☑	☐	☑	☑	☐	☑	☐	operational
PGMs recycling [D]	12	PGM	Au, Ag, Ni	☐	☐	☑	☑	☑	☐	☑	☑	☑	☑	☑	all operational; 2 x involve exports to recycle
REE refining	2	REE		☐	☑	☐	☐	☑	☐	☑	☑	☐	☐	☐	1 construction; 1 x planned
REE recycling	6	REE	Ni, Co, Al, Si	☐	☐	☑	☑	☑	☐	☑	☑	☐	☑	☑	other x2; 1 x operational; 2 x pilot; 3 x planned
Super Alloys [E] processers	3	Co, Ni, Ta, Zr, Mg		☐	☐	☑	☐	☑	☐	☑	☐	☐	☑	☐	all operational
Super Alloys forgers	5	Co, Ni, Ta, Zr, Mg		☐	☑	☐	☐	☑	☐	☑	☐	☐	☑	☐	all operational
SA recycling & refining	6	Co, Ni, Ta, Zr, Mg		☐	☑	☑	☑	☑	☐	☑	☑	☑	☑	☑	other x 3, all operational
Super Alloy Powders	2	Ni, Al, Mo, Nb,		☐	☑	☑	☑	☑	☐	☑	☐	☐	☑	☑	other- atomisation, operational
Silicon mining	1	silica sand	aggregates	☑	☐	☐	☐	☑	☐	☐	☐	☐	☑	☐	operational
Silicon powders	2	Si		☐	☑	☐	☐	☑	☐	☑	☐	☐	☑	☐	operational
Tin recycling	1	Sn	Fe	☐	☐	☑	☑	☑	☐	☐	☑	☑	☐	☐	operational
Tin mining	1	Sn	Cu	☑	☐	☐	☐	☑	☐	☐	☐	☐	☑	☐	target reopening (2027)
Titanium dioxide	2	TiO_2		☐	☑	☐	☐	☑	☐	☑	☐	☐	☐	☐	all operational
Titanium alloys	3	Ti alloys		☐	☑	☑	☑	☑	☐	☑	☐	☐	☑	☐	operational
Tungsten mining	1	W	Sn	☑	☐	☐	☐	☑	☐	☐	☑	☐	☑	☐	target reopening (2026)
WEE recycling	4	Au	Sn, Al, Zn, Cu, PGM	☐	☐	☑	☑	☑	☐	☑	☑	☑	☑	☑	all operational
WEE processers [F]	10	separation		☐	☐	☑	☐	☑	☐	☐	☐	☐	☑	☐	all operational
Zinc powders	2	Zn		☐	☑	☑	☑	☐	☐	☑	☐	☐	☑	☑	other - atomisation, all operational
Zinc [G] Mining	1	Zn, Cu, Ag, Au, Pb		☑	☐	☐	☐	☑	☐	☐	☐	☐	☑	☐	planned

Table 25 - Energy intensity of mineral processing (data from ecoinvent)

Mineral	Electricity MWh/tonne	Other energy GJ/tonne	Mineral	Electricity MWh/tonne	Other energy GJ/tonne
Nickel class 1	9.2	38.9	Yttrium Oxide (Rare Earth Metals)	0.1	6.1
Aluminium	14.9	0.1	Lanthanum Oxide (Rare Earth Metals)	4.0	0.0
Tin	0.9	9.9	Cerium (Rare Earth Metals)	3.6	0.0
Cobalt	375.0	224.3	Dysprosium (Rare Earth Metals)	6.8	598.2
Titanium	1.0	0.0	Samarium (Rare Earth Metals)	2.2	0.0
Titanium dioxide	1.2	32.2	Europium (Rare Earth Metals)	4.3	0.0
Tungsten concentrate	1.8	17.9	Gadolinium (Rare Earth Metals)	16.0	0.0
Lithium carbonate	3.7	54.5	Terbium (Rare Earth Metals)	9.7	853.0
Tantalum	0.7	0.3	Holmium (Rare Earth Metals)	1.8	156.5
Platinum (exhaust treatment)	597.0	407.0	Erbium (Rare Earth Metals)	1.2	105.8
Scandium Oxide (Rare Earth Metals)	18.5	2490.0	Thulium (Rare Earth Metals)	6.0	523.9
Praseodymium (Rare Earth Metals)	5.8	835.4	Ytterbium (Rare Earth Metals)	0.2	18.4
Neodymium (Rare Earth Metals)	0.7	58.8	Lutetium (Rare Earth Metals)	6.4	559.3

Table 25 provides an overview of the energy intensity of mineral processing. This data is taken from ecoinvent which provides life cycle assessments of critical minerals [156]. This data covers the electricity and other energy usage for mineral processing globally.

This reveals the high energy intensity of mineral processing, which in turn creates high energy costs. The highest usage is for platinum, scandium oxide, and terbium.

The processing of rare earth elements is highly energy intensive. The processing of rare earth metals requires the use of acids and other hazardous materials, which produce significant amounts of waste [155]. In addition, rare earth element processing requires very high temperatures which use more heat gas related energy that electricity. This makes the processing more dependent on gas than electricity.

A.3 Stakeholder engagement and thematic analysis methodology

A.3.1 Interview topics

Semi-structured interviews were used as the best possible method to gather the views and insights of stakeholders within the UK critical minerals industry. The research focus was on the UK's current capability and barriers to development, the needs of the industry and policy priorities, and future projects and opportunities. The semi-structured interviews were guided by pre-determined topics which varied by the stakeholder type (industry, academic, or government). The industry topic guide is summarised as follows with the addition of a full list of questions is presented in Annex A.3:

- **UK's current capability:** Understanding the organisation's place in the supply chain, current capacity, skills base, gaps in capability, and biggest challenges.
- **Barriers to capability development and policy priorities:** Discussing the main barriers within the UK's control, policies to overcome barriers, future roadmaps of priorities, policies needed to support industry.
- **Future projects and opportunities:** Exploring diversification opportunities, planned projects, views on how the industry should develop, what influences your vision of the future?

A.3.2 Interview participants

31 semi-structured interviews were conducted with UK senior industry leaders, academia and government policy teams. Table 26 summarises the profile of interview participants. A full list of participants is presented in Annex A.2. Industry participants included directors, senior managers and chief engineers from companies throughout the UK's midstream and recycling supply chain. Academic participants included prominent researchers from leading universities and research centres. Government participants include senior policy advisors and economic analysts from Department for Business and Trade, Cabinet Office, and Innovate UK.

Table 26 - Stakeholder engagement sample

Organisation type	Description	Participants
Industry – Midstream	Directors and senior managers in the UK extraction, processing and refining of rare earth elements industry.	10
Industry – Recycling	Directors and senior managers in the UK and recycling of rare earth elements industry.	11
Academia and research	World leading researchers from Universities of Warwick and Durham, the Critical Minerals Intelligence Agency (CMIC), and the Royal Society of Chemistry.	5
Government	Senior policy advisors and economic analysts from Department for Business and Trade, Cabinet Office, and Innovate UK and DEFRA.	5

Responses have been anonymised and where possible, will not be uniquely identifiable. Any information provided in these interviews has been stored on our secure system for the purposes of transcription and analysis. These interviews were recorded and will be deleted after the project has finished.

A.3.3 Thematic analysis process

Interview transcripts were analysed using thematic analysis to identify common themes, topics, ideas, and patterns. The approach followed six phases of thematic analysis, which is a non-linear method allowing some items to be completed in tandem [133]. These phases include familiarisation, qualitative coding and generating themes:

- **Data familiarisation:** Summarising transcribed data, highlighting initial key responses.

- **Generating initial codes:** Systematically coding key elements of the data, across the entire data set, collating data relevant to each code.
- **Searching for themes:** Collating codes into potential themes, gathering all data relevant to each potential theme.
- **Reviewing themes:** Checking if the themes work in relation to the coded extracts and the entire data set, generating a thematic map of the analysis.
- **Defining and naming themes:** Ongoing analysis to refine the specifics of each theme and the overall answer to the key research questions.
- **Communicating the analysis:** The final opportunity for analysis. Includes compelling extract examples, final analysis of selected extracts, relating back of the analysis to the research questions and literature.

A.3.4 Methodology limitations

All interview participants were happy to discuss their views on the critical minerals industry. Using the available stakeholders and information, a thorough analysis of the project was undertaken. However, there are some noted limitations in the methodology:

- Self-reporting bias can arise in interviews. Typically, bias can arise around aspects that an interviewee was personally involved in. For example, exaggerated claims that a company's product is industry leading, or suggesting future policies that benefit an individual firm more than others. To mitigate the possibility of bias in the result, the study triangulated evidence from the available literature and considered responses in the full context of all other responses offered.
- There is an inherent subjective dimension to undertaking this type of qualitative analysis. The interpretation of the data may differ between analysists. To mitigate subjective bias, each step was completed by multiple researchers in isolation before being cross-referenced to create a balanced analysis.

A.3.5 Full Stakeholder list

Table 27 - List of stakeholder interviews

Organisation	Description	Role
Advanced Alloys	Supplier of high purity metals who has recently received funding to develop its metal recycling and recovery capability.	Managing director
Cornish Lithium	Cornish Lithium is a mineral exploration and development company focused on the environmentally responsible extraction of lithium from geothermal sources.	Business development manager
Cornwall Resources	Focused on advancing the high ground, underground Redmoor tungsten-tin-copper project.	Senior geologist
Iconichem	Specialist producer of Nickel, cobalt, and black mass recycling.	Operations director
Ionic RE / Ionic Technologies	Extraction and processing of byproducts from copper mining and recovery of black mass from mine tailings.	Operations director
Johnson Matthey	World leader in the processing, refining, and recycling of PGMs.	Principal strategy analyst PGMs.
Less Common Metals	World leading rare earth metals manufacturer.	General manager
Materials Processing Institute	Research institute providing innovation and facilities to support start-ups in midstream processing and recycling.	CEO
Tees Valley Lithium	Focused on the refining of lithium and rare earth elements. Aims to transform low grade lithium into battery grade lithium.	Chairperson
Watercycle technologies	Mineral recovery company focusing on the primary extraction for lithium and recycling from batteries.	Co-founder

Altek	ALTEK is the world leader in the design, manufacturing and installation of aluminium dross and scrap processing systems.	Business manager
Altilium Clean Technology	UK-based clean technology group supporting the transformation of the global energy sector from fossil-based to zero-carbon.	Co-founder
Avon Speciality Metals	Avon Specialty Metals is a UK based, privately-owned recycler and trader of Nickel and Cobalt based superalloys and a range of exotic minor metals.	Managing director for technology and innovation
BASF	BASF companies supply raw materials to most industries in the UK. BASF specialise in recycling catalytic convertors in Gloucestershire.	Commercial director
Centre for Process Innovation	Helps companies prove, prototype and commercialise new technologies for the critical mineral supply chain.	Innovation manager
EERA Recyclers	EERA is the voice of Waste Electrical and Electronic Equipment (WEEE) recovery facilities in Europe.	CEO
European Metal Recycling	Metal recycling company focusing on vehicle, and renewable infrastructure recycling.	Manging director – Technology and Innovation
International Energy Agency	The International Energy Agency works with countries around the world to shape energy policies for a secure and sustainable future.	Critical minerals analyst
Mormair	Recently entered the critical minerals industry to refine and recover aluminium, silicon, and rare earth elements using Chemical loop combustion.	Directors
Recyclus	Company focusing on lithium-ion battery recycling and re-use.	Director and co-founder
Unimetals	Provides scrap metal recycling and recycling services for speciality metals.	Founder
Advanced Propulsion Centre/University of Warwick	The advanced propulsion centre based on the University of Warwick provides support to companies to accelerate the transition towards net zero automotive.	Director, automotive transformation
Camborne School of Mines	Part of the University of Exeter and offers specialist courses in earth sciences, geology, and mining engineering.	Professor of applied Mineralogy
Critical Minerals Intelligence Centre	UK agency who produces critical mineral data and the criticality assessment.	Director
Royal Society of Chemistry	Professional body for chemists in the UK. They also publish academic papers in advanced chemistry.	Policy advisor
University of Durham	Durham University has published several papers on critical mineral recycling and circular economy.	Professor of Economic Geography
Cabinet Office	Coordinates across the different government departments that have interest in critical minerals. Such as DBT, DEFRA, and FCDO.	Senior advisor
DBT- Critical Minerals Policy Team (Domestic)	The team within DBT responsible for domestic critical minerals and circular economy policy. They work closely with other government circular economy departments.	Senior policy advisors and Senior Economic Analysts
DBT - Critical Minerals Policy Team (international)	The team within DBT responsible for international critical minerals and circular economy policy. They work closely with other government circular economy departments.	Senior policy advisor
DEFRA	The team within the Department for Food and Rural Affairs who are responsible for battery recycling and circular economy policy.	Senior policy advisors for recycling and circular economy
Innovate UK	Provides grant funding to support Research and Development in innovative critical mineral processing and recycling projects.	Programme lead

A.4 Weightings framework and prioritisation methodology

A.4.1 Weightings framework

The critical minerals industry is a multifaceted policy space with a considerable range of benefits. To create a robust estimate of the future economic opportunity in the UK it is necessary that any future modelling reflects government policy priorities. Weightings frameworks are commonly used to support decision making and policy development in complex policy areas where there are multiple criteria that can influence a decision.

The weightings framework has been developed in the following steps:

1. Identification: Policy criteria was collected during meetings with the DBT critical mineral policy team. This established a longlist of criteria.
2. Shortlisting: The longlist of criteria was down selected through further discussion with the DBT policy team.
3. Ranking: The interviews with government were used to gather a sense of policy priorities. The results of this interview question have been combined to rank the decision criteria.
4. Weightings: Following the interviews, weights will be assigned to each rank, with the highest ranked criteria carrying the greatest weight in the economic modelling. This is done to account for policy trade-offs.

Interviews with government stakeholders indicated that there was not a significant difference in priority between the criteria. These criteria also appeared during industry and academia interviews as opportunities or barriers to the UK. The results of the weightings ranking and associated weights are shown in Table 29.

The impact score, complexity, and cost can be combined to see the potential trade-offs for each policy. For example, a policy may be more complex but also deliver higher benefits. As well as identifying simple but impactful policies. This assessment has been carried out for all 12 policies included in the longlist.

Table 28 - The weightings framework has been developed following interviews with government stakeholders

Criteria	Description	Rank	Weight
Economic impact	Including volumes, demand, return on investment, cost savings to businesses and the wider economy, job creation and regional growth.	1	25%
Security of supply	Including supply chain risks, producer country risks, international, or economic threats.	2	22.5%
Capability	UK capability and competitive advantage, including relationships with other country partners and producers.	3	20%
ESG standards	Environmental, social, and governance (ESG) standards in line with CMIC evaluation approach. This involves reduced supply risk of trading with countries with lower ESG standards.	4	17.5%
UK domestic policy alignment	Including skills, employment and regional impact. Considering interactions with industrial strategy and other upcoming strategies including critical minerals, steel, circular economy, and skills.	5	15%

A.4.2 Policy scoring and prioritisation

Policies have been scored and prioritised using qualitative multi criteria decision analysis (MCDA). During this process each of the longlisted policies has been scored against the weightings framework. Each option has been scored from 1 (low) to 5 (high) for each criterion based on a qualitative assessment of the policy to deliver the benefits listed in the criteria description.

The weighted score for each criterion is calculated as follows:

*Impact score * Weighting = weighted score*

The total weighted score for each policy is the sum of weighted scores. This weighted score represents the relative strength of the policy to deliver benefits to the UK critical minerals industry. The total weighted score is the sum of the scores for each element of the weighting criteria.

A.4.3 Cost estimation

- Rough order of magnitude cost: Costs have been estimated on a policy-by-policy basis. This includes an analogous estimate of capital costs based on similar policies, or previous policies delivered in the UK, as well as a resource cost which is a rough order of magnitude bottom-up estimate of personnel time and capital costs

Table 29 - Policy costing calculation steps

ID	Policy	Costing approach
1	New energy bill relief scheme tailored to the critical minerals supply chain.	Policy costing is based on the size of relief handed out to critical minerals companies. This uses UK data on energy consumption for the following industries [134]: - Iron and Steel - Non-Ferrous metals - Mineral products Total electricity cost to the industry is calculated by doing: *Electricity consumption (kwh) x £/kwh* [135] *12,641,810,000 kwh x £0.25/kwh = £3,160,452,500* The cost of the policy calculated as *Total electricity cost (£) x cost recovery limit (50%)* *£3,160,452,500 x 50% = £1,580,226,250* The above calculation reflects the total value of cost recovery government provides to industry.
2	Extension of the Energy Intensive Industries support scheme.	Policy costing is based on the size of relief handed out to critical minerals companies. This uses UK data on energy consumption for the following industries [134]: - Mineral products Mineral products are not currently included in EII exemption scheme. This policy recommended extending scope to include this sector. Total electricity cost to the industry is calculated by doing: *Electricity consumption (kwh) x £/kwh* [135] *5,245,760,000 kwh x £0.25/kwh = £1,303,676,480* The cost of the policy calculated as *Total electricity cost (£) x cost recovery limit (30%)* *£1,303,676,480 x 30% = £391,102,944*

		The above calculation reflects the total value of cost recovery government provides to industry.
3	Grant funding for innovation in recycling and midstream capability.	There are similar grant programmes in Australia (c.£25m), and Canada (c. £26m) [136] [13] [137]. However, Australia and Canada already have extremely well-established industries. Additional funding will be needed to promote the UK's market. This programme could be a minimum of £50m over a period of 4 years, as that would allow significant collaborative R&D activity to occur without any additional supporting initiatives.
4	Centralised team to support collaboration with regional clusters.	Collaboration with freeports will require a small team of three civil servants to act as relationship managers. This is based on three people being proven as the most efficient team size [138]. The policy will need to run for at least five years for to achieve longer term benefits. The cost of the policy is based on the number of FTE's and the median civil service salary for a band 6/7 [139]. *FTE x annual median pay rate x years* *3 x 60,000 x 5 = 900,000*
5	Amendments to waste classifications	DBT will likely need to commit two FTE to work alongside DEFRA to redefine waste classifications. The cost of the policy is based on the number of FTE's and the median civil service salary for a band 6/7 [139]. *FTE x annual median pay rate x years* *2 x 60,000 x 3 = £360,000*
6	Government procurement plan.	A critical mineral procurement plan will require input from multiple departments. Delivery of the plan will require a small interdisciplinary team of five FTE [140]. The cost of the policy is based on the number of FTE's and the median civil service salary for a band 6/7 [139]. *FTE x annual median pay rate x years* *5 x 60,000 x 1 = 300,000*
7	Targeted school and university outreach.	This will require one FTE to coordinate the outreach, organise events, and collaborate with industry and academia to align on opportunities. The cost of the policy is based on the number of FTE's and the median civil service salary for a band 6/7 [139]. *FTE x annual median pay rate x years* *1 x 60,000 x 5 = 300,000*
8	Facilitate positive promotion of the midstream processing industry.	It is assumed that government will likely need to facilitate and coordinate industry level advertising campaigns to convey key messages over a period of 3 years. This would require some government time of approximately 0.5 FTE over 3 years. The cost of the policy is based on the number of FTE's and the median civil service salary for a band 6/7 [139]. *FTE x annual median pay rate x years*

		0.5 x 60,000 x 3 = 90,000
9	Centralised team to support planning and permitting.	This policy would require two full time equivalent of effort (FTE) for one year to collaborate with other policy teams around government. The cost of the policy is based on the number of FTE's and the median civil service salary for a band 6/7 [139]. *FTE x annual median pay rate x years* *5 x 60,000 x 3 = 900,000*
10	International collaboration	Collaboration with international partners will require a small team of three civil servants to act as relationship managers. This is based on three people being proven as the most efficient team size [138]. The policy will need to run for at least five years for to achieve longer term benefits. The cost of the policy is based on the number of FTE's and the median civil service salary for a band 6/7 [139]. *FTE x annual median pay rate x years* *5 x 60,000 x 3 = 900,000*

A.4.4 Shortlisting and quantitative assessment

The longlist of 11 policies has been reduced to the four most impactful options. These four options have been carried forward to quantitative assessment. This is reminiscent of a green book business case where quantitative assessment is carried out on the four strongest options. The remaining eight policies should still be considered for delivery by DBT but are lower priority than the shortlisted policies.

This qualitative assessment reveals the following policies should be carried forward for economic modelling, these policies represent the largest potential impact, displayed in Table 19.

1. Grant funding for innovation in recycling and midstream capability (4.6 out of 5).
2. Extension of the Energy Intensive Industries support scheme (3.95 out of 5). The extension of the EII scheme will also be modelled due to its similarity with creating a new energy scheme.
3. Centralised team to support planning and permitting (3.95 out of 5).
4. Centralised team to support collaboration with regional clusters (3.93 out of 5).

A.5 Economic modelling methodology annex

A.5.1 Overview

This annex details the approach to estimation the economic impact of government intervention. There are three aspects to this:

- Forecasting a baseline of UK critical mineral production.
- Multiplier analysis, quantifying the economic impact caused increases in production.
- Scenario modelling to estimate the policy effects on production, and subsequently, economic value.

A.5.2 UK Critical mineral production forecast

This section summarises the approach to forecasting the production of UK critical minerals. This forecast is then used as a baseline from which to evidence additionality of selected policies. An autoregressive, integrated, moving average (ARIMA) model was selected which uses historical variations in the data to forecast forward the likely critical mineral production values. Guidance from Meyler et al (1998) [141] is used to structure the approach, with five key steps:

1. Data collection and examination
2. Testing for stationarity
3. Model identification and estimation
4. Diagnostic checking
5. Forecasting and forecast evaluation

A.5.2.1 Data collection and examination

Critical mineral production and import data: 12 minerals were chosen for inclusion in forecasting, which was constrained by the available data. This includes the top ten by consumption (excluding silicon and indium due to lack of data), as well as minerals critical to key green technology – such as rare earth elements, graphite, and cobalt. Finally, tin and platinum were also included due to strong UK capabilities. The full list is:

- Aluminium
- Lithium
- Zinc
- Phosphoros
- Titanium
- Tin
- Graphite
- Cobalt
- REEs
- Sodium Compounds
- Nickel
- Platinum

All historical data on UK critical mineral production and imports comes from the British Geological Survey's world mineral statistics archive [142]and the UK Minerals Yearbook [38]. This dataset includes information on select minerals from 1970, providing a 53-year historical sample size for forecasting.

The benefits of using this dataset exclusively are:

- **Consistency in definitions**: Mineral statistics often include sub-categories, such as nickel imports for unwrought alloys, oxides, ores, and concentrates. Using the same dataset over time ensures a more consistent historical picture compared to multiple datasets with varying sub-category definitions.
- **Consistency in data collection**: Variations between different datasets, such as those from the US Geological Survey, are common to differences in data collection and amalgamation techniques. Prioritising consistency in this instance helps maintain data integrity.

However, relying solely on this data source limits the ability to address data availability concerns when other sources are available. This trade-off was made to generate more consistent and repeatable results.

Data availability is the primary limitation of these datasets. Data is not always available for the entire period for each mineral, and it is unclear whether this is due to a lack of data collection or true zero production or import values. Therefore, all missing data is considered as zero values.

UK production data is limited to the minerals shown in Figure 32. For modelling purposes, the baseline forecast was estimated based on all critical mineral production data combined. This is then proportioned out based on 2022 production totals so that specific price data for each mineral can be used.

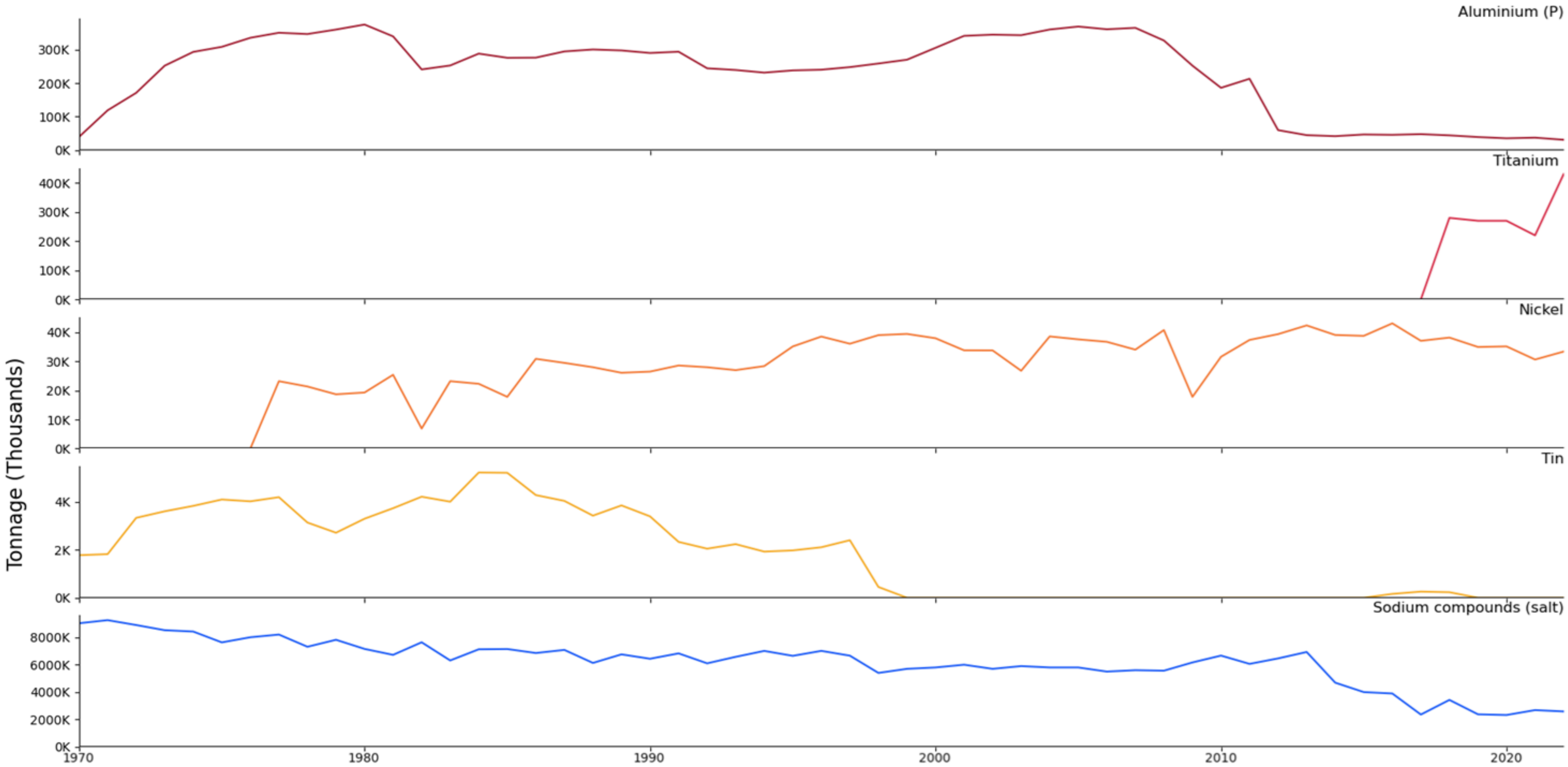

Figure 32 - Historical UK Critical Mineral Production (1970 – 2022)

Supporting data: Supporting data were used within analysis is presented in Table 30.

Table 30 - Proposed modelling control variables

Variable	Source	Reason for investigation
Bank of England base interest rate	BoE database [143].	The interest rate was chosen to proxy access to capital finance for critical minerals companies and projects.
Multi-factor productivity	ONS MFP dataset [144].	MFP measures productivity within the economy, capturing technological advancement over the time period.
UK energy price	ONS CPI index [145].	UK energy price was explored to measure energy input costs.
UK manufacturing output	ONS manufacturing index [146].	Manufacturing output was chosen to indicate demand for critical minerals in the UK, given their use in manufacturing processes.
UK average wages in mining	ONS ASHE Table 5 [147].	Average wages in mining were chosen to measure labour costs for the critical minerals industry.
UK critical mineral imports	British Geological Survey's world mineral statistics archive [142], and the UK Minerals Yearbook [38].	UK imports were included as a measure of UK demand for critical minerals.
World production of critical minerals	British Geological Survey's world mineral statistics archive [142], and the UK Minerals Yearbook [38].	World production was included to reflect the global market and demand for critical minerals.

A.5.2.2 Testing for stationarity

Time series data must be stationary before it can be incorporated into a suitable ARIMA model. The *pmdarima* autoARIMA function was used to implement the ARIMA approach [148]. As part of this, the function automatically conducts a Kwiatkowski–Phillips–Schmidt–Shin to determine whether the time series is stationary and implements the appropriate degree of differentiation.

A.5.2.3 Model identification and estimation

An automatic algorithmic approach was used to select model parameters. The ARIMA model was fit to the historical time series for the production of UK critical mineral, with no exogenous variables. This was fit using the *pmdarima* autoARIMA function [148], which implements a stepwise approach using the Akaike Information Criterion, as laid out in Hyndman and Khandakar (2008) to determine the autoregressive and moving average orders [149].

A.5.2.4 Diagnostic checking

To ensure the model is satisfactory a number of diagnostic tools were used. Figure 33 shows an autocorrelogram of the residuals. If the model is correctly specified, the residuals should be 'white noise'. Therefore, a plot of the autocorrelogram should immediately become insignificant from one lag on, as demonstrated.

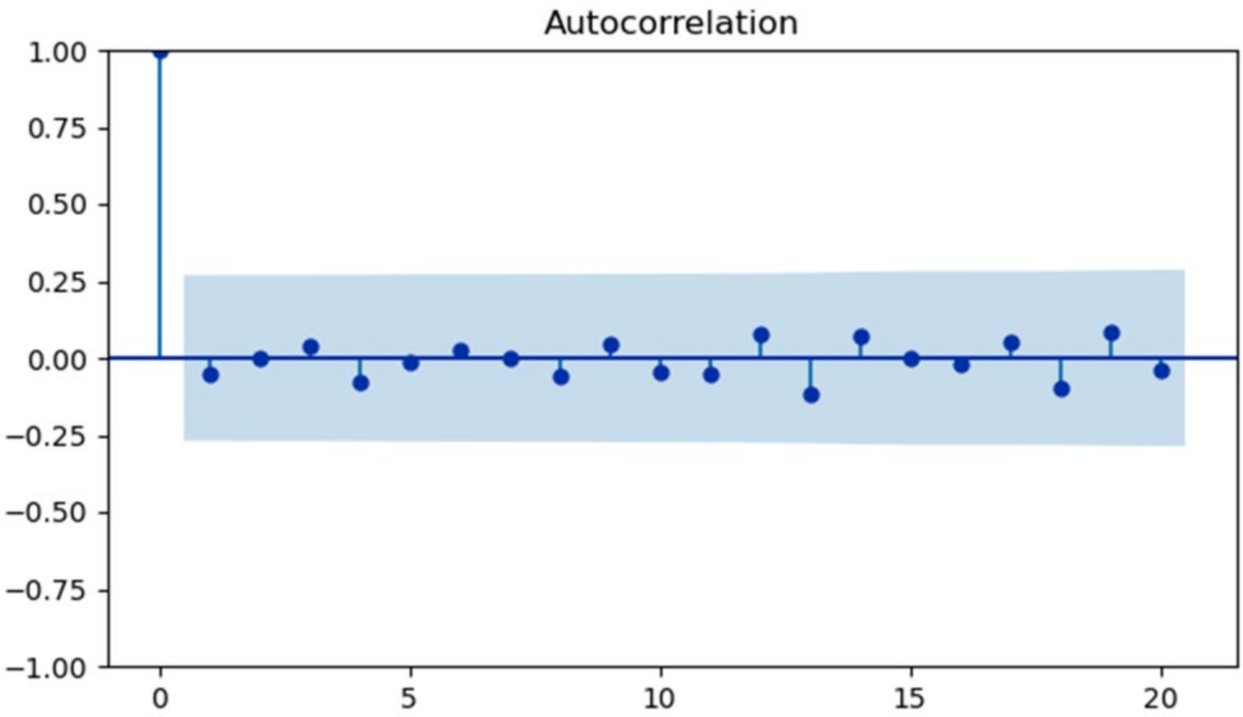

Figure 33 - Autocorrelogram of baseline model residuals

A.5.2.5 Forecasting and forecast evaluation

With the baseline ARIMA model fit using existing historical data, it was then used to forecast forward to 2035. This implemented a single step approach, where one period was forecast and then the model was refit using the new period estimate before estimating another period.

Additional planned UK capabilities: Using the CMIC database, data on future planned UK critical minerals capability was collected [1]. This is summarised in Table 31, which is also presented in the body in Section 2. Sites with no estimated output were not considered. Additionally, the planned Strategic Minerals site was not included, as its forecasted output in 2030 distorted potential policy impacts. Production from pilot sites was incorporated post 2026, under construction sites from 2028, and planned sites from 2030.

Table 31 - Planned UK critical mineral sites (Reproduced from [24])

Site	Location	Site Planned Processing Capability
Northern Lithium	County Durham, England	**Status:** Planned pilot. **Critical mineral:** Lithium carbonate from geothermal waters, estimated 10,000 tonnes per year. (1,000 tonnes per year during pilot phase)
Cornish Lithium Plc	Trelavour, Cornwall, England	**Status:** Planned. **Critical mineral**: 7,800 tonnes lithium hydroxide per year.
Imerys British Lithium	Roche, Cornwall, England	**Status:** Pilot. **Critical minerals**: Estimated 20,800 tonnes per year of lithium carbonate equivalent.
Cornish Lithium Plc	United Downs / Cross Lanes, Cornwall, England	**Status**: Pilot. **Critical mineral**: Direct lithium extraction from geothermal waters. Estimated 500-1,000+ tonnes per year of lithium carbonate.
Tungsten West Plc	Devon, England	**Status:** Under construction. **Critical minerals:** 3,900 tonnes tungsten oxide predicted, as well as 600 tonnes of tin by year 3.

A.5.3 Economic impact estimation

The UK wide impacts arising from forecasted critical mineral values and volumes produced in the UK were estimated by multiplier analysis using the Office for National Statistic (ONS) input-output analysis, which gives a snapshot of an economy at a given point in time. The market revenue forecasts, provided by the economic model, estimated the potentiation future market transactions that include:

The estimated total impact on UK gross value added (GVA) and job-years created from these market transactions was derived from the component flow of transactions throughout the economy: the direct, indirect and induced impacts. The key assumptions made during this estimation which are not mentioned elsewhere in the report include:

- **Leakage**: Only the forecasted values for critical minerals produced in the UK are carried forward into the economic impact estimate. This is because critical mineral imports are forecasted separately and are already treated as leakage in the forecasting model. Essentially money spent importing critical minerals acts as money leaving the UK and is therefore a leakage. Whereas money spent on UK production of critical minerals acts as an input into the UK supply chain and wider economy. Therefore, production values are the key input into the economic impact model.
- **Expenditures by industry**: Each expenditure type was mapped to a UK industry (SIC, 2007) based on the registration information of the companies likely to undertake the respective activity. This mapping is based on the SIC codes of companies included in the Critical minerals intelligence centre (CMIC) which was supplemented with the industry stakeholders included in this study. This sample was made up of 58 companies throughout the critical mineral value chain. The outputs of the 2-digit SIC code mapping is shown below and has been used to allocate critical mineral revenues into each sector:

Table 32 - Critical minerals sector SIC code basket

2-Digit SIC code	Industry	Expenditure (%)
38	Waste collection, treatment and disposal services; materials recovery services	34%
24	Other basic metals and casting	30%
71	Architectural and engineering services; technical testing and analysis services	6%
07	Extraction of crude petroleum and natural gas & mining of metal ores	6%
27	Electrical equipment	6%
08	Other mining and quarrying products	4%
09	Mining support services	4%
20	Industrial gases, inorganics and fertilisers (all inorganic chemicals)	4%
46	Wholesale trade services, except of motor vehicles and motorcycles	4%
72	Scientific research and development services	2%

A.5.3.1 Critical mineral value estimation

To estimate the additional value of the increased production of critical minerals, we assumed constant 2025 prices over the forecast period. These prices were forecasted from several sources, summarised in Table 33 . The difference in price between minerals highlights the importance of portioning out production into mineral streams. It also highlights the importance of considering mineral specific policy effects when estimating economic value.

Table 33 – Mineral price data

Mineral	Price (£) per tonne	Price data source
Aluminium (Primary)	2,190	London Metal Exchange [150]
Lithium	8,625	London Metal Exchange
Zinc	2,346	London Metal Exchange
Phosphorus	127	IndexMundi [151]
Titanium	233	SMM [152]
Nickel	12,667	London Metal Exchange
Tin	26,313	London Metal Exchange
Graphite	4,167	Jinsun Carbon [153]
Cobalt	17,637	London Metal Exchange
Rare earth elements	394,583	Strategic Metals Invest [154]
Sodium compounds	98	Business AnalytIQ [155]
Platinum	28,980,183	London Metal Exchange

A.5.3.2 Estimating potential GVA and job-years impact

The impact estimation used the major spending flows within an economy including:

- Final demand (i.e. consumer spending, government spending investment and exports to the rest of the world).
- Intermediate spending patterns (i.e. what each sector buys from every other sector though the supply chain).
- How much of that spending stays within the economy.
- The distribution of income between employment and other forms such as corporate profits.

The ONS input-output tables are a matrix representation of the UK's interconnected economy. This was used to create multiplier effects for each industry by tracing inter-industry transactions – that is the value of goods and services that are needed (inputs) to produce each pound sterling of output for the individual sector being studied.

The direct suppliers' procurement spending was broken down to identify the contribution to GVA by industry. Each of the industries in the direct channel had the revenue split between UK taxes on products, imports (including overseas taxes but net of UK taxes) and net-of-tax domestic supplies, based on ratios in the ONS input-output tables. The GVA of the entire supply chain could then be worked out, using the share of GVA in each industry's output. The resulting indirect and induced GVA impact estimate was calculated using Type II multipliers calculated by the Leontief method, using the ONS input-output analysis.

The number of job-years supported by the GVA contribution to the UK economy was calculated using the forecast GVA per job values, taken from ONS Annual Business Survey results. To note these are gross estimates as much of the critical mineral economic activity comes from displacement and substitution. The total GDP and employment impacts are the sum of the separate direct, indirect and induced impacts.

A.5.4 Policy modelling calculations

The following section details the approach taken to model the four chosen policies, building on the baseline model estimated.

A.5.4.1 Energy cost relief schemes

Calculation steps: The new relief bill and extension of EII policies are calculated in the same way, with different assumptions. These steps are summarised below:

1. A series of log-level OLS regressions were estimated for the relationship between total UK critical mineral production (in log format) and control variables (as levels), using the historical data available from 1970-2022. From this a range of significant estimates of the coefficient of the relationship between mineral production and energy prices was found. This found a 0.24% - 0.3% increase in the mineral production for a unit reduction in energy price.
2. For the new relief bill, a range of 30 - 70% reduction in energy prices was adopted, whereas for the extension of EI the assumed reduction ranges from 10 – 30%. For both policies the reduction takes place from 2030.
3. The OLS estimates were applied to the unit change in energy to calculate the effect on total critical mineral production for each policy. The difference from the baseline was then calculated to estimate the additional production as a result of the policies.

The result of these steps is an estimate of the additional production of critical minerals in the UK.

4. The final step combined estimate for the new relief bill was inputted into the multiplier model to generate GVA and job-year estimates. The extension of EII was also inputted into a multiplier model, but with an altered basket of SIC codes due to the targeted effects of the policy on metal casting companies only.

A.5.4.2 Grant funding for innovation in recycling and midstream capability

Calculations steps: There are two aspects to calculating the economic impact of grant funding. The first is the additional productivity resulting in improved recycling rates, and the second is a reduction in energy costs, resulting from increased energy efficiency. The additional productivity calculation steps are as follows:

Table 34 - UK Critical mineral waste statistics

Commodity	Annual mass exported (tonnes)	Value (£)	End of Life Recycling Rate (%)
Iron, steel and ferro-alloy scrap	8,813,525	3,424,051	2.5
Nickel scrap	13,782	179,061	4.6
PGMs	5,771	969,912	8.4
Zinc scrap	7,075	15,022	7.0

1. Using UK critical mineral waste exports and End of Life Recycling Rate (EoLRR) data [1], the annual mass generated was calculated by combining the mass of exports and mass of recycled minerals.
2. Profiled waste exports forward, using the rate of increase in UK production and imports for each mineral as a measure of consumption.
3. Assumed a recycling rate increase of 12.5, 25, and 37.5% to produce adjusted EoLRR.
4. From 2030 onwards, applied adjusted recycling rates to waste exports to estimate the reduction in waste as a result of increased recycling.
5. Calculated a £/tonne value of waste per mineral, using figures in Table 34.
6. Calculated the £/tonne of the reduced waste exports.
7. Calculated the difference between waste £/tonne, and mineral price £/tonne, to produce value-adjusted estimates for increased mineral production.
8. Added value-adjusted estimates by mineral to baseline model.

The next steps cover the calculation of the reduced energy costs effects on mineral production.

1. A series of log-level OLS regressions were estimated for the relationship between total UK critical mineral production (in log format) and control variables (as levels), using the historical data available from 1970-2022. From this a range of significant estimates of the coefficient of the relationship between mineral production and energy prices was found. This found a 0.24% - 0.3% increase in the mineral production for a unit reduction in energy price.
2. A 3% reduction in energy prices was assumed. From this the unit change in energy price was calculated. This reduction comes into effect in 2030.
3. The OLS estimates were applied to the unit change in energy to calculate the effect on total critical mineral production, using the baseline plus additional recycling value calculated in step 8.

The result of these steps is an estimate of the additional production of critical minerals in the UK

4. The final combined estimate was inputted into the multiplier model to generate GVA and job-year estimates.

A.5.4.3 Centralised team to support collaboration with regional clusters

Calculation steps: The economic impact for this policy is calculated using the same method as the increased productivity effect of grant funding, steps 1-8. Assumptions are updated and summarised below. It is worth noting that while the modelling approach is the same, the economic logic is different. This policy results in improved capabilities which increase recycling rate, where the grant funding improves access to waste streams, increasing recycling rate.

1. Using UK critical mineral waste exports based on Table 34 and End of Life Recycling Rate (EoLRR) data from the CMIC 2024 Criticality Assessment report, calculated the mass generated.
2. Profiled waste exports forward, using the rate of increase in UK production and imports for each mineral as a measure of consumption.
3. Assumed a recycling rate increase of 50, 75, and 100% to calculate adjusted EoLRR for three scenarios.
4. From 2030 onwards, applied adjusted recycling rates to waste exports to estimate the reduction in waste as a result of increased recycling.
5. Calculated a £/tonne value of waste per mineral, using figures in Table 34.
6. Calculated the £/tonne of the reduced waste exports.
7. Calculated the difference between waste £/tonne, and mineral price £/tonne, to produce value-adjusted estimates for increased mineral production.
8. Added value-adjusted estimates by mineral to baseline model.

The result of these steps is an estimate of the additional production of critical minerals in the UK.

9. The final estimate was inputted into the multiplier model to generate GVA and job-year estimates.

A.5.4.4 Centralised team to support planning and permitting

Calculation steps: The effect of this policy is streamlined planning and permitting for new projects. The below steps describe the calculation steps to estimate the economic effect.

1. Planned future projects currently assumed to become operational in 2030 were profiled to become operational in 2029. A range of values from 30 – 100% were used to estimate the available production time in a year, i.e. in the low scenario production starts only 3 months early, whereas for the high scenario a full year's extra production is modelled.

The result of these steps is an estimate of the additional production of critical minerals in the UK.

2. The final estimate was inputted into the multiplier model to generate GVA and job-year estimates.

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