



Strategic Command
Defence Support



TEAM
DEFENCE
INFORMATION

Securing Critical Raw Materials for Defence

A Decision Support Framework

EXECUTIVE SUMMARY

Establishing a UK-based recovery and reclamation capability for Defence Critical Raw Materials offers significant economic, environmental, and strategic benefits. The key advantages include:

- **Economic Growth & Revenue Generation** – Unlocking new domestic and export opportunities in high-value material recovery.
- **Advanced Manufacturing & Innovation** – Developing cutting-edge technologies in robotics, automation, and less polluting chemical processing.
- **Enhanced UK Material Security** – Reducing reliance on unstable supply chains and increasing resilience in critical industries.
- **Job Creation Across Skill Levels** – Generating employment in both high-skilled R&D roles and broader industrial operations.

By investing in advanced recovery and refining processes, the UK can position itself as a global leader in critical mineral recovery and reclamation, enhancing both industrial competitiveness, national security and growing UK skills that are attractive within a global market.

Socio-Political Context

Across NATO and global markets, demand for Critical Raw Materials (CRM) - of which Rare Earth Elements (REE) are a part - continues to rise, driving competition for access to virgin materials. A circular economy approach, focused on reclamation and extending material use, presents a key opportunity to secure future

supply and enhance resilience. However, at the platform, system, and product levels, significant challenges remain in implementing CRM reclamation effectively.

Aim and Objectives

This Quick Look Task examines how the Defence sector can mitigate CRM supply chain risks by harvesting Defence Critical Raw Materials from end-of-life platforms and establishing sovereign UK recovery capabilities.

The objective is to develop a decision-making framework applicable across capabilities, platforms, sub-systems, and components to:

- Provide a demand signal to industry and guide investment decisions in UK recovery and reclamation infrastructure.
- Inform the development of autonomous and less environmentally damaging recovery technologies.
- Influence design and supportability analysis to incorporate metal and mineral reclamation.

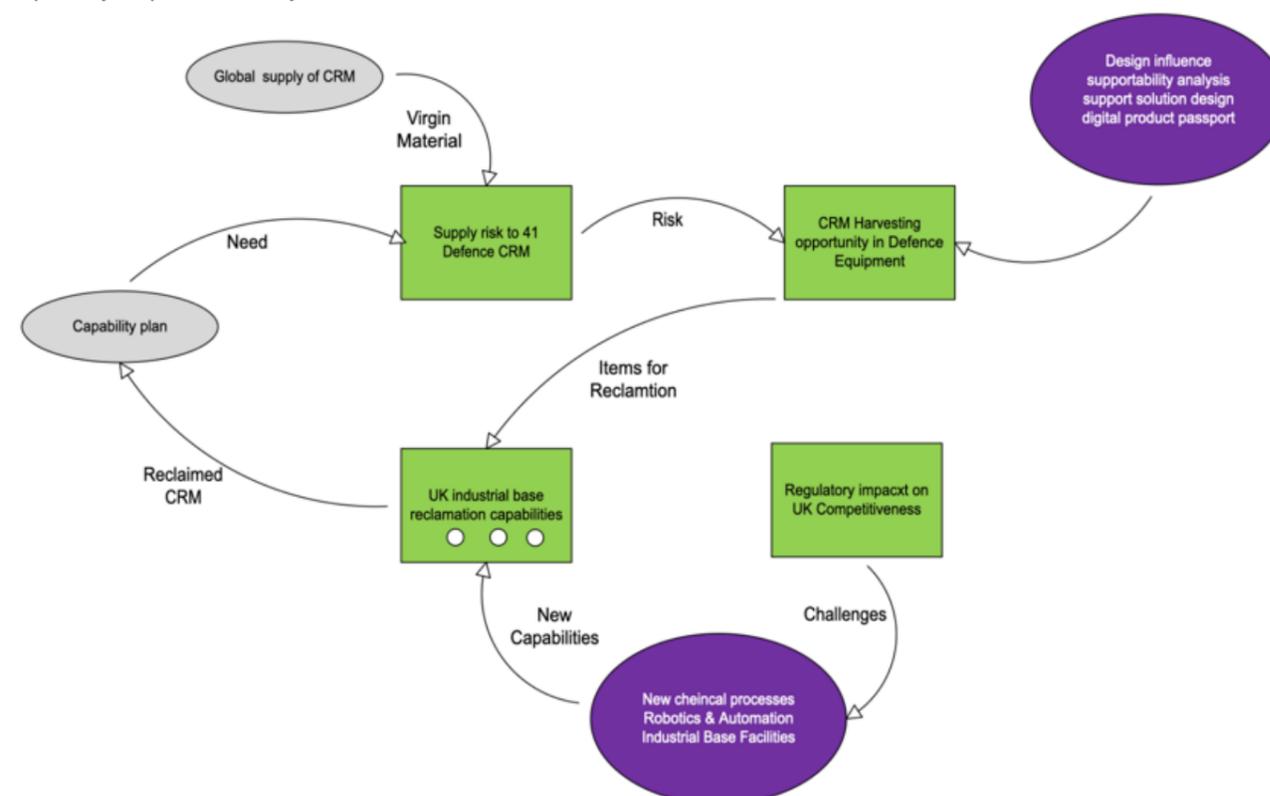
The Framework

The proposed decision support framework consists of four key stages:

- **Defence CRM Supply Chain Risk** – Identifying vulnerabilities in global supply chain ability to meet Defence equipment programme needs.
- **Harvesting Defence CRM Opportunity** – Evaluating opportunities for recovery of Defence critical raw materials from military assets.

- **Maturity of UK Recovery Capability** – Understanding domestic processing and refining gaps.
- **Regulatory Impact on UK Competitiveness** – Assessing legislative and regulatory driven implications and how to overcome them across:
 - Virgin material extraction.
 - Current and future UK recovery capabilities.
 - Waste export and disposal practices.

These stages can be conducted independently but are most effective when applied iteratively with the start point and perspective depending on the stakeholder—whether UK MoD, OEMs, Primes, or recovery and reclamation service providers—and their role in the capability or product lifecycle.



Outputs and Outcomes

While the framework is still in early development, its application will provide structured guidance for deeper analysis, leading to:

- **Quantification of CRM accessibility** within Defence Platforms, identifying modifications for easier harvesting, recovery, and reclamation.
- **Assessment of UK processing and refining maturity**, highlighting areas for investment or strategic collaboration with allies.

These insights will support decision-making across the CADMID lifecycle, influencing:

- **Capability Programs by shaping:**
 - Reclamation and data requirements in system design.
 - Solutions to reduce CRM dependency and enhance material recovery.
 - Supportability engineering to integrate CRM recovery and reclamation strategies.
- **Development of Methodologies & Toolkits to support:**
 - ASD S3000L (Task Analysis & Level of Repair Analysis)¹.
 - ASD S1000D (Standardized Data Dictionary)².
 - Digital Product Passports
 - Support Solution Envelope Guidance
 - AI and Machine Learning applications for automated CRM recovery assessments.
- **Investment Decisions regarding:**
 - Sovereign capabilities within the Defence Industrial Base.
 - Near-shore refining infrastructure for sustainable material processing.
 - Robotic and automated handling technologies to enhance efficiency and safety.
 - Intellectual Property (IP) creation in environmentally friendly chemical processing.

● **For selected CRM, funding and development will be aligned as follows:**

- Defence will fund only areas unique to its operational needs.
- UK Research and Innovation via Innovate UK and EPSRC will support dual-use novel chemical processes for broader industry application.
- Innovate UK and the High Value Manufacturing Catapult centres will develop cross-sector processing capabilities for near-shore operations.
- The UK Defence Industrial Strategy will drive national investment to establish a resilient and sovereign UK supply chain.

Next Steps

To validate and refine the framework, it must be tested across pilot platforms, systems, and products. This will require:

- OEM design data to assess CRM accessibility.
- Subject matter experts in CRM recovery and reclamation processes.
- Focus on CRM materials deemed most vulnerable by the Defence sector.

By systematically addressing these challenges, the UK can build a robust, self-sustaining CRM recovery and reclamation ecosystem, reducing supply chain risks while driving innovation and economic growth.

¹ [S3000L Issue 2.1, dated April 2023](#)

² [S1000D Downloads](#)

CONTENTS

Table of Contents	
Securing Critical Raw Materials for Defence	2
Executive Summary	2
Value Proposition	2
Socio-Political Context	2
Aim and Objectives	2
The Framework	2
Outputs and Outcomes	4
Next Steps	4
Introduction	8
Aim and Objectives	8
Approach	8
Findings	9
<i>Framework Overview:</i>	9
<i>Stage 1: Assessment of Critical Raw Materials' Supply Risk</i>	9
<i>Stage 2: Harvesting Defence Equipment for CRM</i>	9
<i>Stage 3: Assessment of UK CRM Recovery and Refining Capability</i>	9
<i>Stage 4: Regulatory Challenges Impacting UK Competitiveness</i>	9
<i>Iterative Application</i>	10
Stage 1: Assessment of Critical Raw Materials' Supply Risk	12
<i>Stage 1a: Identification of high-risk Critical Raw Materials</i>	14
<i>Stage 1b: Determination of Risk to Defence's Operational Resilience</i>	14
Stage 2: Harvesting Defence Equipment for CRM	15
<i>2a. Preliminary Screening and Equipment Mapping</i>	15
<i>2b. Sub-System Analysis to identify potential concentrations of CRM.</i>	16
<i>2c. Sectoral Correlation and CRM Clustering Analysis</i>	16
<i>2d. Material Composition Characterisation</i>	16
<i>2e. CRM Reclamation Task Definition</i>	16
<i>2f. Reclamation Feasibility and Lifecycle Integration</i>	17
<i>Harvesting Opportunity Process Flow</i>	18
<i>Harvesting Opportunity</i>	19
<i>Actions to Improve Defence Equipment CRM Harvesting</i>	20
Stage 3: Assessment of UK CRM Recovery and Refining Capability	21
<i>Stage 3 Overview</i>	21
<i>Stage 3 Activity</i>	22
<i>Step 3b: Classification and Routing for Recovery</i>	22
<i>Sovereign Capability Assessment</i>	26
<i>Priority Actions to Enabling CRM Recovery Through Strategic Investment</i>	27

Stage 4: Regulatory Challenges Impacting UK Competitiveness	29
<i>Path Towards Innovation-Led Regulatory Adaptation</i>	30
<i>Assessing UK competitiveness</i>	30
<i>Strategic Enablers for Global Competitiveness</i>	30
<i>Path to Global Leadership: Technology-Driven, Secure, and Sustainable</i>	31
Conclusion: Advancing Strategic Autonomy Through Circular CRM Practices	32
<i>Framework Development and Application</i>	32
<i>Enabling Implementation Across Defence Programs</i>	32
<i>Strategic Investment and Innovation Priorities</i>	32
<i>Next Steps: Pilot Validation</i>	33
<i>Strategic Outcomes</i>	33
<i>Value Creation</i>	33
<i>Economic Growth and Revenue Generation</i>	33
<i>Advanced Manufacturing and Innovation</i>	34
<i>Enhanced UK Material Security</i>	34
<i>Job Creation Across Skill Levels</i>	34
Recommendations	34
<i>Pilot Program Objectives and Scope</i>	34
<i>Proposed Pilot Candidates</i>	35
<i>Next Steps</i>	35
<i>Acronyms</i>	36
<i>Contributors</i>	36
<i>Glossary</i>	37



INTRODUCTION

The demand for Critical Raw Materials (CRM) in Defence is rising³. However, with adversarial influence dominating supply chains, there is an increased risk to operational support, equipment programs, and future capability development.

Integrating circular economy principles across the capability lifecycle will extend the use of CRM, enhancing Defence supply chain resilience while also reducing the sector's carbon and environmental impact⁴.

Currently, most Defence equipment is disposed of at the end of its life⁵.

AIM AND OBJECTIVES

This study aims to develop a decision framework for policymakers, design engineers, supportability analysts, and commercial teams to ensure that once acquired the value of CRM is exploited within the Defence ecosystem.

The framework will guide design decisions to minimize CRM dependency, promote recyclability, and support investment in new chemical processes, automation, and infrastructure to build sovereign capability. Additionally, it will set the conditions to embed key performance indicators (KPIs) in procurement processes to drive recycling and mitigate ESG risks.

This approach aims to reduce supply chain risk, enhance resilience in the supply of Defence critical materials, and maintain the UK's operational advantage. Additionally, establishing a high-value recycling capability in the UK will create jobs, advance intellectual property in chemical processing and automation, and strengthen the national industrial base.

The resulting framework will contribute to the Defence Industrial Strategy Consultation and support the implementation of circular economic principles in Defence.

The goal is to secure a reliable supply of Defence critical materials for the UK Defence sector.

APPROACH

Over four weeks, a small team of volunteers from Defence and Industry, including UK Based reclamation Small Medium Enterprises (SMEs), collaborated remotely to develop an initial framework. The work progressed as follows:

- **Week 1:** Document trawl and literature review
- **Week 2:** Development of the high-level framework design
- **Week 3:** Framework population and integration
- **Week 4:** Documentation of findings

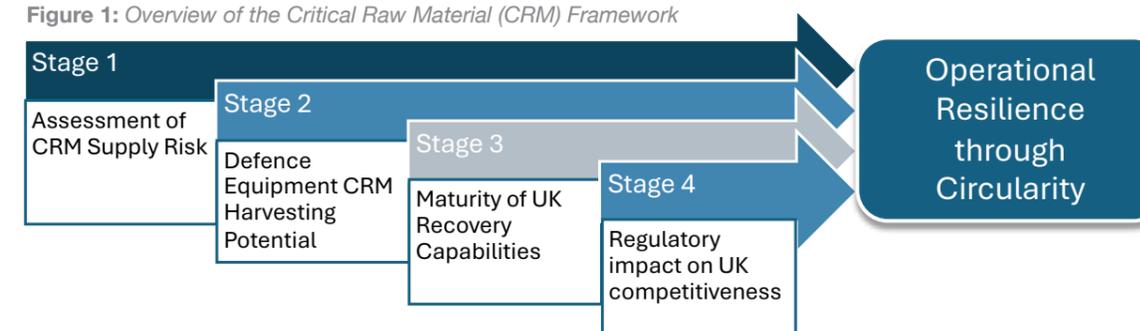
An iterative approach was used to develop the framework, starting with an initial outline that was refined through a review of existing approaches, methodologies, and frameworks. As understanding evolved and new ideas emerged, the framework was further enhanced and expanded. Key considerations included the types of decisions it would support, the relevant decision-makers, and the use of visualizations to aid decision-making.

FINDINGS

Framework Overview:

The proposed framework outlined in this document is composed of four key stages, [Figure 1](#).

Figure 1: Overview of the Critical Raw Material (CRM) Framework



Stage 1: Assessment of Critical Raw Materials' Supply Risk

This stage involves evaluating the risks associated with specific CRMs by identifying current and future vulnerabilities in the global supply chain. The analysis also considers how these risks could impact Defence operational capabilities and levels of dependency.

This stage assesses the UK's current sovereign capabilities for domestic CRM recovery, reclamation, and processing. It also identifies existing gaps in the market and considers opportunities for collaboration with allies or investment in UK infrastructure where appropriate.

Stage 2. Harvesting Defence Equipment for CRM

This stage explores the potential for End-of-Life (EOL) Defence equipment to serve as a source of reclaimed CRMs. It involves identifying viable recovery opportunities and assessing their practical implementation.

Stage 4: Regulatory Challenges Impacting UK Competitiveness

This stage evaluates the regulatory and legislative factors affecting CRM use across their life cycle. This includes analysis of virgin material extraction, current and projected UK processing capabilities, and end-of-life disposal practices.

Each stage features specific, weighted criteria used for scoring, with accompanying guidance to support consistent evaluation. Visual tools are integrated throughout the framework to highlight key priority actions.

Stage 3: Assessment of UK CRM Recovery and Refining Capability

³ <https://Strategic-Raw-Materials-for-Defence-HCSS-2023-V2.pdf>

⁴ https://Sustainable_circular_economics_for_Defence_concept_note.pdf

⁵ Defence ICT is managed through a contract where items that cannot be reused are shredded and recycled with CRM reclaimed

Iterative Application

Each stage can be applied independently; however, the true value of the framework emerges through its interconnections. This integrated approach enables an iterative process and offers flexibility, accommodating the diverse perspectives, expertise, and needs of all stakeholders involved. Each stage functions independently but their interconnections create a dynamic, iterative process that enhances overall insight and decision-making. This map, [Figure 2](#), highlights the key feedback loops and dependencies critical to strategic CRM planning.

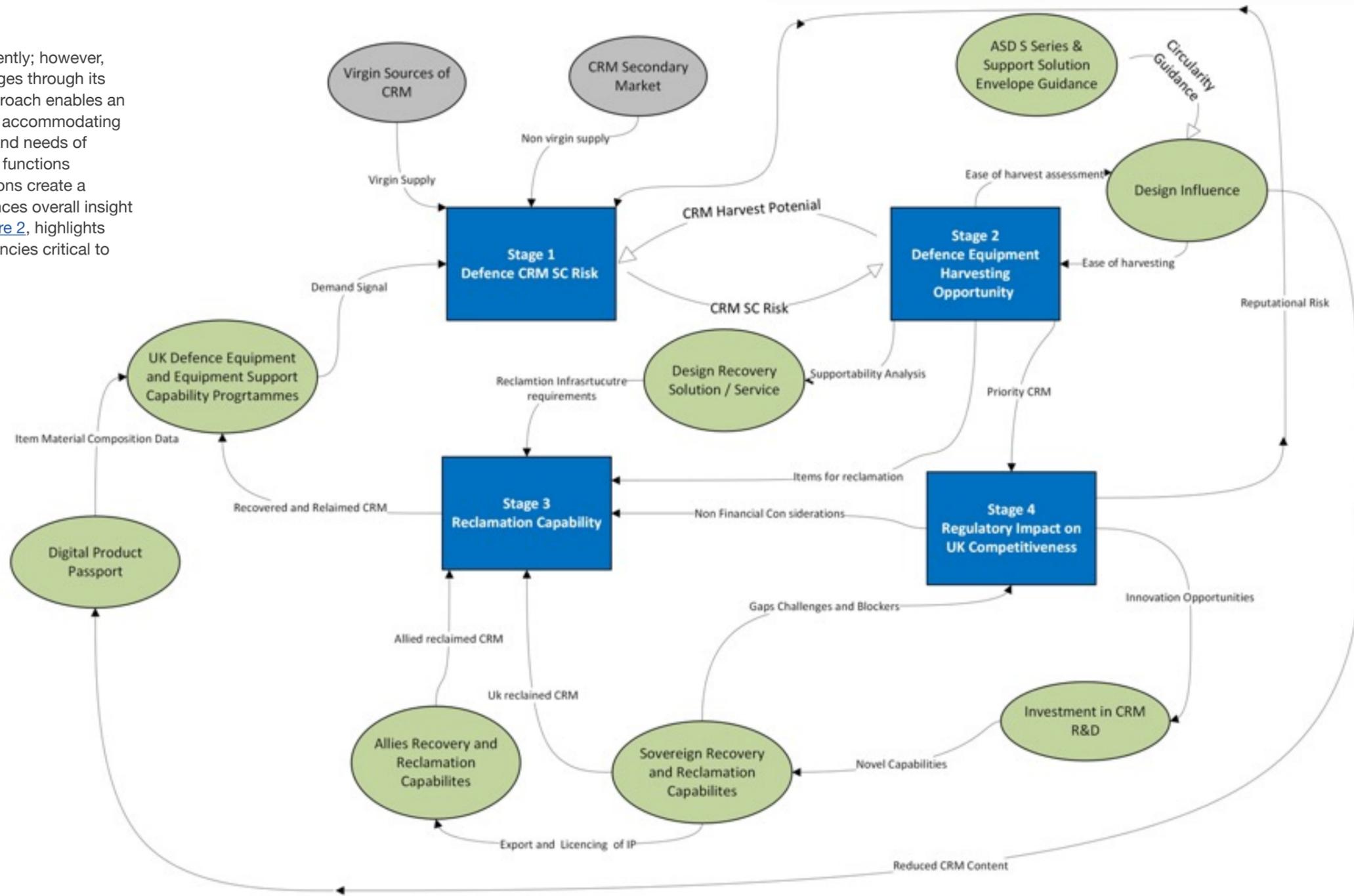


Figure 2: High-Level Influence Map illustrating the interactions within the Framework.

STAGE 1 ASSESSMENT OF CRITICAL RAW MATERIALS' SUPPLY RISK

Stage One of the proposed framework utilises a decision matrix, [Figure 3](#) designed to identify high-risk Critical Raw Materials⁶ (CRMs) and assess their potential impact. While it is acknowledged that all CRMs carry inherent risk, this stage focuses on evaluating their relative supply risk to highlight priority areas of concern.

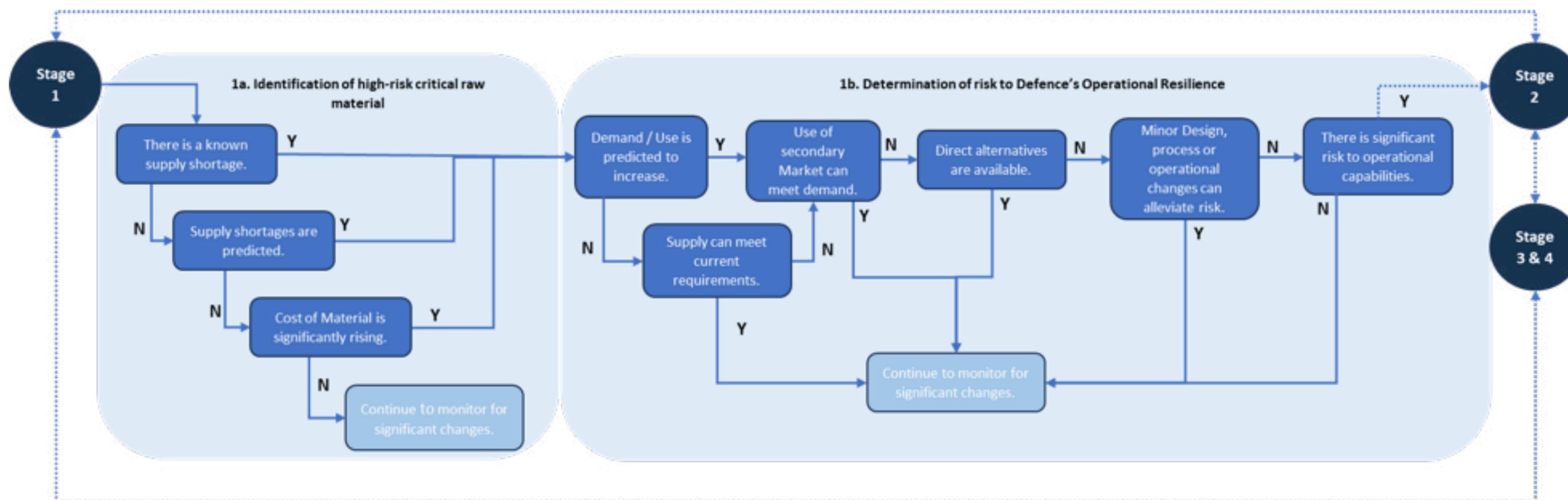


Figure 3: Decision Matrix for Stage 1 of the framework, 'Assessing a critical raw materials' supply risk'.

⁶ The UK MOD have identified 41 materials that they consider critical to maintaining current and future capabilities.

Stage 1a: Identification of high-risk Critical Raw Materials

The risk level of a CRM is assessed by evaluating it against three key scenarios:

- **Known Supply Shortage:** A confirmed, ongoing national or global shortage of the CRM.
- **Predicted Supply Shortage:** Emerging concerns within the market or supply chain suggesting a potential shortage or disruption. These may stem from geopolitical shifts, newly imposed export restrictions, or announced tariffs.
- **Significant Price Increase:** A sharp rise in CRM cost, which—while not definitive—may indicate market instability and serve as an early warning of potential supply issues

Stage 1b: Determination of Risk to Defence's Operational Resilience

This stage evaluates the potential impact of a high-risk CRM on Defence sector operational resilience, using the following criteria:

- **Projected Increase in Demand:** Anticipated rise in CRM use for future Defence applications.
- **Current Supply Meets Demand:** Existing supply is adequate to support current Defence needs.
- **Secondary Markets Can Supplement Supply:** Availability of established secondary sources (e.g., scrap metal) to offset potential supply disruptions.
- **Direct Alternatives Exist:** The CRM can be replaced without requiring changes to design, processes, or operations.
- **Minor Adjustments Mitigate Risk:** Small design, process, or operational changes—without affecting performance—can reduce or eliminate CRM dependency.
- **Operational Capability is at Risk:** The CRM is critical to core Defence functions such as mobility, lethality, survivability, command & control, or supportability.

Next Steps: If all criteria are met, further evaluation through Stages 2, 3, and/or 4 is recommended. If any criterion is not met, no further action is required beyond routine monitoring for significant market changes, [Figure 3](#).

Note: As the framework supports non-linear use, analysis in later stages may influence earlier conclusions drawn in Stage 1.

STAGE 2 HARVESTING DEFENCE EQUIPMENT FOR CRM

This stage focuses on the systematic assessment of End-of-Life (EOL) and Beyond Economic Repair (BER) Defence platforms, subsystems, and components to determine the feasibility and value of recovering CRM. The intent is to inform strategic resource planning, support circular economy principles, and enhance sovereign resilience in CRM supply chains.

This stage consists of the following steps.

2a. Preliminary Screening and Equipment Mapping

Utilising the taxonomy defined in the January 2023 report by The Hague Centre for Strategic Studies, “Strategic Raw Materials for Defence: Mapping European Industry Needs”⁷, candidate platforms are screened to identify those with potential CRM content, [Figure 4](#). This initial filter establishes alignment between known CRM applications and the selected equipment, enabling prioritisation for further analysis and subsequent harvesting.

Supply risk for critical raw materials in military applications

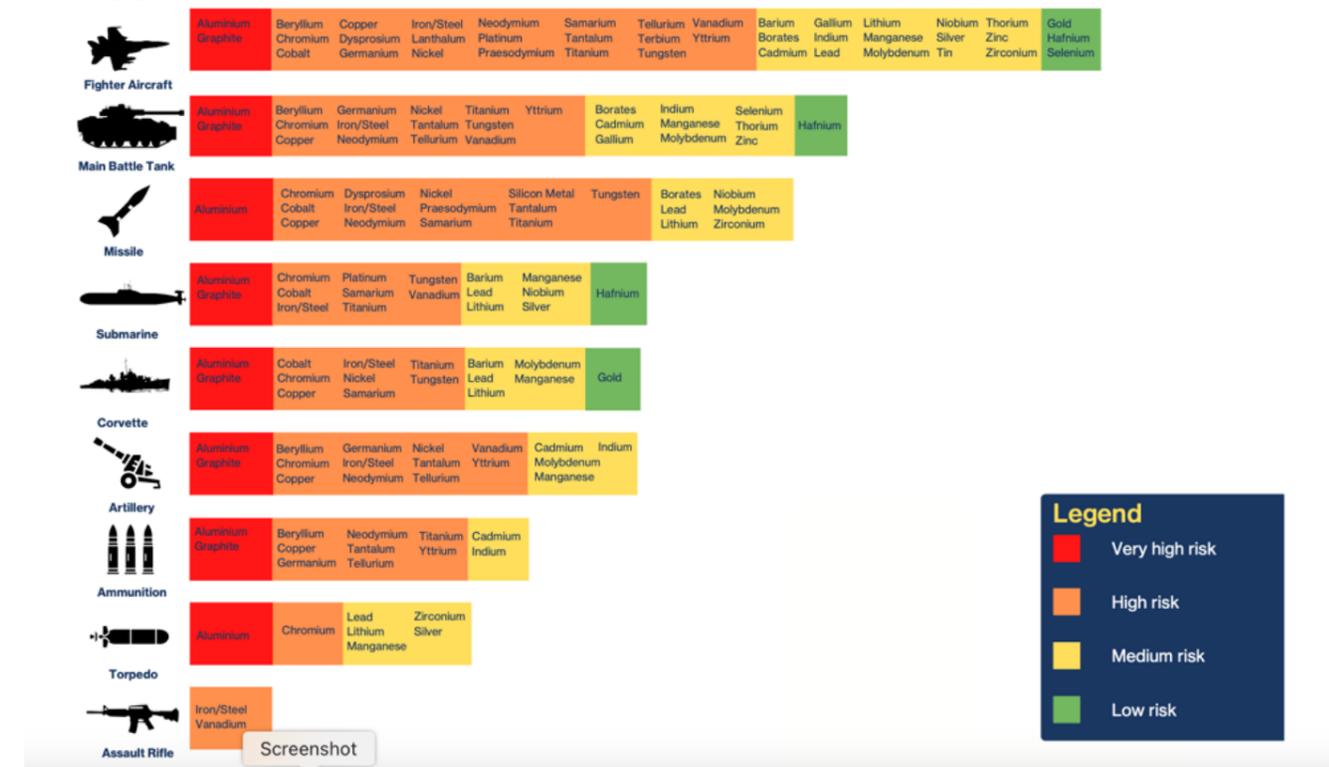


Figure 4: CRM Risk across Defence Equipment⁷ provides an indication of harvesting potential

⁷ <https://Strategic-Raw-Materials-for-Defence-HCSS-2023-V2.pdf>

⁸ IBID

2b. Sub-System Analysis to identify potential concentrations of CRM

The next phase of analysis involves breaking down the candidate source into its subsystems or components, which can then be cross-referenced with the previously mentioned paper⁹. This process combined with item description data provides indicative information on the item's size, weight, and material handling requirements, as well as the concentration and composition of CRM.

2c. Sectoral Correlation and CRM Clustering Analysis

Given the tendency of CRMs to occur in clustered material systems rather than in isolation, platform components are then categorised in alignment with established industry classifications (e.g., WEEE Directive categories for electronic waste). Comparative analysis with equivalent civilian or commercial systems supports inference of CRM recovery potential, refining expectations around processing routes and material flow.

2d. Material Composition Characterisation

If preliminary analysis confirms potential CRM presence, a tiered methodology is applied to characterise material composition:

- **Gold Standard:** Full materials database with declared raw material composition and CRM-tagged components
- **Silver Standard:** Availability of a complete Bill of Materials (BoM) and raw material specifications, validated through design authority inputs
- **Bronze Standard:** Component-level equipment breakdown, supported by supplier declarations or part specifications

In cases of insufficient data, two alternative approaches are deployed:

- **Subject Matter Expert (SME) Judgement:** Informed estimation based on analogous systems, historical usage trends, and available technical references (e.g., Ref 1)
- **Reverse Engineering Techniques:** Application of advanced diagnostic technologies, such as:
 - XRF/FTIR Spectroscopy
 - Hyperspectral Imaging
 - 3D Laser Scanning and Surface Profiling
 - Ultrasonic and other Non-Destructive Evaluation (NDE) methods

NOTE: Emerging AI/ML-powered tools may enhance material classification precision but require cost-benefit assessment in context of scale and platform complexity.

2e. CRM Reclamation Task Definition

Following material characterisation, a CRM-specific Task Analysis is conducted—modelled on ASD S3000L Maintenance Task Analysis principles¹⁰—to define the physical and logistical requirements for material extraction. Typical operations include:

- Disassembly (component/system level)
- Cover and shield removal
- CRM-containing part extraction
- Sorting, segregation, and interim storage
- Preparation for primary/secondary processing
- Security-driven processes (e.g., data sanitisation, crypto fill removal, secure destruction)

The Task Analysis also specifies required resources:

- Labour profiles and skillsets
- Tooling and support equipment
- Handling, storage, and containment solutions

2f. Reclamation Feasibility and Lifecycle Integration

A comprehensive assessment is conducted to determine the feasibility of CRM reclamation, considering the platform's position within the CADMID lifecycle. This may include:

- Design-for-recovery reviews
- Prototype-based disassembly trials
- Human/system interface analysis for task simplification and efficiency gains

Outcomes from this stage - reclamation quantification, feasibility, tasking, and resourcing - inform subsequent analysis in Stage 3 and are cross-referenced with Stage 4 to ensure alignment with national policy and strategic objectives.

⁹ IBID

¹⁰ S3000L Issue 2.1, dated April 2023

Harvesting Opportunity Process Flow

The process flow for the steps is illustrated in [Figure 5](#).

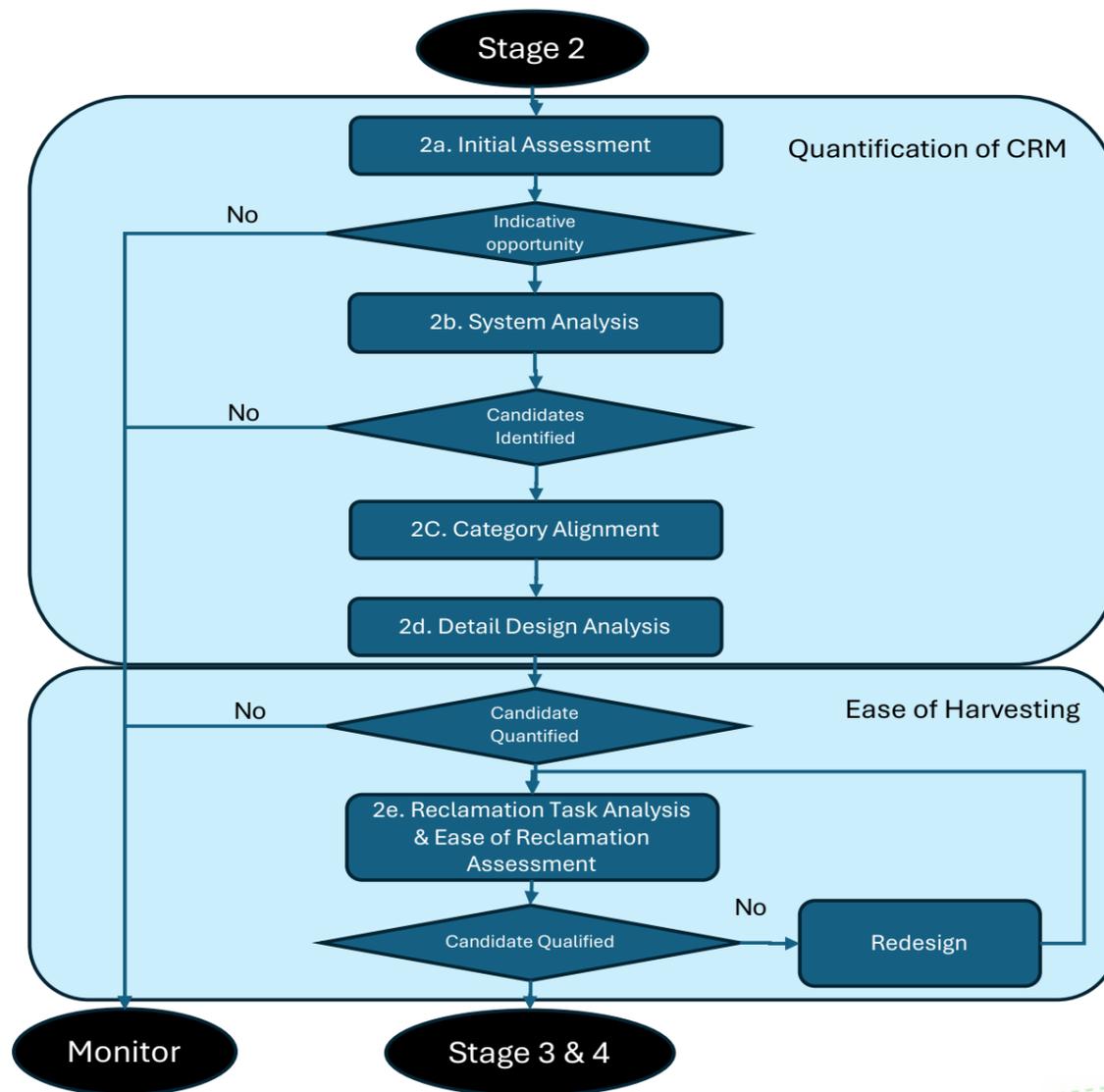


Figure 5: CRM Harvesting Opportunity Assessment Process Flow

Harvesting Opportunity

As each step is completed the scoring matrix, [Table 1](#), is completed, this is subjective and should be populated using expert judgement panels.

Step	Score				Comment
Candidate item contains CRM	None	Unquantified	Some	Significant	Indicative size of opportunity
	0	1	2	3	
Design Information Available	None	Bronze	Silver	Gold	Confidence in analysis
	0	1	2	3	
Alignment with Industry Categorisation	No	Partial	Fully aligned		Implied availability of reclamation capabilities
	0	1	2		
Ease of Reclamation	Difficult	Specialist Task	Un-skilled		Suggests availability of workforce
	0	1	2		

Table 1: Harvesting Opportunity Scoring Matrix

Upon completion of the assessment matrix, results should be synthesised by correlating Defence Supply Chain risk with the relative ease of CRM recovery across the evaluated platforms, subsystems, and components. This mapping enables strategic prioritisation by identifying high-risk materials that are both critical to Defence capability and technically feasible to recover, thereby supporting targeted investment and policy action in recovery and reuse pathways, [Figure 6](#).

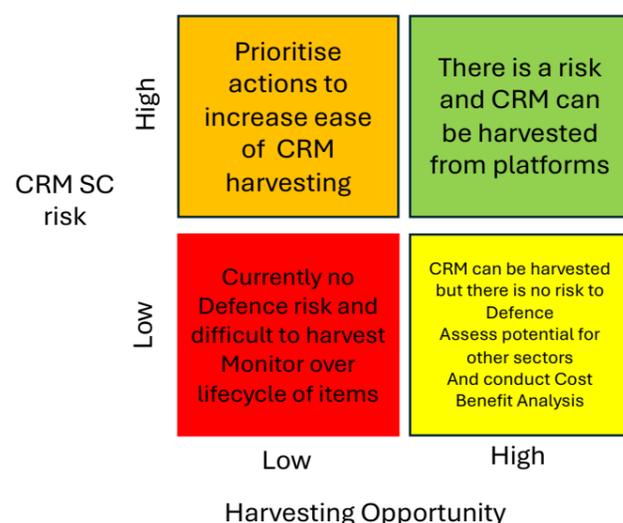


Figure 6 Visualisation correlating Defence Supply Chain risk with the relative ease of CRM harvesting across the evaluated platforms, subsystems, and components informs prioritisation of action

Actions to Improve Defence Equipment CRM Harvesting

Key actions in this stage are targeted at both Design and Supportability Engineering functions:

- **Design Engineers** should prioritise the elimination or substitution of CRMs during the conceptual and detailed design phases. Where elimination is not feasible, designs should be optimised to enable efficient end-of-life recovery — for example, through material simplification, use of modular assemblies, or selection of reversible fastening methods and benign solvents.
- **Supportability Engineers** should integrate CRM reclamation considerations into the Through Life Support strategy. This includes embedding recovery pathways into Level of Repair Analysis (LORA) and leveraging common facilities or processes to support disassembly and material reclamation activities.

These efforts should be iterative and continuous throughout the system lifecycle, with feedback loops from later stages (e.g., recovery outcomes or legislative constraints) informing future design and support decisions. Integration across all stages of the CRM framework is essential to maximise resilience and sustainability.

STAGE 3 ASSESSMENT OF UK CRM RECOVERY AND REFINING CAPABILITY

Stage 3 Overview

This stage evaluates the UK's ability to recover and refine Critical Raw Materials (CRMs) through integrated collection, disassembly, processing, and refining operations.

Collection and Disassembly

A vertically integrated upstream recycling capability—where single entities manage both collection and disassembly—offers efficiency gains through streamlined logistics and reduced material loss. The UK benefits from a mature recycling infrastructure, particularly in electronic waste management under the WEEE Directive, with:

- 81 Approved Authorised Treatment Facilities (AATFs)
- Multiple Designated Collection Facilities (DCFs)

These facilities operate under Best Available Treatment, Recovery, and Recycling Techniques (BATRRRT), enabling effective CRM recovery. Mechanical pre-processing at these sites further enhances the concentration of valuable materials, optimising downstream recovery potential.

Material Recovery

CRM recovery from disassembled components or processed concentrates requires specialised and often feedstock-specific technologies. While the UK currently has limited recovery capacity—largely focused on precious metals (e.g. gold, silver, PGMs)—emerging domestic capabilities are advancing through mid- to high-TRL innovation. Notable actors include:

- DEScycle, Royal Mint, Pensana, HyProMag, Ionic Technologies, and CellCycle (TRL 7–9)
- Academic and corporate R&D efforts (<TRL 6), contributing to the development of next-generation recovery technologies

Despite progress, significant volumes of CRM-rich material are still exported for processing abroad.

Metal Refining

The refining stage upgrades intermediate products to high-purity, specification-grade metals. UK refining infrastructure remains limited and is concentrated in precious metals. Key constraints include:

- Lack of large-scale domestic CRM feedstock
- High operational costs
- Absence of refining capacity for critical categories such as Rare Earth Elements (REEs) and battery-related materials like Precursor Cathode Active Materials (P-CAM) and Cathode Active Materials (CAM)

While allied nations across NATO provide refining capacity for various metals, expanding UK-based refining remains a strategic challenge and potential opportunity for industrial policy alignment.

Stage 3 Activity

Step 3a: Pre-Processing Assessment for CRM Recovery

Following the identification of relevant platforms, components, and subsystems in Stage 2, the initial action in Stage 3 is to determine whether these assets should be transferred as complete assemblies or disassembled into constituent parts prior to third-party CRM recovery. This decision must align with Defence-specific operational, security, and regulatory considerations.

Key assessment criteria include:

- **Material Handling Requirements.** Evaluate size, mass, structural complexity, and the need for specialised tooling or lifting equipment to ensure safe and efficient transport or disassembly.
- **Military Specification & IP Protection.** Assess the risk that full system transfer could expose sensitive design features or compromise proprietary technologies, system performance, or platform integrity.
- **Data and Cryptographic Security.** Determine if the asset contains classified data or cryptographic components. If present, define and implement appropriate sanitisation, data-wipe, or physical destruction measures.
- **Safety and Environmental Compliance.** Identify hazardous materials (e.g. batteries, compressed gases, or legacy substances like asbestos) and ensure compliance with applicable environmental, health, and safety standards.

Step 3b: Classification and Routing for Recovery

Upon completing pre-handling assessments, CRM-containing assets—including full platforms, major assemblies, repairable units, and discrete components—are triaged and routed through defined recovery and refining pathways.

Actions include:

- **Material Classification.** Components are categorised based on material type, CRM concentration, and processing method requirements.
- **Processing Pathway Assignment.** Each category is aligned with a corresponding approved or licensed UK recovery and recycling facility capable of handling that specific material class, [Table 2](#).

Group	Description	Register of Capabilities
Defence Specific	Nuclear capabilities, whole platforms, Special armour, explosives and munitions	no current repository of capability
WEEE	IT and telecommunications equipment, radios, screens, Lighting equipment, Electrical and electronic, Medical devices, Monitoring and control equipment	DCF and AATF Government Register
Ferrous Metals	Steel	
Non-Ferrous Metals	Alu, Copper, Lead, Zinc, Titanium	
Batteries	All types	Registered ABTO&E
Magnets	Disassembled magnets for a specialist recycler.	
Mixed	Mixed waste that doesn't fit into above categories. Treated at a "MRF" (Materials Recovery Facility)	

Table 2: CRM Group Reclamation Capabilities

This classification and routing approach enables traceable, secure, and efficient CRM reclamation while supporting regulatory compliance and maximising material recovery yield. [Figure 7](#) provides a representation of how the framework outputs fit together.

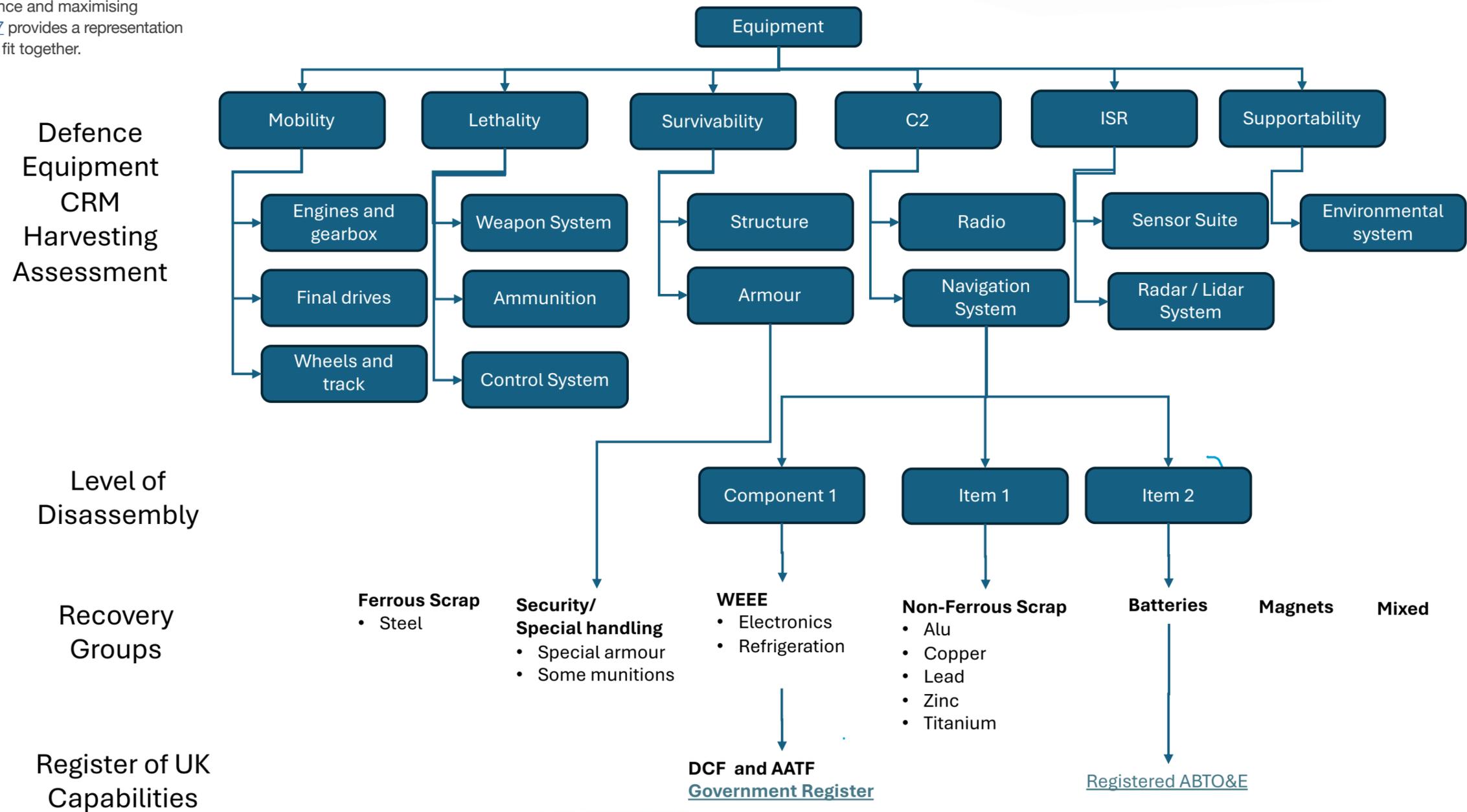


Figure 7 Illustrative representation mapping linkages across the stages

Sovereign Capability Assessment

As each step is completed the scoring matrix is filled in, this is subjective and should be populated using expert judgement panels, [Table 3](#)

Step	Score				Comment
	Yes	Unquantified	Some	No	
Need for Defence disassembly	0	1	2	3	Need for Defence Specific capability (assumes there are currently none)
	Yes	Unquantified	Some	No	
What is to be processed	0	1	2	3	Assumption is that it is easier to process at item level
	Platform	Sub-system / assembly	SRU/LRU	Item/ Component	
Availability of Uk Sovereign capabilities	0	1	2		Ability to process in UK
	None	Some	Full		
Availability of NATO/EU facilities	0	1	2		Ability to partner and process with Allies
	None	Some	Full		

Table 3: Stage 3 scoring matrix

Once the grid is complete, the information can be summarized by mapping the Defence Supply Chain risk against the availability of recovery and refinery capabilities.

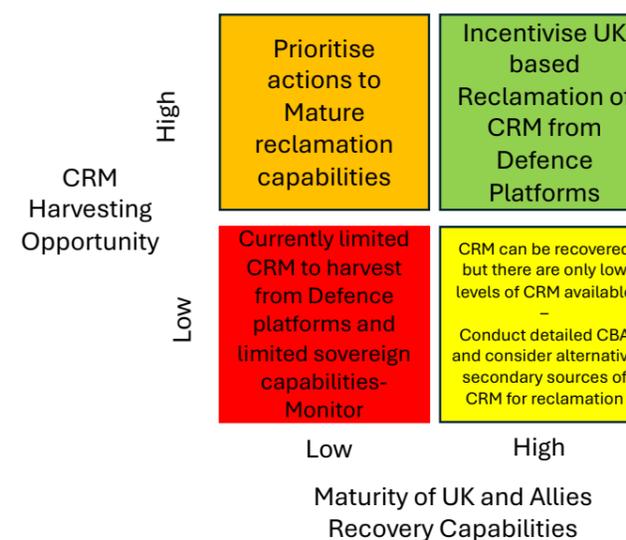


Figure 8: Stage 3 Visualisation

Priority Actions to Enabling CRM Recovery Through Strategic Investment

Where the recovery of Critical Raw Materials (CRM) from Defence assets can mitigate supply chain risk, but no UK sovereign or allied recovery capabilities currently exist, targeted investment is essential to bridge capability gaps:

- **Investment should be driven by:**
 - **Capability Gap Analysis** – Identify shortfalls in domestic recovery and refining infrastructure.
 - **Cost-Benefit Assessment** – Ensure value-for-money across the investment lifecycle.
 - **ESG Considerations** – Address regulatory barriers, policy drivers and leverage opportunities for sustainable growth.
- **Priority investment areas:**
 - **Infrastructure Expansion** – Build or scale facilities in line with the Defence Industrial Strategy (DIS) to increase sovereign resilience.
 - **Advanced Technologies** – Develop and deploy robotics, AI, and automation to optimise CRM recovery efficiency and safety.
 - **Green Processing Solutions** – Innovate low-impact chemical processes that meet environmental standards and reduce operational risk.

Outcome: Strategic investment across these domains will reinforce the UK's CRM supply chain resilience, align with Defence readiness objectives, and promote sustainable industrial capability.

STAGE 4 REGULATORY CHALLENGES IMPACTING UK COMPETITIVENESS

The UK was the first major economy to make legally binding Net Zero emissions targets. Utilising regulation as a tool to encourage industry and incentivise innovation for environmental progress, the UK has demonstrated that the right regulatory toolkit can be a key enabler of a thriving industry for the future. It is also an important pillar of protecting the interests of vulnerable ecosystems, habitats and communities, while at the same time creating an environment for innovation to prosper. By navigating this balance with skill and sensitivity, the UK has the potential to become a leading Western economy in the drive for a domestic CRM market and supply chain.

Some of the key regulatory frameworks that influence the domestic development of CRM recovery and refining infrastructure include:

- The WEE and the Environmental Protection Act 1990 regulate emissions, waste processing, and hazardous materials
- Permitting and compliance requirements apply to chemical-intensive processes for Rare Earth Element (REE) recovery

Currently, there is a lack of robust incentives for CRM recycling initiatives. These could include tax reliefs, subsidies or strategic funding, all of which has been proved successful policy interventions in other key sustainability areas, such as emerging low carbon fuel technologies. Further to this, planning and environmental permitting processes face long delays and put a high administrative burden on businesses, which can further delay infrastructure deployment. Also, the broader waste shipment controls¹¹ for managing waste in an environmentally sound manner, producer responsibility regulations and certain prohibitions within UK Trade

Tariffs can impact the export and shipment (and transit) of CRM waste for processing in other countries.

There are clear incentives for strengthening the regulatory attractiveness of a domestic CRM market. For example, the current lack of domestic refining capacity forces reliance on overseas facilities, such as facilities in China, which can expose supply chains to geopolitical risk. Elevated UK energy prices and higher corporate taxes can also increase barriers to market entry and scale-up.

Global view:

- U.S. and Australia have announced plans to ease restrictions via national strategies to incentivise domestic REE processing.
- Countries including Canada and Australia offer competitive tax incentives and streamlined investment paths to CRM projects.
- The EU is supporting domestic (to the bloc) CRM projects through the Critical Raw Materials Act.
- Japan uses public-private partnerships to localise refining and secure supply chains.
- U.S. and EU are legislating to onshore CRM processing.
- China maintains competitiveness via subsidised energy and lower compliance thresholds. Laxer environmental enforcement benefits low-cost large-scale processing.
- U.S. and Australia counterbalance costs with targeted government support.

¹¹ Waste Shipments Regulation EC No 1013/2026 (as amended) covers the export of waste

Path Towards Innovation-Led Regulatory Adaptation

To restore competitiveness while upholding environmental and safety standards, the UK should:

- Target R&D investment toward compliance automation, green recovery processes, and low-emission refining technologies.
- Align innovation funding with regulatory pain points to enable UK CRM industries to overcome structural constraints.
- Incentivise sustainable CRM development through policy mechanisms that reduce reliance on virgin material extraction and overseas processing.

A regulatory environment that actively supports innovation—through adaptive policy, funding, and public-private collaboration—can strengthen sovereign capability, reduce environmental impact, and build industrial resilience across the Defence supply chain.

Assessing UK competitiveness

The following scoring matrix identifies areas where innovation can maintain the UK as a leader in regulatory compliance while improving productivity, [Table 4](#).

Process factor	Low	Medium	High
Labour intensive			
Hazardous			
Environmental Impact			
Energy Consumption			
Carbon Footprint			

Table 4: Opportunities to increase UK competitiveness through innovation

Mapping the impact against current UK capabilities using a Boston Box provides a clear visual representation of where targeted investment can close capability gaps, enhance competitiveness, and reinforce the UK's global leadership in environmental sustainability, employment, and health and safety compliance.

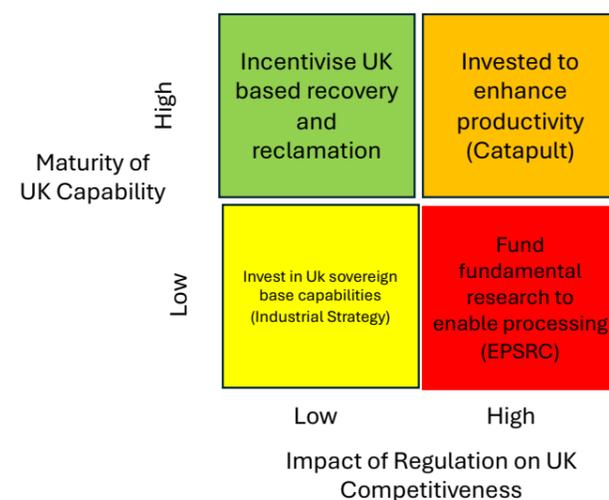


Figure 9 Prioritising Research and Development for UK Advantage

Strategic Enablers for Global Competitiveness

To remain competitive in the evolving global critical raw materials (CRM) landscape, the UK must address structural barriers and capitalise on innovation opportunities. Key actions include:

- 1. Accelerated Permitting Frameworks.** Streamline environmental and planning approvals to reduce lead times for CRM recovery and refining projects.
- 2. Targeted Financial Incentives.** Introduce grants, tax credits, and low-interest financing to de-risk private investment in rare earth recycling and refining infrastructure.

- 3. Sovereign Processing Mandates.** Strengthen policy levers to retain strategic materials within the UK, minimising reliance on overseas processing and mitigating geopolitical exposure.
- 4. Public-Private Collaboration.** Facilitate coordinated R&D and infrastructure development through long-term government-industry partnerships focused on sustainable, economically viable recycling solutions.

performance rare earth recycling—enhancing supply chain resilience, driving clean growth, and supporting national Defence and energy security.

Without decisive action in these areas, the UK risks losing ground to countries actively reshoring CRM capabilities and attracting global investment through favourable regulatory and financial environments.

Path to Global Leadership: Technology-Driven, Secure, and Sustainable

By integrating advanced technologies and aligning policy support, the UK can position itself at the forefront of rare earth recycling:

- **Automation & Robotics** – Reduce operational costs and increase processing throughput.
- **Green Chemistry** – Minimise environmental impact through cleaner, low-emission refining techniques.
- **AI-Powered Sorting & Analysis** – Improve material recovery accuracy and efficiency.
- **Modular Recycling Plants** – Enable scalable, decentralised processing closer to source.
- **Traceability** – Ensure transparent, secure tracking of recovered materials across the supply chain.

When coupled with strategic government backing and targeted industrial investment, these capabilities could transform the UK into a global hub for ethical, high-

CONCLUSION: ADVANCING STRATEGIC AUTONOMY THROUGH CIRCULAR CRM PRACTICES

At the macro level, NATO faces escalating demand for Critical Raw Materials (CRM) amid intensifying global competition for finite virgin resources. Embedding circular economy principles into Defence logistics and acquisition strategies—particularly the reclamation and reuse of CRM—presents a critical opportunity to enhance supply chain resilience and reduce strategic dependency.

However, to translate these principles into operational impact, more granular implementation is needed at the platform, system, and product levels.

Framework Development and Application

The proposed CRM recovery framework is in its early stages and requires further refinement and validation. By applying its methodology across the CADMID lifecycle, stakeholders can:

- **Assess CRM Accessibility and Design Dependencies.** Identify where design modifications can enable easier CRM recovery or reduce reliance on scarce materials.
- **Evaluate National Processing and Refining Capabilities.** Pinpoint gaps where investment or Allied cooperation is essential to building sovereign or secure near-shore processing capacity.

Enabling Implementation Across Defence Programs

The framework supports CRM reclamation in capability and support planning by:

- **Incorporating CRM Requirements Early.** Embedding reclamation and data traceability within capability requirements and design specifications.
- **Supporting Supportability Engineering.** Integrating CRM considerations into Level of Repair Analysis and in-service support planning.
- **Driving Data and Process Standardisation.** Aligning with key methodologies and toolkits, including:
 - ASD S3000L (Task and Maintenance Analysis)¹²
 - ASD/AIA S1000D and AXi 1000D (Data Dictionary)¹³
 - IAM Asset Registers, materials databases, and emerging digital product passports
 - AI/ML tools for CRM detection and disassembly planning

Strategic Investment and Innovation Priorities

To close capability gaps and foster industrial maturity, investment decisions should be evidence-led and aligned with UK strategic goals:

- **Defence-Unique Capabilities.** Defence funding should focus on CRM processing capabilities essential to sovereign operational requirements.
- **Dual-Use Innovation Pathways.** Innovate UK and EPSRC funding should support novel chemical processing methods with civilian and military applications.

- **Cross-Sector Infrastructure Development.** Innovate UK and the High Value Manufacturing Catapult centres should facilitate development of near-shore, cross-sector refining capacity.
- **Emerging Technologies.** Prioritise R&D in robotics, AI, and green chemistry for CRM reclamation, and secure IP in sustainable processing techniques.

Next Steps: Pilot Validation

To mature and validate the framework, it should be tested against representative defence platforms and products. This requires:

- Access to OEM design data and subject matter expertise in CRM recovery
- A focused approach targeting CRM most critical to Defence capability sustainment
- Cross-stakeholder collaboration between Defence, academia, industry, and Catapults

Strategic Outcomes

By addressing these challenges, the UK and NATO can:

- Strengthen strategic autonomy in critical materials
- Enhance resilience against supply chain disruption
- Support environmentally responsible resource management
- Foster a globally competitive, sustainable Defence industrial base

A proactive, circular approach to CRM recovery is not just an environmental imperative—it is a strategic necessity.

Value Creation

Establishing a UK-based recycling capability for rare earth metals and minerals offers substantial economic, environmental, and strategic benefits. Several key areas highlight the value proposition:

Economic Growth and Revenue Generation

- **Domestic Revenue:** The Royal Mint's new facility in Llantrisant, Wales, demonstrates the economic potential of processing electronic waste. The plant will handle 4,000 tonnes of circuit boards annually, recovering valuable metals such as gold, copper, silver, and palladium.
- **Export Opportunities:** UK companies like Ionic Technologies and Hypromag are developing circular supply chains for rare earth elements, reducing waste and providing high-purity recycled materials to global markets. This positions the UK as a leader in sustainable resource management.
- **IP and Technology Licensing:** Innovations in green chemistry, such as the QUILL research centre's work at Queen's University Belfast, have led to advancements in ionic liquid-based rare earth metal recovery. These technologies can be licensed internationally, strengthening the UK's position in sustainable materials science.

¹² [S3000L Issue 2.1, dated April 2023](#)

¹³ [S1000D Downloads](#)

Advanced Manufacturing and Innovation

- **Robotics and Automation:** The Royal Mint's facility utilizes advanced extraction technologies, demonstrating how automation can enhance efficiency in modern recycling operations.
- **Eco-Friendly Chemical Processing:** The University of Edinburgh is pioneering biological methods to extract metals from old batteries and electronic waste, using bacteria to create a low-impact, sustainable recycling process.

Enhanced UK Material Security

- **Reducing Foreign Dependence:** By establishing domestic recycling capabilities, the UK can secure a stable supply of critical materials, reducing reliance on foreign sources and mitigating geopolitical risks.
- **Strategic Sectors:** Defence, energy, and high-tech industries depend on rare earth metals. A resilient recycling infrastructure strengthens national security and ensures long-term resource availability for these critical sectors.

Job Creation Across Skill Levels

- **High-Value Jobs:** The expansion of recycling facilities and technological innovation generates demand for skilled professionals, including material scientists, chemical engineers, and software developers. The Royal Mint's initiative, for example, supports both sustainability and high-skilled employment in the region.
- **Broad Employment Opportunities:** Recycling operations also create jobs in logistics, warehousing, and material handling, contributing to local economies and offering employment across various skill levels.

Building a robust rare earth metals recycling industry in the UK delivers a strategic advantage, fostering economic growth, innovation, job creation, and resource security. By leveraging cutting-edge technologies and sustainable practices, the UK can establish itself as a global leader in rare earth metal recycling.

RECOMMENDATIONS

Pilot Program Objectives and Scope

Pilot projects are essential to test and validate the proposed CRM reclamation framework and to ensure its practical applicability across the defence enterprise. These pilots will serve to:

- **Validate the Framework.** Test the end-to-end approach across selected platforms and systems to ensure feasibility, relevance, and repeatability.
- **Identify Data Requirements.** Determine what design, maintenance, and materials data is needed at each stage of the CADMID lifecycle to enable effective CRM reclamation.
- **Develop Cost Modelling Inputs.** Capture key cost drivers and variables (e.g., disassembly, handling, processing, compliance) to inform whole-life cost modelling and investment appraisal.
- Inform Strategic Decisions on Multiple Fronts:
 - **Policy Direction:** Define where the UK should act unilaterally, collaborate with allies, or rely on market solutions.
 - **Framework Maturation:** Refine and embed CRM recovery principles into existing policy frameworks such as ASD standards and IAM guidance.
 - **Supportability Engineering:** Develop updated guidance and tools for Support Solution Engineers to design-out CRM dependency or design-in reclamation pathways.

- **Infrastructure Investment:** Identify optimal UK cluster locations for near-shore CRM processing and refining.
- **Technology Innovation:** Guide prioritised investment in environmentally sustainable chemical processes and next-generation automation for CRM disassembly and recovery.

Proposed Pilot Candidates

Pilots should be selected based on platform complexity, CRM criticality, and lifecycle phase (new development, in-service, or upgrade). An example set of initial candidates could include:

- **CR3 Upgrade Program.** Opportunity to assess CRM accessibility and reclamation potential from legacy systems being upgraded or retired.
- **Field Power Systems.** Examine CRM usage in portable and vehicle-mounted energy systems (e.g., fuel cells, lithium batteries, alternative energy), and identify modular designs for reclamation.
- **Future Combat Air System (FCAS).** Integrate CRM reclamation principles early in the design phase, and test new data standards and digital engineering approaches to track and recover materials.
- **Type 31e Frigate (Above Water).** Use new-build opportunity to assess CRM traceability, modularisation, and digital twin capabilities for recovery planning.
- **Strategic Deterrent Assets (Below Water)** (e.g., Submarine Delivery Agency platforms). Explore secure handling, disassembly, and recovery of CRM from sensitive systems under stringent data and security constraints.

Next Steps

To activate the pilot phase will require:

- Cross-departmental sponsorship (DE&S, DIO, DefSp, SDA, etc.)
- Engagement and collaboration with OEMs, design authorities, and the High Value Manufacturing Catapult for platform data access and technical input
- A CRM prioritisation matrix based on strategic value, recoverability, and risk
- Leadership and governance from a cross-functional delivery team to track outcomes and iterate the framework

CONTRIBUTORS

The following stakeholders have been key contributors to the creation of this whitepaper:

Organisation
AMRC
Army
Babcock
BAE Systems
Conceptare
Defence Support
DESCycle
Mott Macdonald
Rolls Royce
Team Defence Information
Innovate UK
Uplift360
Visionary Agile Technology
Whitetree

Table 5 – Key Contributors to Whitepaper

ACRONYMS

Please see below for a glossary of terms referred to in this whitepaper to ensure consistency in terms of knowledge and understanding.

Acronyms	Description
AATF	Approved Authorised Treatment Facilities
AI	Artificial Intelligence
CADMID	Concept, Assessment, Demonstration, Manufacture, In-service, Disposal
CR3	Challenger 3
CRM	Critical Raw Materials
DCF	Designated Collection Facilities
DefSp	Defence Support
DE&S	Defence Equipment & Support
DIO	Defence Infrastructure Organisation
DIS	Defence Industrial Strategy
EPSRC	Engineering and Physical Sciences Research Council
FCAS	Future Combat Air System
IP	Intellectual Property
IUK	Innovate UK
NATO	North Atlantic Treaty Organisation
OEM	Original Equipment Manufacturer
R&D	Research and Development
REE	Rare Earth Elements
SDA	Submarine Delivery Agent
WEEE	Waste Electrical and Electronic Equipment

Table 6 – Glossary of Terms

GLOSSARY OF TERMS

Critical Raw Materials (CRM). raw materials that are vital to the economy and have a high risk of supply shortage. This term is used interchangeably with ‘Critical Minerals’.

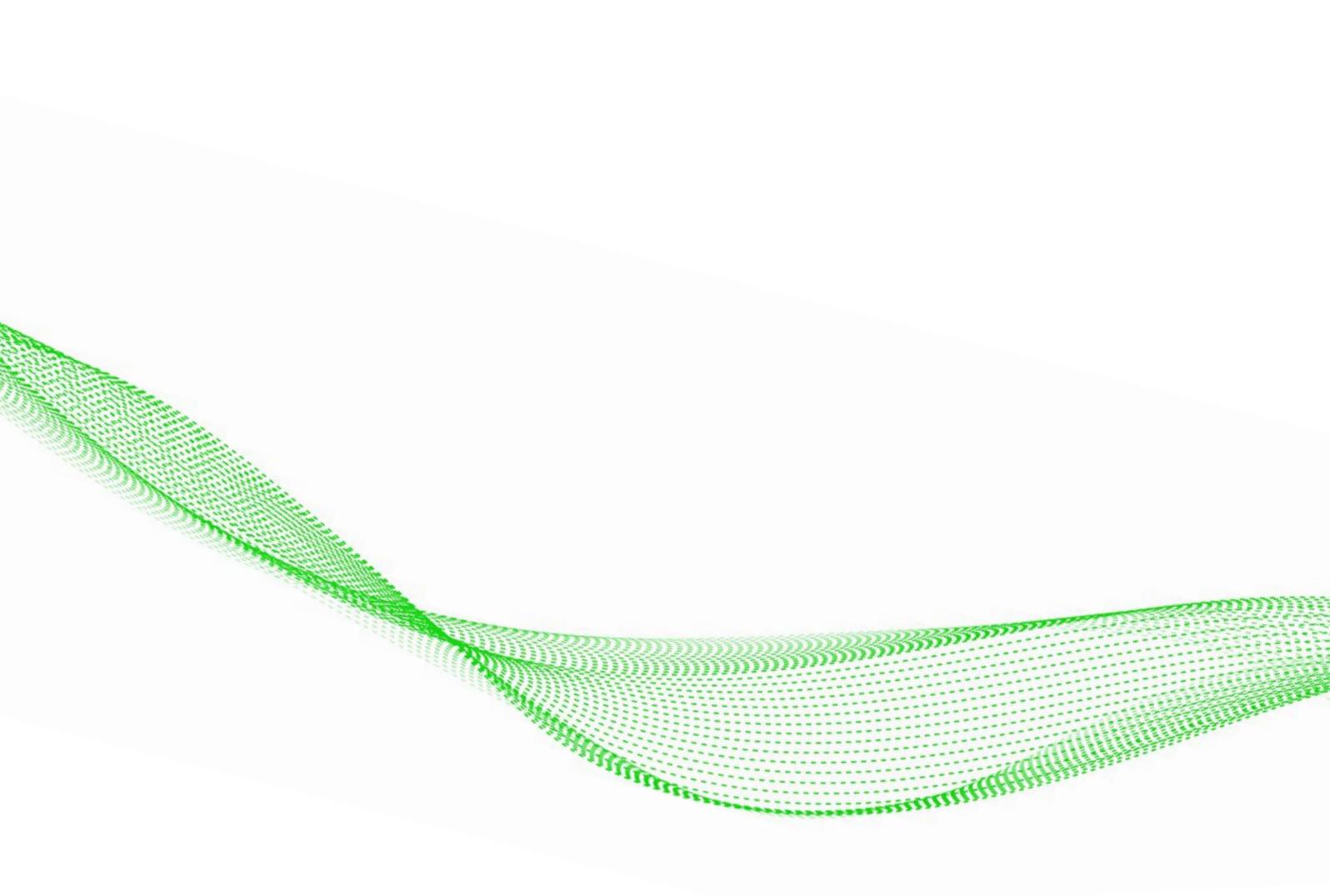
Rare Earth Elements (REE) are a group of 17 elements on the periodic table that are vital to many modern technologies

Defence Critical Raw Materials UK MOD have identified 41 materials that are considered critical to the maintenance of current in-service and future capability programmes

Harvesting. Targeted collection of Items with CRM/REE content with the intention of recovering the raw materials.

Reclamation. The recovery of CRM/REE materials where the material properties and quality are equal to their original state and they can be used for same purpose.

Recovery. The extraction and refinement of CRM/REE from items and components for use in secondary markets or purposes which may or may not require the same level of quality.



Strategic Command
Defence Support



TEAM
DEFENCE
INFORMATION