ENGAGING WITH DEFENCE AND SECURITY ON THE CIRCULAR ECONOMY

A position paper on exploratory work carried out as part of the UKRI NICER Programme's CEctor project

Fiona Charnley

Ananda Nidhi

Alexandra Lake

Georgie Hopkins

Markus Zils

CE-HUB UKRI National Interdisciplinary Circular Economy Research

NICER PROGRAMME

University of Exeter

UK Research and Innovation

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About the National Interdisciplinary Circular Economy Research Programme

The National Interdisciplinary Circular Economy Research (NICER) Programme is a four-year £30 million investment from UKRI to move the UK towards a circular economy.

The Programme is made up of five Circular Economy Research Centres, each focused on a speciality material flow, and the co-ordinating CE-Hub (detailed below). The Programme aims to deliver research, innovation, and the evidence base to move the UK towards a resilient UK circular economy. The NICER programme is the largest and most comprehensive investment in the UK Circular Economy to date and is delivered in partnership with industrial organisations from across sectors and the Department for Environment, Food and Rural Affairs (DEFRA), to ensure research outcomes contribute to the delivery of industrial implementation and government policy.

The 4 year programme launched in January 2021, initially comprising of 34 universities and over 150 industrial partners, with a key aim of growing the Circular Economy community through a significant programme of outreach and collaboration.

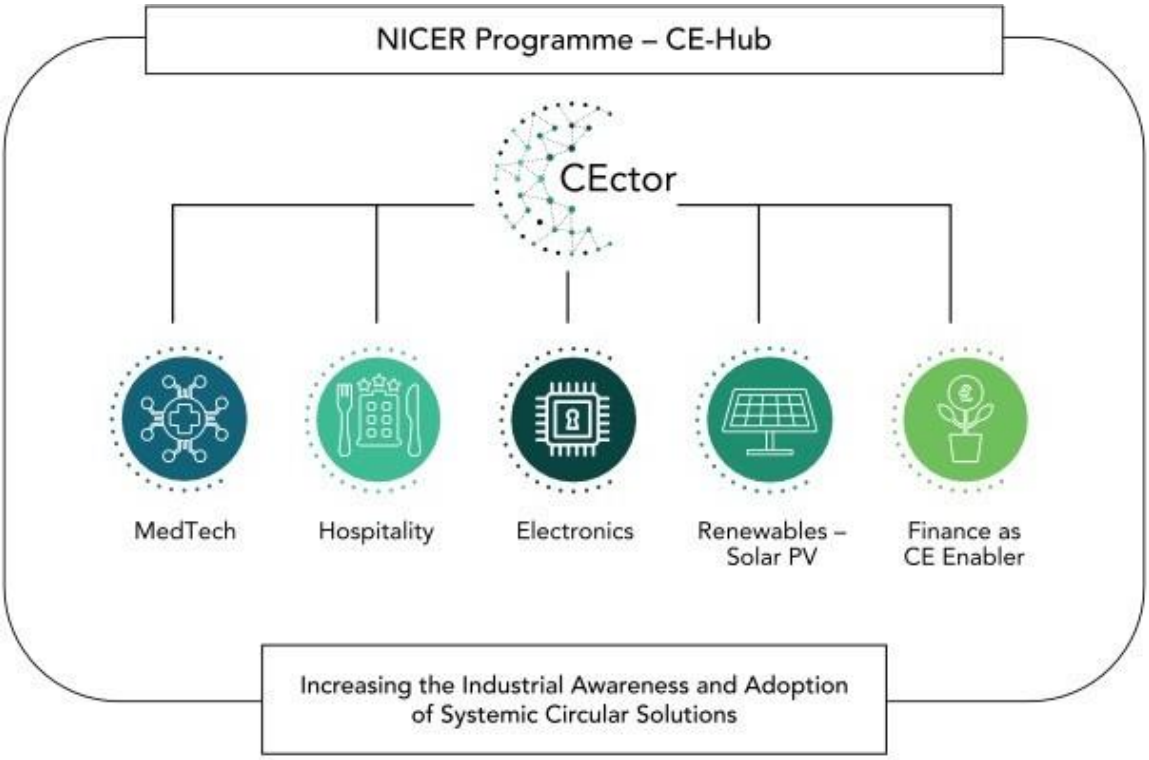
- The National Interdisciplinary Circular Economy Research Hub (CE-Hub), led by the University of Exeter
- The Textiles Circularity Centre (TCC), led by the Royal College of Art
- The Interdisciplinary Circular Economy Centre for Mineral-based Construction Materials (ICEC-MCM), led by UCL
- The National Interdisciplinary Centre for the Circular Chemical Economy (CircularChem), led by Loughborough University
- The Interdisciplinary Circular Economy Centre for Technology Metals (Met4Tech), led by the University of Exeter
- The Interdisciplinary Centre for Circular Metals (CircularMetal), led by Brunel University London.

Authors note

The views expressed in this discussion paper are those of the authors, intended to generate discussion and draw attention to some of the enabling requirements for, and examples of, CE as relevant to the defence and security sector.

Purpose of the report

As part of the National Interdisciplinary Circular Economy Research programme (NICER), the CEctor project is a dedicated workstream within the University of Exeter CE Hub. CEctor has the scope to explore five different UK sectors and identify opportunity to accelerate Circular Economy (CE) uptake and implementation. The five sectors are: 1. Medical Technology, 2. Hospitality, 3. Electronics, 4. Renewables-Solar PV, and 5. Finance. The purpose of the project includes engaging with stakeholders, building CE knowledge and understanding, and enabling mechanisms to deliver outcomes and impact.



As an additional output of the CEctor project, this Position Report acts as a document to draw together knowledge and insight from a six-month collaboration with key stake-holders in the Ministry of Defence (MOD) family of organisations, including: DSTL, DE&S & UK Stratcom. It provides a rationale to progress towards in-depth analytical work that willprove the case for CE adoption within the Defence and Security sector.

The intended use of this Position Paper is to document our initial engagement and exploration of the case for the adoption of a CE within the defence sector. By emphasising the reduction of waste, resource optimisation, and opportunity for whole system thinking in procurement and operations, the report showcases how embracing CE principles can not only enhance environmental sustainability but also drive cost savings, operational efficiencies, and supply chain resilience. Moreover, it underscores the alignment of CE strategies with broader defence objectives, including mission readiness, resilience and national security.

Authors and Acknowledgements

Professor Fiona Charnley, Ananda Nidhi MBA, Alexandra Lake, Georgie Hopkins MBA, Professor Markus Zils

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Defence Equipment and Support (DE&S)
Strategic Command – Defence Support (StratCom)
Armoured Test and Development Unit (ATDU)
Navy Support and Logistics Division

Notes on Methodology

This report is an output of the work undertaken by the CE Hub CEctor project team from July 2023 to February 2024. The research included:

- High level review of key Defence strategy documents and relevant industry reports.
- Engagement with stakeholders from across the MOD family, including participation in Circular Defence event hosted by MOD in October 2023, the design and delivery of a workshop in December 2023 & a presentation in February 2024 by the University of Exeter. The outputs included initial recommendations which have been synthesised into the wider findings of this report.
- Selected stakeholder interviews for development of specific case examples and understanding barriers and drivers of circularity within MOD.

> ‘If you don’t deal with it today, you will not be able to deal with it tomorrow...’
>
> Lt Gen. Richard Nugee, CB CVO CBE
> Climate Change and Sustainability Review Lead in Defence

Systemic challenges within defence

We live in an increasingly volatile, uncertain, complex and ambiguous (VUCA) world where symptoms of economic & environmental distress are affecting supply chains, disrupting prices and creating geopolitical vulnerability. The recent sequence of global disruptions, spanning from the COVID-19 pandemic to state-led aggression in Ukraine and environmental challenges stemming from climate change, has underscored the precariousness of supply chains within both the defence sector and wider industry.

Within Defence, this fragility has evolved from years of cost-cutting measures and a relentless pursuit of efficiency gains.[1] Conversely, in industry, the repercussions of upstream incidents and vulnerable points within intricately interconnected and globalised supply networks have become evident. Persistent external pressures on existing systems and frameworks have driven a "new normal" characterised by perpetual disruption, necessitating a re-evaluation of strategies to enhance resilience and adaptability.

As shown in Figure 1, the UK defence sector currently faces the following systemic challenges:

- <u>Global supply chain volatility & traceability</u>: The current global supply chain is highly interconnected and designed to be 'just-in-time' with maximum efficiency in mind. There have been unpredictable fluctuations and disruptions in the flow of goods and services globally triggered by various factors like natural disasters, geopolitical tensions, economic instability and increasingly, climate change impacts. Case in point being a recent disruption in supply of defence batteries due to a shortage of cardboard packaging[2] whose demand had risen due to stockpiling in anticipation of Brexit and increased e-commerce during Covid19 pandemic.[3]

  Alongside this, anti-slavery obligations of the UK Government necessitate MOD to ensure greater transparency and accountability throughout complex international supply chains, as it increasingly strives to eradicate forced labour and human trafficking from their operations, failing which risks reputational damage to the organisation.[4]

- <u>Decarbonisation</u>: Climate change is seen as a "threat multiplier"[5] by NATO Allies who in 2022 set a 'Net Zero by 2050' target for both their civilian & government militaries. The UK Government is legally bound to achieve this target from commitments during its COP26 presidency. As the MOD is responsible for 50% of UK central Government's emissions, there is a need to keep pace with commercial and civilian players who are more advanced in their pursuit of decarbonisation. Currently, industry sometimes must downgrade technical capability to meet MOD requirements which at times may be outdated (Defence Support Futures, 2023). For Defence to be a 'fast follower'[6] it needs to support innovation and experimentation to accelerate the integration of civilian advancements in decarbonisation and explore their application in military contexts.

Figure 1. Overview of systemic challenges within defence

- Energy geopolitics: The UK is currently pursuing a two-pronged approach[7] in addressing its vulnerability due to energy geopolitics exposed by dependence on Russian energy export. The first approach is maximising sources of supply (of fossil fuels) in the immediate term by striking partnerships with Gulf states, and the second is by accelerating the transition to clean energy. Caution must be exercised that the transition to green technologies does not come with more compromising strategic dependencies on other countries[8] who could weaponise energy systems in the future.

- Material availability: The Defence sector relies heavily on a variety of critical materials, metals, and components for various products and applications, including radar systems, portable power sources, and armoured vehicles/vessels, among others. Some of these materials, like rare earths, such as neodymium, and gallium, are classified as scarce and are subject to commodity price volatility. This dependency is expected to intensify in the future due to increased demand driven by electrification technologies including electric vehicles, solar PV, and wind turbines.[9] For instance, MRI scanners rely on rare earth-containing permanent magnets, primarily sourced from Chinese supply chains, posing vulnerability to potential disruptions.[10] Similarly, global shortages of semi-conductors could impact multiple data, control, and analytical processes essential for various Defence devices. In 2022, increasing competition to ensure security of supply evident amongst discussions of Allies the United States and the European Union prompted the UK government to issue 14 Final Orders under the National Security & Investment Act to block or set conditions on acquisitions that posed a risk to national security, and to also launch the UK's first Critical Minerals Strategy.[11]

- Impact of climate change: Climate change is exacerbating the different stressors in the changing environment within which Defence operates. As a more immediate challenge, Defence is often the first responder to natural disasters as well as humanitarian crises both at home and overseas which are becoming both more frequent and intense in nature. As for future challenges, Defence needs to integrate climate change considerations into departmental planning through broader adaptation efforts, ensuring proactive preparation. The escalating threats posed by climate change, including rising seas and desertification, are likely to exacerbate tensions necessitating immediate remedial action to resolve conflicts. To address these challenges, Defence will have to align equipment and force design with a climate-changed world, preparing for temperature increases of +2° to 4°C as recommended by the Committee on Climate Change.[12] This involves integrating a 'climate lens' into Force development processes, enhancing self-sufficiency on operational deployments to minimise reliance on strained local communities and safeguard personnel in harsh conditions or disrupted supply chains.

- Legacy systems & infrastructure: Assets and infrastructure that have reached the end of their useful lifecycle have a significant and multifaceted impact on UK Defence, presenting challenges in terms of reduced efficacy, increased costs of disposal & maintenance, hindered digital transformation & increased cybersecurity threats. Outdated technology and aging inventory management systems currently result in data silos, making it difficult to track equipment accurately and efficiently. At present, the Royal Navy has double the number of nuclear submarines in storage, awaiting safe decommissioning, than the number successfully deployed at sea.[13] Some assets are unserviceable[14] and many of which are 40-50 years old.[15] This creates a space constraint for incoming new technology capabilities.

The recent Vallance review has recommended innovation on priority waste streams that cannot currently be recycled or re-used due to real or perceived regulatory barriers (HMT, 2023). Clearly there is an understanding across a range of stakeholders that things need to change in terms of how we treat waste and how it can become resource.

As we have seen, Defence is part of a complex dynamic system consisting of an extended supply chain, vulnerable to scarce materials and energy geopolitics, and one that is heavily impacted by climate change. Defence recognises the negative feedback loop where it is adding to the climate crises due to the nature of its operations causing it to expand its work. The cost of inaction to address these systemic challenges will far outweigh the costs of action today. Defence is on the right track by factoring emissions and social value into finance policies, processes and controls by 2025, however more needs to be done to translate this ambition into concrete action.

The CE as a structural solution

Accelerated adoption of renewable energy & energy efficiency will only offset 55% of GHG emissions by 2050. The other 45% of GHG emissions come from the way that we make and use products and food and how we manage land. This is where a CE can contribute via alternative models of production and consumption with an emphasis on materials reduction leading to greater GHG emissions reduction.

A linear economy is extractive. It is an approach which extracts systems value whether that is social, economic or environmental and thereby degrades the very 'capitals' (not just material resources but social and economic resources as well) upon which the economy needs to thrive. By contrast, a CE is regenerative by design, constantly restoring and rebuilding the systems capitals through circulation. So, when considering new ways of creating value in a CE, a re-definition of the meaning of value is required. The CE goes beyond financial profit and is not simply about tweaking the existing system, but changing it entirely. This is an important starting point for the mindset shift which is required by the CE.

The CE concept is underpinned by four core principles, which originate from the Ellen Macarthur Foundation:

- Eliminate waste and pollution (through design)
- Circulate materials and products at their highest value for as long as possible
- Regenerate natural capital
- An economy run on renewable energy.

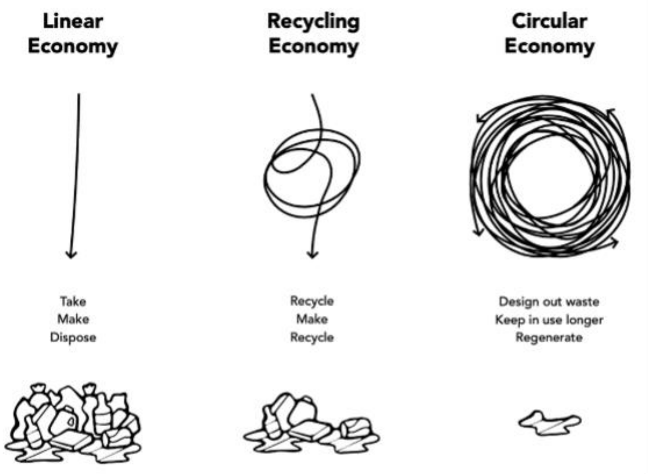

Figure 2. A linear, recycling and circular economy in three images (adapted from Circular Flanders)

However, CE is sometimes wrongly interpreted as an enhanced form of recycling, which in itself should be the last resort. Rather, a truly CE rebuilds and maintains capital, promoting higher quality stocks and flows of materials, components and products for repeated life cycles and cascades as clearly shown in Figure 2.

The Ellen MacArthur Foundation's 'butterfly diagram' (Figure 3) illustrates the transition from the linear take-make-use-dispose model to a CE which is a systems solution. This diagram identifies two material spheres: the durable technical materials and the biodegradable biological materials. This Position Paper primarily focuses on the technical sphere, aiming to prolong the lifespan of materials, products, and components through repair, remanufacture, or refurbishment to maximise value and minimise environmental impact.

Levers of a CE

In the context of a CE, the value chain is viewed as a continuum where resources, products, and materials flow through various stages, each offering opportunities for circularity. The three key phases within this value chain present distinct levers for advancing circularity and sustainability, as shown in Figure 4.

Inflow Phase: This initial stage involves the acquisition and sourcing of raw materials and components. In the CE, the focus is on optimising resource flows, minimising waste and promoting sustainable sourcing practices. Levers in this phase include:

- **Sustainable Material Sourcing**: Prioritising the use of recycled, renewable, or responsibly sourced materials to reduce environmental impact and minimise reliance on virgin resources.
- **Design for Circularity**: Incorporating circular design principles such as modular design, material recovery, and easy disassembly to facilitate repair, reuse, and recycling at end-of-life stages.
- **Supply Chain Transparency**: Implementing systems to trace the origin and lifecycle of materials, promoting transparency and accountability throughout the supply chain.

In-Use Phase: During this stage, products are utilised by consumers or businesses. Circular strategies in this phase aim to maximise product lifespan, minimise resource consumption, and encourage responsible consumption behaviours. Levers in this phase include:

- **Product Longevity**: Designing products for

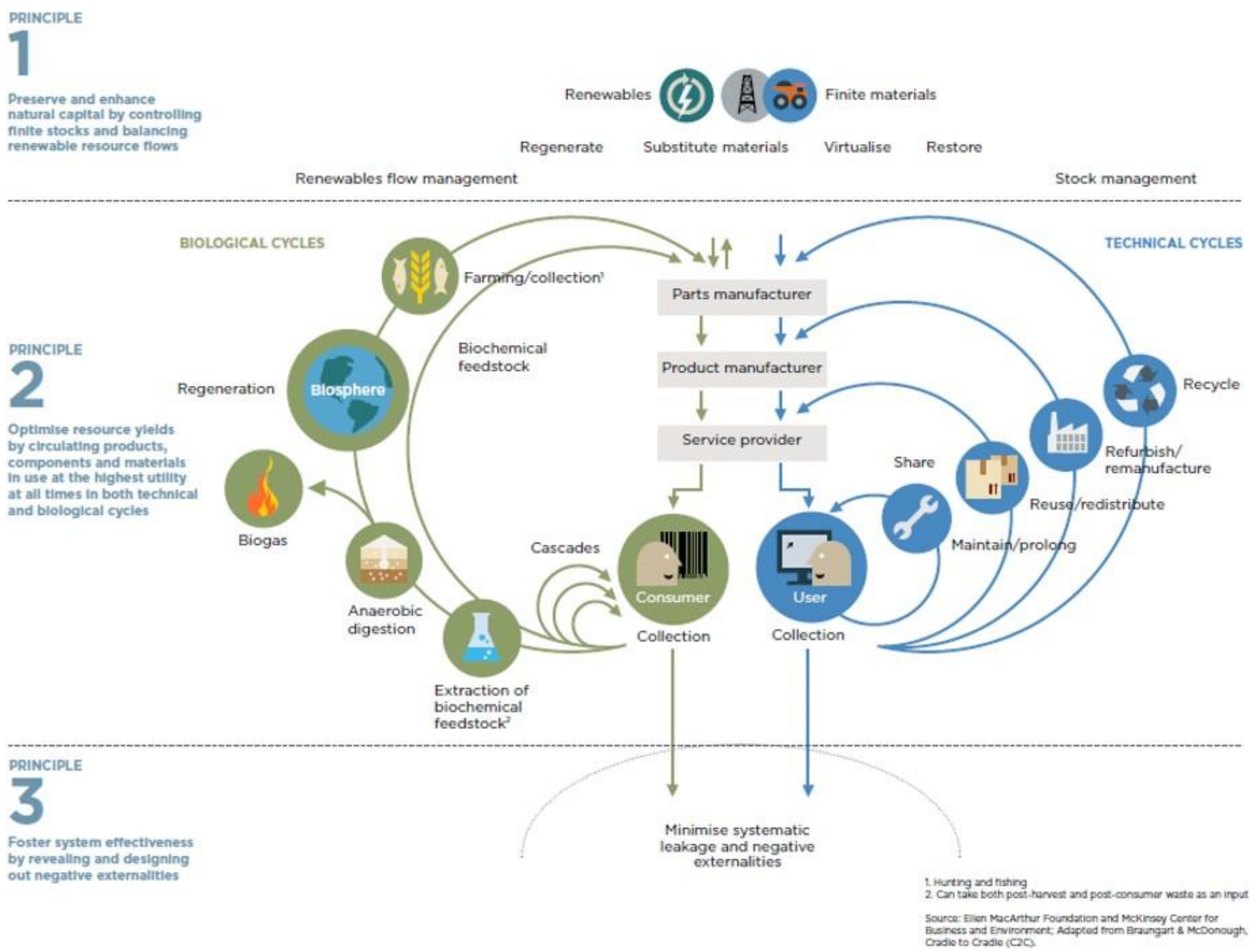

Figure 3. Circular economy system diagram (Ellen MacArthur Foundation, 2015)

durability, reliability, and longevity to extend their useful lifespan and reduce the need for frequent replacements.

- **Product-as-a-Service (PaaS)**: Shifting from ownership models to service-based models where consumers pay for access to products or functionalities, encouraging manufacturers to design for durability and enabling better product stewardship.
- **Maintenance and Repair**: Promoting repairability and providing access to spare parts and repair services to extend the life of products and reduce premature disposal.

<u>Outflow Phase</u>: This final stage involves the end-of-life management of products and materials, including disposal, recycling, and recovery. Circular strategies in this phase aim to minimise waste, recover valuable materials, and close the loop in the value chain. Levers in this phase include:

- **Closed-Loop Recycling**: Establishing systems and infrastructure for the collection, sorting, and recycling of materials to reintegrate them into the production process, reducing the demand for virgin resources.
- **Extended Producer Responsibility (EPR)**: Holding producers accountable for the end-of-life management of their products, encouraging take-back programs, and facilitating responsible disposal and recycling.
- **Circular Business Models**: Exploring innovative business models such as product leasing, remanufacturing, and resource recovery to extract maximum value from products and materials at the end of their lifecycle.

By strategically applying CE principles and leveraging these levers across the inflow, in-use phase, and outflow stages of the value chain, Defence can transition towards a more sustainable and regenerative economic model, where resources are used more efficiently, waste is minimised, and environmental impacts are reduced.

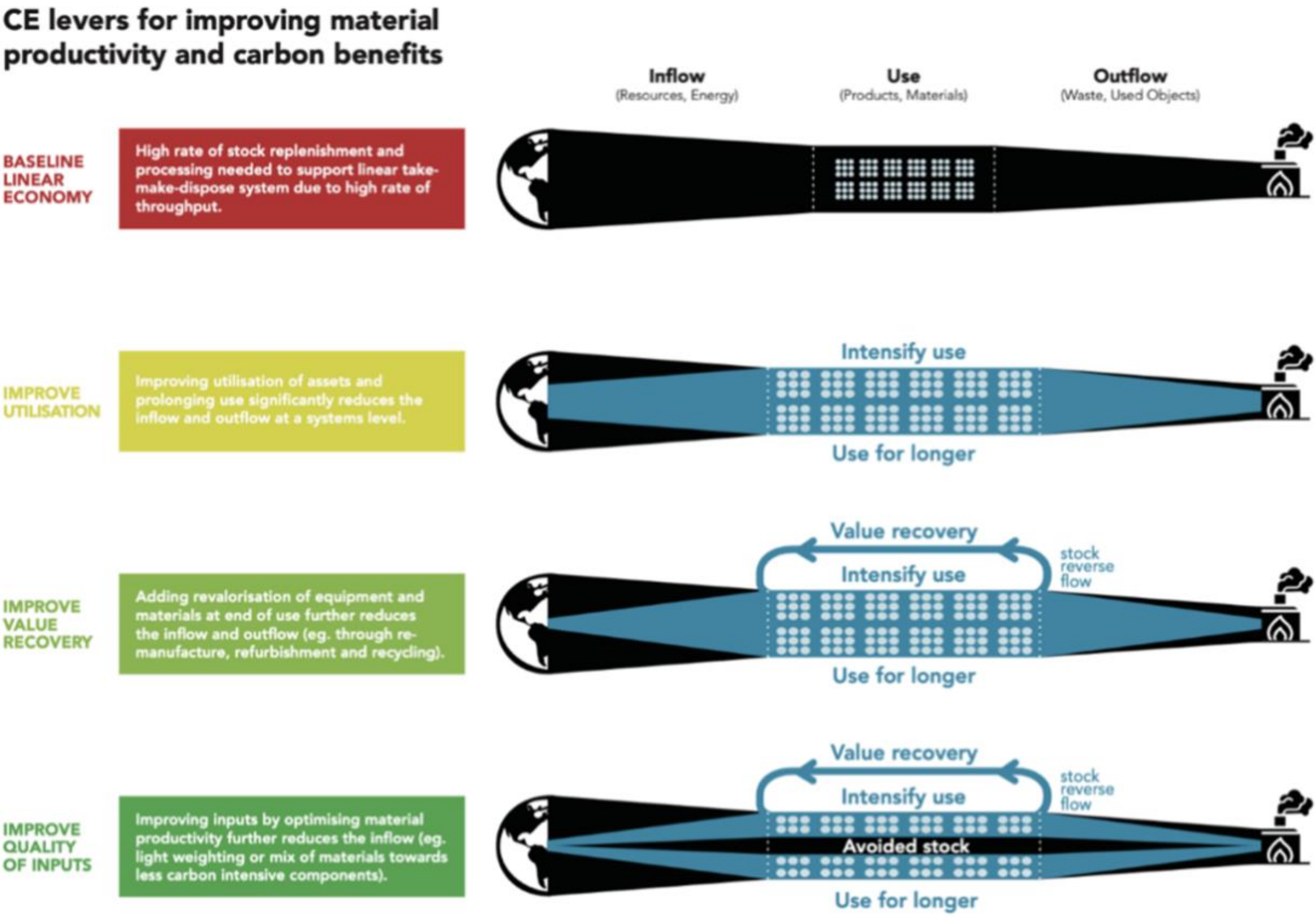

Figure 4. CE levers for improving material productivity and carbon benefits (adapted from Zils, 2021)

The CE in practice

This section draws together examples from both defence and wider industry of circular interventions across the value chain, which can be immediately applied, especially within Estates.

Inflow phase: reduce inflow

Workwear Procurement

In 2014, the Dutch Ministry of Defence (MoD) embarked on a circular procurement of military workwear by setting out a tender with mostly functional requirements to stimulate the market for circular solutions. The requirement was to use at least 10% recycled post-consumer cellulose fibre in new items and the supplier needed to demonstrate this using microscopic testing. Successful bidders for the 53,000 overalls & 100,000 towels were able to learn and innovate during the 4-year contract period and successfully increased the recycled content in the new textiles to 36% (towels) & 14% (overalls). More details can be found here.

Office Furniture

Office furniture constitutes 11% of global furniture consumption, valued at $47 billion.[16] In the EU, 10 million tonnes of furniture are discarded by businesses each year, a majority of which is destined for either landfill or incineration.[17] Since the early 1990s, Ahrend single product can have multiple lives. Ahrend offers their customers furniture-as-a-service (FAAS) where customers pay a monthly fee and return the furniture when they no longer need it with the Ellen MacArthur Foundation in the UK as their very first FAAS customer. Rype Office remanufactures used office furniture to a 'like-new' condition and designs furniture from waste materials, providing employment opportunities and training to individuals with disabilities, creating significant social benefit in the process. Rype Office has experienced significant growth, doubling revenue and staff annually, serving over 260 customers while preventing over 400 tons of waste and saving approximately 1,000 tons of CO2e emissions, all while providing over 7,000 hours of living wage employment.

Similarly, Steelcase is another American furniture manufacturer that has shown how to set up and deliver a profitable 'closed' loop furniture reclaim and re-sale model in US and European markets, worth millions of pounds. Their refurbished & remanufactured furniture is re-sold often at a higher margin (15-40%) than the original product delivering both higher revenue and carbon savings.

In Use phase: asset optimisation

Vehicle life extension

Project LURCHER originated from a Light Mobility Sprint competition backed by an £800k investment from the British Army. It exemplifies grassroots innovation and provides a valuable opportunity for an SME that is active in the civilian sector, Electrogenic, to collaborate with a prime contractor, Babcock for the uptake of a dual use technology. The project involves converting four in-service military Land Rovers, including two protected vehicles and two general service vehicles, from diesel to electric vehicles (EVs) using a drop-in kit and modified battery system. This initiative offers a chance to explore alternative engine technology and compare its performance against diesel and hybrid equivalents in a test environment, enabling the British Army to prolong the lifespan of its Land Rovers as diesel technology becomes outdated. The core advantage lies in the comprehensive control over every aspect of the electric drivetrain, significantly enhancing performance, especially in challenging conditions and off-road terrain, making it a perfect fit for military vehicles.

Other public sector entities like Transport Scotland is leading the way in decarbonising its bus fleet via switching to EV technology. In 2021, it awarded £62mn to 9 bus operators and local authorities for 276 buses and associated charging infrastructure under phase one of the Scottish Zero Emission Bus Challenge Fund[18] representing the scale of investment needed for this mobility transition.

Lighting

Schiphol Airport aims to become the world's most sustainable airport, with a primary focus on reducing energy consumption. During the refurbishment of its Lounge 2, the airport partnered with Signify, formerly Royal Philips lighting division, to develop 'sustainable luminaries' designed for easy and swift repair or replacement, a significant cost factor in lighting operations. These luminaries outperform previous LED lights, lasting 75% longer, consuming 50% less energy, and coming with a 5-year maintenance contract, extendible for an additional 5 years. By meeting stringent performance standards outlined in the contract, Schiphol can concentrate on its core business of travel, reallocating resources to other energy-saving initiatives. The airport benefits from reduced Total Cost of Ownership (TCO) and addresses end-of-life lighting concerns by returning them to Signify for remanufacturing or recycling.

Other cases in consumer electronics and civilian jet engines provide valuable examples of product life and performance extension.

Additive manufacturing

The US military is at the forefront of leveraging additive manufacturing[19] to address challenges related to obsolete parts for aging equipment and vehicles. For instance, in 2020, the U.S. Army faced a shortage of hatch plugs for combat vehicles, prompting them to utilise 3D printing technology to quickly produce cost-effective replacements. Similarly, the US Airforce Lifecycle Management Center regularly employs 3D printing to manufacture obsolete parts for various legacy fighter jets, such as the B-52s, C-5M Super Galaxy, and B-2 Stealth Bomber.

In 2022, the UK Ministry of Defence (MoD) responded to the "Additive Manufacturing (AdM) as a Service Challenge" as set by Lieutenant General Richard Wardlaw by establishing a Centre of Expertise (CoE) focused on High Value Manufacturing (HVM).[20] This initiative along with the first AdM Framework aims to address challenges like upscaling AdM usage and certifying additively manufactured parts for platform systems. Through partnerships with industry, the MoD is working to fit eleven non-safety critical metallic parts onto in-service platforms,[21] enabling realisation of benefits ranging from enhanced availability of parts to Front Line Commands to improve maintenance capabilities, streamlining supply chains, extending the lifespan of military assets and a reduction in global carbon emissions. UK SMEs like AMS are supporting the MoD's efforts to establish a resilient UK-based supply chain, which includes the supply of vital minerals like titanium. This initiative underscores a commitment to a high-value circular economy approach to feedstock sourcing, positioning the MoD as a central player in shaping future supply dynamics.

Outflow phase: post-use asset recovery

Naval platform recycling

The former HMS Illustrious, a light aircraft carrier of the British Royal Navy weighing 16,000 tonnes, ceased operational service with the Royal Navy on the 1 August 2014. Initially, proposals were sought for repurposing the vessel into a conference venue, visitor attractions, museum, and heliport, but after exploring all options, recycling became the only viable route. Defence Equipment Sales Authority (DESA) awarded the Turkish company LEYAL Ship Recycling Ltd preferred bidder status for recycling the vessel at their facility in Aliaga, Turkey. LEYAL reported completing the recycling process in just six months, meeting EU waste management legislation and the UK's ship recycling strategy. Despite some equipment removal for operational use in other vessels like engines, generators, and flight-deck lighting, 94.06% of the former HMS Illustrious's material was recovered and recycled, amounting to 13,657 tonnes.[22]

Similarly, an example of how Thales Group is helping French Air Force and other NATO Allies dismantle and repurpose reconnaissance pods can be found here.

Uniform and material recovery

In 2016, the Dutch MoD collaborated with a company (Biga Groep) to recycle and reuse more retrieved uniforms and materials. Unusable uniforms were shredded and sold as fibres and materials to the private sector. By reusing and repairing instead of buying new, the Dutch MoD saved €8 – 10 million annually and income for the first year of shredded fabric was approximately €168,000 in sales. More details can be found here.

Strategic material recovery

The U.S military's Defense Logistics Agency (DLA) has a Strategic Material's Strategic Material Recovery and Reuse Program (SMRRP), operating under the Strategic and Critical Material Stock Piling Act, addressing shortages in vital materials like Germanium and Super-alloys. By partnering with Anniston Army Depot, SMRRP successfully recovers Germanium-containing parts slated for disposal, ensuring their inclusion in the National Defense Stockpile (NDS). Additionally, the program focuses on Super-alloys (generally nickel and cobalt-based alloys containing metals such as rhenium, tantalum, tungsten, niobium etc.) used in U.S Airforce aircraft engines, recovering, demilitarising, and transferring these alloys to the NDS through contracted services, thereby bolstering domestic supplies crucial for defence and civilian industries during emergencies.

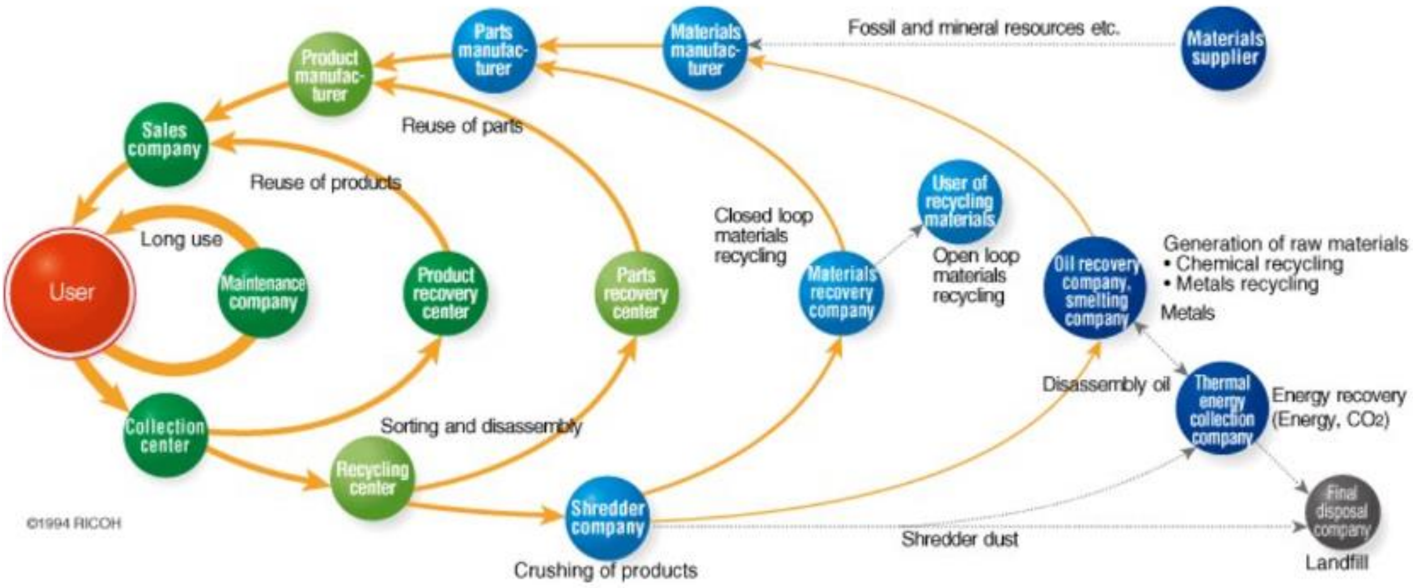

Figure 5. The Ricoh Comet Circle™ concept for realising a circular economy (Comet Circle | Global | Ricoh, n.d.)

Harmonic Shear

Harmonic shears are MedTech devices used in minimally invasive surgeries to handle multiple surgical jobs such as dissecting, cauterising and sealing. Two types of harmonic shears falling under the OEM Class IIb single use devices (SUD), the HARH36 and HARH2337, can and have been successfully remanufactured meeting all of the requirements of the Medicines and Healthcare Products Regulatory Agency (MHRA) guidance on SUD remanufacturing. NHS data for the financial year to March 2023 reported £16.2m recorded sales of harmonic shears with 71% eligible for remanufacture and 27% noneligible. With a median sales price of approximately 50% of the OEM sale price, remanufactured devices accounted for 1.7% of the total, though this increased by 350% to 6.9% to date in 2023/2024. German medical remanufacturing company, Vanguard has over 25 years' experience in the remanufacture of a wide range of medical devices including harmonic shears. The devices are currently transported to Germany where they undergo several remanufacturing stages including cleaning and disinfecting; labelling for traceability and multiple component tests to guarantee safety and functionality. Devices are then packaged and sterilised in line with industry standards and placed into supply stock.

Working with Vanguard, Leeds Teaching Hospitals Trust in the UK which uses around 700 Harmonic shears per annum introduced a remanufacturing programme to deliver savings and a reduction in waste and environmental impact of clinical procedures. In 2022, through collections of used devices, the Trust diverted 70kg of devices from waste and earned £2,068 for those collections as Vanguard pay for accepted used devices. Through using remanufactured devices, the Trust saved an estimated £73,800 and reduced its scope 3 emissions by 285 kg CO2e.

Under the CEctor project, University of Exeter carried out a high-level analysis under 3 different circularity ambition scenarios which showed that the current purchase of remanufactured devices has the potential to deliver cumulative savings between £2.5m -£9.7m through to 2030 and a carbon saving of 2.3%-9.2% compared to purchasing new (non-remanufactured) eligible devices. The full report can be found here.

Printing as a service

Ricoh, the global leader in Digital Imaging and Print Management operated a Circular Economy Product Service Business Model since 1994 (Figure 5). This model combines maintenance, upgrades, and product life extension in a service arrangement beneficial to both clients and Ricoh. Under a pay-per-print structure, Ricoh retains ownership of hardware and consumables, which are serviced by field engineers, providing customers with guaranteed reliability and full cost transparency. Consumable devices are continuously returned and refilled without performance loss. At the end of a contract, the main imaging device is remanufactured to meet British Standard 8801 specifications of 'as good as new' and resold to customers at a discounted rate, resulting in reduced Total Cost of Ownership. Each remanufactured device retains over 90% of its materials

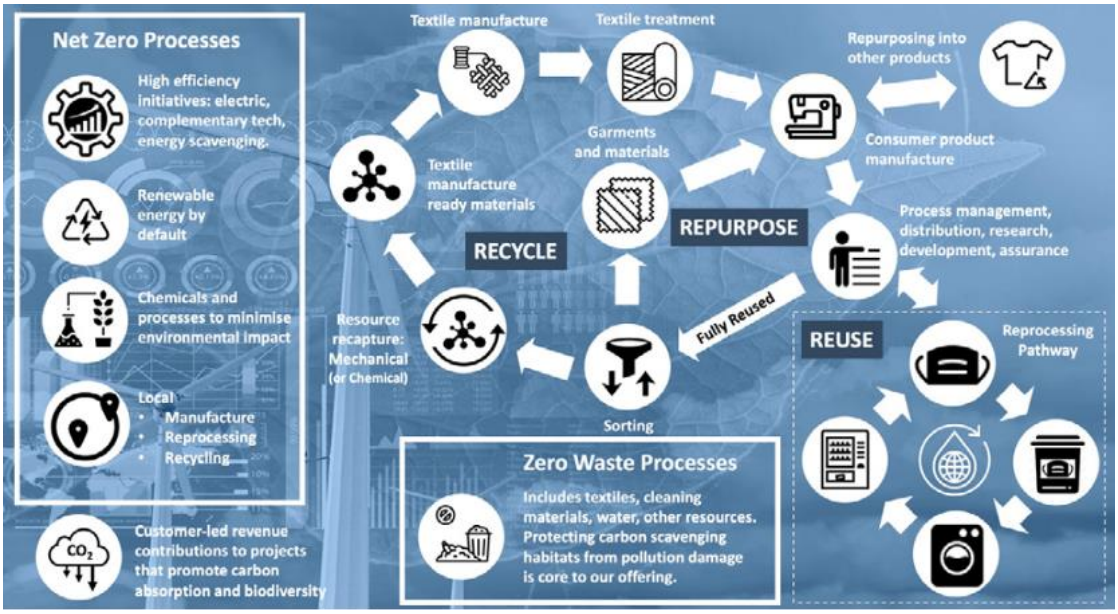

Figure 6. Revolution-ZERO CE model for medical textiles integrating reuse, repurpose & recycle cycles

and components by weight, as well as the embodied energy and carbon from the original manufacturing process – remanufactured individual printers are sold at around 80% of the price of new devices and with a 6-80% lower carbon footprint than new. The Ricoh remanufacturing model is worth an approximate £15M per annum in Europe and capped to avoid impacts on the sale of new products.

Full system

Renault

Renault has developed a CE ecosystem over the past decade, generating approximately 100 million Euros in annual cost savings, with a goal of reaching 1 billion Euros by 2030. Starting with the recovery and remanufacture of gearboxes and smaller components, the program has expanded to national networks involving end-of-life recovery partners and mobility-as-a-service initiatives. Renault is redesigning its vehicle portfolio to extend product life, incorporating easier maintenance, upgrades, and recycled materials. These efforts reduce carbon and material footprints while addressing supply chain shocks and commodity price volatility, which have cost the business over 1 billion Euros in the past three years.

Revolution-ZERO

A MedTech CE company established in 2020, Revolution-ZERO aims to address issues within the single-use medical textile industry, including supply chain resilience, quality, emissions, and waste (Figure 6). Prior to incineration (at a cost of around £600/tonne), these textile products cost over £400 million annually, excluding logistics expenses. Revolution-ZERO collaborates with circular economy experts to establish a comprehensive cradle-to-cradle lifecycle for reusable PPE, designing and manufacturing advanced products like reusable face masks, surgical gowns, drapes, wraps, and aprons. It integrates these products into both existing and new methods of decontamination, laundering and sterilisation, offering a fully traceable solution adaptable to any organisational workflow.

As an example, since 2023, their solutions have been successfully implemented in 10 surgical teams at St Michael's Hospital, Cornwall, integrating with the Cornwall NHS sterile services to supply sterile surgical textiles. By launching a modular state-of-the-art processing unit with a 25-year unit and 40-year material guarantee, the company has delivered 50% cost savings compared to traditional builds. This strategy facilitates rapid scalability and cost-efficiency, enabling reprocessing units to be quickly deployed across multiple sites, extended, or relocated as needed. This intervention has resulted in a significant PPE waste reduction of around 3kg per total hip or knee replacement surgery at the Cornish hospital and associated carbon savings and 58% EBIT for the NHS Trust. The high-upfront cost of re-useable PPEs (around £16 per piece) are reaching a break-even point and paying for themselves after around 15 uses compared to disposable ones that cost around £3.2 per use.

System enablers

System enablers catalyse system change through initiatives that support CE innovation and business model design.

The Defence BattleLab

The Defence BattleLab is a collaborative project involving the Defence Innovation Unit, single Services, Dstl, DASA, Dorset Council, and Dorset Local Enterprise Partnership (LEP). It serves as a hub for trialling cutting-edge technology with potential for commercialisation, bridging the gap between the MOD and UK's innovative companies, particularly SMEs. With 2,108sq.m of office space and 450sq.m of workshop space, the BattleLab fosters collaboration and creativity amongst military personnel, academic institutions, corporates and SMEs, housing facilities such as multi-domain ranges at Lulworth, live trial and showcase workshops, 5G testbeds, and rentable desks. While not focused on one specific area, the BattleLab encourages innovative solutions across land, sea, and air military domains, aiming to modernise equipment and accelerate its deployment to the frontline. The successful Hackathon hosted by the British Army and Adarga in Sept 21 brought together military personnel and industry teams to deploy innovative AI and software solutions for field experimentation as part of the Army's Digital Readiness Experiment (DRE). With support from Adarga, an SME British AI leader in information intelligence, the DRE aims to help the Army procure and adopt next-generation technology quickly to maintain its competitive edge.

Rare Earths in magnet value chain

The collaboration between the Met4Tech team and CE-Hub at University of Exeter involves an agnostic CE-value stream mapping of rare earth element (REE) magnets for electric vehicles (EVs), identifying current flows and barriers to circularity and responsible sourcing. This project demonstrates that in addition to addressing raw material challenges, other actions are crucial for fostering a circular, secure, and environmentally sustainable rare earth economy in the UK. The "Rare-Earth Recycling for E-Machines" (RaRE) project, funded by Driving the Electric Revolution (UKRI), supports Hypromag in establishing NdFeB magnet recycling in Birmingham. Furthermore, UK companies are exploring REE deposits, particularly in African countries, with proposals for REE refineries in the UK, integrating primary raw materials and recycled material processing.

The next phase involves engaging a broader stakeholder group, including industry partners, research projects, and governmental decision-makers, to tackle key barriers hindering supply security and circularity in the value chain. The CE-Hub is developing a conceptual framework based on the results, while the Met4Tech team is focusing on specific REE applications in the UK, such as EV mobility and wind power, to develop a tech metals Roadmap.

Another demonstration of a sectoral case study is the NICER Programme Steel Circularity Roadmap which proposes multiple scenarios for extending the lifecycle of steel through material, technological and behavioural innovations.

The MoD will accumulate large stocks of REE PMs within electric vehicles, hardware and other applications over the next 30 years, which will appreciate in value and provide a potential stock of secondary REE products and materials than can be re-used or recycled at profit. As an illustration the UoE team has modelled and quantified the material quantity and value of REE PMs in EVs and Wind turbines in the UK through to 2050, approximately 35,000 tonnes and £7.5Bn value at today's prices. With commitment, and the relevant track and trace and recovery systems, MoD could become an important value chain actor in future UK REE PM and other CRM secondary material value chains, reducing material and product security risk.

Identifying challenges to CE adoption in Defence

The following four key challenges to CE implementation have been synthesised from various stakeholder engagements including interviews and workshops.

1. **Maintaining Military Capability**: Operational resilience and military capability remains a critical, prevailing focus of the sector. To remain fit for purpose, adoption of a CE must not compromise the ability of Defence to deliver on the primary focus of Mission readiness & security. The urgent need to replace outdated or damaged assets (and a risk averse approach) often leads to the procurement of new materials rather than exploring opportunities for repair, reuse or refurbishment. Additionally, the rigorous training and deployment schedules of military personnel necessitate reliable and readily available resources leading to asset ownership by MOD, leaving minimal opportunity for experimentation with circular practices such as servitisation and performance based models to date.

The sector's reliance on complex supply chains, often spanning multiple countries and industries, further complicates efforts to implement CE initiatives due to stringent requirements for security, reliability, and compatibility. This also poses challenges to determine what optimal inventory levels are to meet considerations of 'resilient, effective and efficient' inventory management.

Operational Complexity: The diverse range of equipment and platforms with differing operational requirements, systems integration and unique maintenance, repair, and disposal needs within different branches and units of Defence makes creating uniform strategies for sustainable resource management very complex. Moreover, accommodating the diverse needs of end-users, from frontline soldiers to support staff, adds another layer of complexity to designing and implementing CE initiatives that effectively address the entire spectrum of Defence operations.

2. Organisational Challenges: A shift to a CE requires systems-level changes which face challenges based on the MOD's organisational structure and culture.

- A risk averse approach inhibits the willingness to embrace innovative approaches due to the fear of failure or disruption to established processes, resulting in activities such as outsourcing of disposal of assets.
- A degree of bureaucratic inertia further compounds this challenge, as entrenched procedures and hierarchies impede the agility needed for transformative change.
- Siloed departmental structures and approaches exacerbate the issue, limiting collaboration and knowledge sharing across different units or functions. It is important to note that such structures are sometimes intentionally designed to be so.
- A lack of clarity regarding decision-making authority complicates the adoption of CE initiatives, with stakeholders requiring clear leadership to align on priorities and responsibilities.
- Behaviour & culture change poses a significant hurdle in deeply hierarchical institutions, where entrenched norms and power dynamics may resist efforts to shift mindsets and practices towards innovative circular approaches.
- Competing S&T Agendas & Prioritisation can cause misalignment between long term S&T planning, prioritisation and investment to the agendas and requirements to FLC customers and Innovation functions across the services with shorter term and more immediate demands for technology pull-through and exploitation.
- Knowledge Base – Circular Economy is in its infancy within MOD and it needs to invest more in training its civilian and military personnel to fill this knowledge gap.

3. Inventory & Infrastructure: Good inventory management systems enable identification of repair, reuse and remanufacturing opportunities, thereby extending product lifespan and fostering circularity. Inventory management challenges, characterised by deficient system infrastructure and outdated data tracking mechanisms, present significant barriers in Defence including inventory obsolescence. With a shortage of skilled workforce, physical facilities such as smart warehouses and financial support,[23] MOD is struggling to effectively manage their inventory, hindering efforts to track materials and assets throughout their lifecycle.

Moreover, obsolete data systems that lack interoperability exacerbate the problem (e.g., 35 types of 40+ year old Log-IS systems), impeding the flow of information critical for effective resource utilisation and waste reduction. The prevailing practice of outsourcing disposal tasks without exploring opportunities for value capture reflects a missed opportunity to integrate CE strategies into inventory management practices.

4. Procurement: Good procurement practices can promote circularity by fostering partnerships for innovative circular solutions and optimising resource use throughout the product lifecycle. Two main procurement challenges of MOD include:

- Barriers to SMEs - SMEs are recognised to deliver innovative business models, accelerating circular solutions. However, their engagement with Defence is deterred due to the stronghold of established contractors (primes) and the complex procurement process which can disadvantage, at times even when intended to assist. An example is the need to demonstrate social value to be awarded tenders which requires specialised administrative resources that SMEs do not necessarily have at their disposal.
- Annual budgets - The annual budgetary cycle and the lack of consideration for end-of-life treatment in procurement decisions omits the opportunity for understanding total cost of ownership and hinders

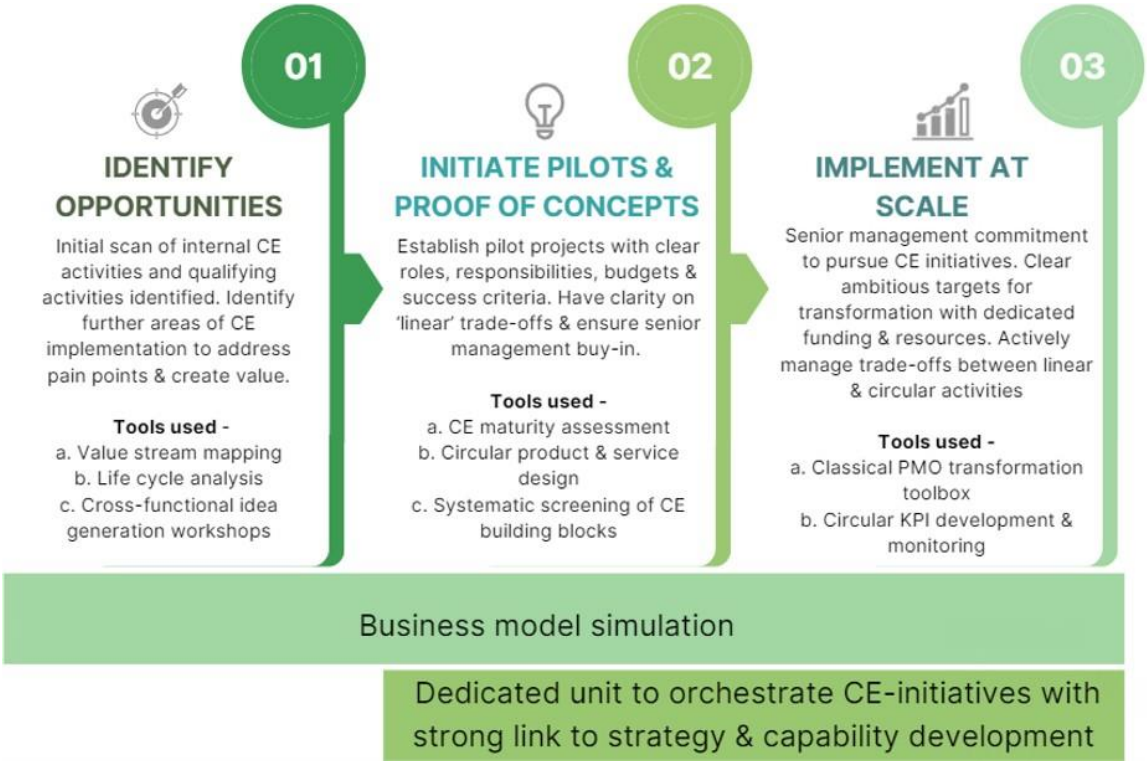

Figure 7. CE as a programmatic approach (adapted from Zils et al, 2023)

efforts to incorporate circularity into purchasing decisions. Additionally, the absence of a centralised working group overseeing the entire Concept, Assessment, Demonstration, Manufacture, In-service, and Disposal/Termination (CADMID/T) lifecycle further complicates efforts to integrate CE practices into Defence procurement which is siloed currently without cross functional collaboration and with an element of internal competition and conflict of priorities/KPIs (e.g., cost savings/lowest cost) present across the silos.

Towards a Circular Defence sector

Establishing CE in Defence for the future within the UK MOD demands decisive leadership and proactive collaboration from all stakeholders across the value chain. We broadly see progress across three phases, which could be incorporated with the three Epochs outlined in the MOD's Climate Change and Sustainability Strategic Approach (Figure 7).
In Phase 1, a diagnostic assessment is conducted to evaluate the current maturity level of CE within the sector, identifying critical challenges and potential opportunities for value generation. This assessment commonly employs diagnostic tools including lifecycle analysis to identify hotspots, and value stream mapping to inform future pilots and experimentation scenarios. Given the CE requires cross-functional insight, it is important in this first phase to bring together stakeholders from across the value chain, building understanding and engagement. A Pareto analysis scoping risk and opportunity of the over 200 platforms used by MOD will allow identification of the critical 20% of issues that can yield the 80% of quick wins.

Phase 2 provides proof of value through a coordinated program of pilots. Through data analysis and business model simulation, Defence organisations can assess the feasibility and effectiveness of various circular strategies, such as product-as-a-service, remanufacturing, and resource capture. This phase requires the development of a stakeholder engagement programme to explore different value creation opportunities and make informed decisions to maximise CE benefits, optimising resource allocation, and mitigating risks before committing resources to full-scale implementation.

Selection of signature products for pilots can be a challenge, especially in a sector of such breadth of activity and reach. In the spirit of innovation and progress, it can be beneficial to develop a simple taxonomy against which stakeholders can propose products for inclusion. This enables prioritisation of pilot initiatives that maximise the benefits of CE principles, while addressing key operational and environmental challenges. One such framework for Defence could be based on the three tiers of inventory and additional criteria as explained below:

1. Permanent Inventory Tier: Identify high-value, long-lasting assets crucial for Defence operations, such as armoured vehicles or aircraft. Focus on products with significant lifecycle costs and environmental impacts.
2. Intermediate Inventory Tier: Target components or subsystems essential for maintaining and upgrading permanent assets, such as engine parts or communication systems. Prioritise items with frequent replacements or upgrades.
3. Consumables Inventory Tier: Select frequently used items with high consumption rates, like workwear, ammunition or fuel. Consider products that contribute significantly to operational costs and environmental footprints.

Additional criteria for consideration:

- **Criticality**: Assess the importance of each product to mission success and overall Defence capabilities. Prioritise items vital for maintaining operational readiness and strategic advantage.
- **Resource Intensity**: Evaluate the environmental impact of each product throughout its lifecycle, including extraction, production, use, and disposal.
- **Feasibility**: Consider the ease of implementing CE practices for each product, including factors like existing infrastructure, technological feasibility, and regulatory constraints.
- **Innovation Potential**: Identify products with potential for innovative circular solutions that could serve as showcases for broader adoption within the defence sector.
- **Strategic Alignment**: Ensure alignment with Defence strategy and overarching goals, such as sustainability targets, resilience, and cost efficiency.

Through stakeholder engagement a number of potential products were discussed which may be valuable to capture here, including field power, solar panels and batteries, off-grid power products, workwear, uniforms, flight suits, temporary shelters and bases.

Scaling implementation in Phase 3 requires a comprehensive transformation roadmap, a clear leadership structure and ring-fenced resources, underpinned by sector-specific key performance indicators (KPIs). Insights and knowledge gained from Phase 2 will uncover the dynamic abilities needed for system integration into governmental, industry, and Defence decision-making processes, as well as wider collaboration.

To ensure a consistent approach and facilitate scalable implementation during this phase, it is essential to establish a common data framework and IT infrastructure system with an agreed taxonomy and governance structure. Equally, a dedicated unit is essential to coordinate and orchestrate CE initiatives, ensuring alignment with overarching strategy and capability development. Such a unit can streamline efforts, facilitate knowledge sharing, and foster collaboration across different departments and stakeholders. By providing strategic direction and oversight, this unit can effectively drive the integration of CE principles into Defence operations, promoting sustainability and resilience.

Key capabilities for adopting a CE

In practice, companies and organisations who are already benefitting from the CE typically succeed by harnessing four core building blocks:

Design: For the Defence sector, this entails collaborating with the supply chain responsible for designing assets, products, and services to minimise consumption, decrease dependence on fossil fuels, encourage maintenance, extend product lifespans, and eradicate harmful materials that hinder reuse or recycling. This will require streamlining procurement procedures, including creation of working groups overseeing the entire CADMID/T cycle of assets (instead of parts of it as currently carried out), fostering greater collaboration between prime contractors and SMEs to bring in product and process innovations, and integrating CE considerations into the entire procurement lifecycle.
Reverse Logistics: From the outset, establish an adaptable lifecycle strategy with reverse loops connecting back to suppliers, third parties, or adjacent

value chains to guarantee that valuable products, components, and materials can be effectively recirculated for profitability. As seen in the Dutch MoD workwear example, immediate impact can be achieved through planned resource recovery.

Business Models: This entails moving towards operating models that prioritise the entire cost of ownership and carbon footprint, transitioning to performance-based models that encourage increased utilisation while ensuring guaranteed performance and offering options for substantial product lifespan extension through upgrades, repairs, refurbishment, remanufacturing, and collaborative efforts across value chains (e.g., industrial symbiosis). Leasing models could be readily adopted for mature product categories such as office furniture, printing and desktop IT to name a few.

System enablers: Six key pillars will play a crucial role in advancing CE practices within Defence:

- Leadership: Strong leadership is essential for setting the strategic direction and mandate for adopting a CE approach. This involves assigning clear responsibility and accountability for CE initiatives within each organisation. Leaders must champion the transition to a CE, ensuring that it becomes a core aspect of the Defence organisation's mission and values.
- Appropriate workforce: The MOD needs to develop a full understanding of the people and skills it needs across its logistics function, especially inventory management to ease staffing pressures that are currently posing risks to delivery to the front line. By developing a more detailed understanding of the roles it requires and where it has gaps, the MOD can recruit sufficient workforce of the right skill level to ensure its IT enabled transformation programmes can be implemented successfully to deliver financial and operational benefits.
- Education: Educating stakeholders (including users, industry & supply chain partners) about the principles and benefits of CE is vital for fostering understanding and buy-in across the organisation & supply chain. This includes raising awareness about how CE addresses the challenges faced by the defence sector, such as resource scarcity, waste generation, and environmental impact. Updated training programs, workshops, and awareness campaigns can help build knowledge and capacity among stakeholders at all levels.
- Behaviour Change: Overcoming inertia and driving behaviour change is essential for successfully implementing CE practices. This involves developing a culture of innovation, collaboration and continuous improvement within the sector. Effective communication strategies are needed to engage employees and stakeholders along the value chain, inspiring them to embrace new ways of thinking and working that prioritise circularity.
- Data: Access to accurate, timely, and interoperable data is critical for informing decision-making and optimising CE initiatives. This includes data on resource flows, material usage, lifecycle impacts, and performance metrics. Establishing robust data management systems and leveraging technologies like IoT, blockchain, and machine learning can improve visibility, traceability, and transparency throughout the defence supply chain, facilitating more informed and efficient resource management decisions. By addressing these system enablers, Defence can create the necessary foundations for successful adoption and implementation of circular economy practices, driving innovation, sustainability, and resilience across their operations and supply chains. The Defence Data Research Centre (DDRC), led by the University of Exeter is part of the MOD's Defence AI Centre. It aims to address challenges associated with utilising data for AI applications, particularly when data is inaccessible or unusable in its raw form. Focused on defence-related issues, the DDRC seeks to develop solutions that can also be applied across various sectors to enhance the broader UK economy.
- Finance: By directing investment towards defence firms that prioritise sustainability, ESG (Environmental, Social, and Governance) finance encourages the adoption of circular principles in their operations. This includes initiatives such as reducing resource consumption, minimising waste generation, and promoting eco-friendly practices throughout the supply chain. Moreover, ESG frameworks incentivise transparency and accountability, ensuring that defence companies integrate environmental and social considerations into their decision-making processes. Ultimately,

ESG finance drives positive change by aligning financial incentives with CE goals, fostering innovation, and enhancing the overall sustainability[24] of defence industry practices.

Conclusion

As a short précis of our initial engagement with the Defence sector, this report highlights how a CE presents a holistic solution to the systemic challenges faced by MOD organisations, from resource scarcity to waste generation and environmental impact. Given the Defence sector oversees a vast array of assets and equipment and exhibits a clear desire for change, it stands in a good position to pioneer innovation and adopt CE principles. This shift has the potential to substantially enhance asset and resource efficiency, lower costs, and contribute to achieving ambitious net-zero targets, which aligns with the strategic goals of the sector, promoting resilience, sustainability, and efficiency across operations and supply chains along with economic security. To fully realise the value creation opportunities, strong leadership, education, behaviour change, aligned investment priorities and data management are essential. Moving forward, concerted efforts are needed to integrate CE principles into organisational culture, policies, and practices, driving innovation and fostering a more sustainable and resilient defence sector for the future.

Supporting next steps

The transition to a CE requires multiple stakeholders working together and collaborating over long time periods to shape and implement effective interventions and outcomes. The activities of the CE-Hub include supporting networks and strategic initiatives through workshops, roundtables, conferences, specialist meetings and webinars and engagement with many national and global networks enabling:

- Dialogue and diverse perspectives and expertise to foster innovation and inspire entrepreneurial thinking.
- Access and translation of leading scientific knowledge, policy, industry and NGO insights into CE system transitions.

As a leading provider of research-led CE executive and practitioner education programmes and courses, the CE-Hub draws on the expertise of our 1000+ research strong research community at University of Exeter, and excellent relationships with industrial partners. We have curated and shaped inspiring and high impact education and training that enables leadership and managerial capabilities of organisations to deliver effective CE solutions through the following activities:

- Open Programme – An Introduction to the Circular Economy Masterclass Supported by the Ellen MacArthur Foundation, our CE Masterclass provides the opportunity to learn directly from leading experts in the field of Circular Economy. The 6-week online course goes beyond the basics, providing an understanding in value creation, capture and scaling and the capabilities required at different stages. Managers engaged in CE share insight into successful case examples and can give practical advice on how to overcome barriers and make the case for change within your organisation.
- Bespoke education – including bespoke mini-masterclasses and CE workshops, designed for a specific set of organisational challenges against a context of value creation.
- Corporate Consultancy - our consultancy services give you access to our world-class academic expertise and cutting-edge research facilities. We help you get the best possible results with project support from beginning to end.
- Knowledge Transfer Partnership - a collaborative project between a company seeking change and an academic team applying their research in a business environment.
- Graduate Internships – our internship and graduate recruitment schemes aim to close the gap between education and industry and enhance the employability of students. There are different schemes available that can help your business to grow future skills and create a talent pipeline.
- MBA Consultancy Projects - students help to solve real business challenges, providing a cost effective project to take advantage of the latest management research.

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