Enhancing collaboration

EPSRC expects that projects of this nature will require the integration of multiple stakeholders and broad interdisciplinary teams.

Therefore, in order to maximise the value of this activity to the wider community, the text from the 'summary' Je-S section for the successful outlines, along with the principal investigator name and institution, can be found in this document.

This aims to support potential additional partners to identify, approach and join programmes. Any investigators involved in outlines that are not prioritised are encouraged to engage with those that are prioritised, where appropriate, as the full stage proposal interdisciplinary consortia are scoped and developed. EPSRC may consider facilitating conversations between aligned proposals if deemed necessary.

Outline proposals invited to full application stage (listed in alphabetical order of lead institution)

PI name	Professor Z Fan
Lead institution	Brunel University London
Je-S summary text	Metallic materials are the backbone of the global manufacturing industry and the fuel for economic growth. As a foundation industry, metal production underpins the competitive position of many other industrial sectors, such as energy conversion, transportation, construction, communication and healthcare. However, extraction and processing of metals are extremely energy intensive and cause severe environmental damage. The extraction of iron and aluminium alone accounts for 9% of the global primary energy demand and 11% of the global greenhouse gas (GHG) emission. The grand challenge facing the entire world is decoupling economic growth from environmental damage, in which metals have a critical role to play. It is time we change our way of using natural resources from a linear take-make-waste approach to a circular approach; and it is also time for us to be more innovative so we can live with what we have, make best use of what we have and do more with what we have. Such circular economy approaches will provide us with effective mechanisms for decoupling economic growth from environmental damage. Based on the CE principles, we have developed full metal circulation as our long-term ambition: the global demand for metallic materials will be met by a full circulation of secondary metals through reduce, reuse, remanufacture, recycling and recovery without the need for either mining or metal extraction. A systems approach to delivering full metal circulation includes: closing the loop, narrowing the loop and slowing down the loop. The MHS project will focus on slowing down the flow rate of metallic materials in the global economy by significantly extending their service life. Our vision is that analogous to the National Health Service (NHS), under a circular economy in the future there will be a "metal health service" (MHS) for metallic components, where all metallic components have a health record; "tired" components can be identified and rejuvenated; "sick" components can be diagnosed and cured; and "broken" components can be assessed and repaired. We envisage that under the care of the MHS, metallic components will have orders of magnitude longer service life compared with the current one-off service. The MHS

	project aims to lay down a solid foundation for the MHS to significantly extend the service lives of metallic components. To deliver the MHS project, a truly multidisciplinary academic research team has been assembled from 4 UK universities (Brunel, Manchester, Coventry and UCL). It will be strengthened by a strong industrial consortium spanning the entire metal supply chain. We will develop technologies: (1) for manufacturing metallic components with generic longevity; (2) for rejuvenating "tired" components; (3) for recovering "sick" components; and (4) for repairing "broken" components. A successful MHS will make a quantum leap in the transition to a circular economy by slowing down significantly the flow rate of metals, which will inspire research in other natural resources and will accelerate the transition to a circular economy. In addition, the MHS will result in a substantial reduction in annual demand for metallic materials. This will in turn contribute to both narrowing and closing of the loop of metallic materials, facilitating the realisation of full metal circulation. The overall impact will be a significant reduction of CO2 emission and primary energy consumption per year. Furthermore, metals are closely associated with resource scarcity and supply security. This is particularly true for the UK, which relies almost 100% on the import of metals. Realisation of full metal circulation facilitated by the MHS will make the UK self-sufficient in metallic materials and will eliminate supply security concerns. The overall impact of the MHS will be an accelerated transition to a circular economy.

PI name	Professor Elizabeth Gibson
Lead institution	Newcastle University
Je-S summary text	Delivering circularity and Net Zero in the process industries (where raw materials are transformed into higher value formulated materials and products) by 2050 requires urgent research work now across a range of materials, technology, modelling and circular economy system disciplines. The ProCircular programme has been designed to deliver this multi-disciplinary research, using a wide range of expertise across leading UK Universities. The programme will co-create and co-deliver circular economy research projects with industrial partners across chemical, fast-moving consumer goods (FMCGs) and water sectors in a new ProCircular Innovation Alliance (PCIA). The PCIA will engage relevant industrial and policy stakeholders and provide the critical feasibility evidence to enable a technology roadmap for circularity in FMCG, and related process industries, to be developed. This roadmap can then be used to drive policy and investment decisions that will ensure the UK is leading global competition, and that UK companies and citizens benefit from delivering a sustainable circular economy. The PCIA will optimise FMCG product ingredients and formulations through novel materials and chemistry to increase resource circularity and make large reductions in carbon emissions and an early environmental impact. FMCGs are products that have a short useful lifetime and are typically designed for single or limited uses followed by disposal. Today, their disposable nature, combined with ineffective waste recovery systems, are causing global environmental problems. The PCIA aims to respond to consumer demands for goods to be

	produced sustainably with minimal environmental impact. The research will also help FMCG companies to meet their ambitious decarbonisation targets while offering quality and value that customers expect. While much of the circular economy focus to date has been on packaging, attention needs to turn to the package contents. Outcomes from the PCIA will include: accelerating the transition from petroleum-based raw materials to renewable and/or bio-based materials; developing new clean, low energy and low carbon production methods; developing more effective formulations and usage methods to reduce resource use; and moving to biodegradable or recoverable materials. In the face of 'greenwashing' concerns, the PCIA will provide methods to prove that ingredient and product claims are traceable and backed by solid evidence. For products that involve water use (e.g. personal hygiene, laundry, dishwashing), research will consider material improvements that could have a large impact on domestic water use, energy consumption and carbon emissions. As FMCG materials often end up in wastewater streams and/or in municipal waste, the research will also address the major challenges of how to recover, recycle or reuse formulated materials. A key advantage of the ProCircular approach comes from bringing FMCG, water/waste, and chemical/material processing companies together with academic researchers to co-create innovative solutions. This is needed to coordinate efforts to move to clean and circular models of manufacturing, product use, resource recovery and reuse. The PCIA will also consider aligned technology developments in other sectors (e.g. energy, hydrogen), as well as socio-ethical aspects, consumer education and behaviour change and, importantly, industrial standards, Government policies, regulation, and support measures needed to secure investment to transform to a circular, low carbon economy. Many of the research outcomes and lessons learned will be applicable to other process industries (e.g. ceramics/glass, pulp/paper, food/feed, minerals, metals etc). There is great scope for the PCIA to extend to other process industries in future and sustain as a model for impactful academic-industry-public sector-third sector collaboration.

PI name	Professor Allan Walton
Lead institution	University of Birmingham
Je-S summary text	RECREATE (REcycling CRitical Elements in Advanced Technologies for the Environment) Technology critical metals (TCMs), such as lithium, cobalt, rare earths and platinum group metals (PGMs), are those which are economically important but at risk of short supply. The UK Government's Net Zero Strategy: "Build Back Greener" (2021) highlights the supply of these critical materials as a key challenge for the UK's energy transition. They are used in electrical generators (such as offshore wind-turbines), electrical motors and in batteries (both essential for electrical vehicles) and in the hydrogen economy.

	The Government's (2022) Critical Minerals Strategy, Resilience for the Future, emphasises the global supply-chain pressures arising from the growth in demand for such materials and that Government plans "will only happen in the UK if there is a resilient supply of these minerals". The UK published its first critical mineral list in 2022 with 18 "technology critical minerals and metals" (British Geological Survey, 2022). Currently, recycling rates for TCMs are very low, for example just 5% for neodymium used in rare earth magnets (Critical Raw Materials Resilience EU report). This is due to a number of factors including a lack of specific incentives or legislation to drive the circular economy, the current product designs which impede separation, in some applications the very low concentration of the critical material, the fragmented nature of the recycling value-chains, and the often rather crude current recycling processes (most of which were designed for less-precious bulk metals). The overarching aim of RECREATE is to develop a circular economy for TCMs, keeping the materials or components in the highest value form with the lowest environmental footprint. The project brings together leading industrial and public-sector players and policy makers, all involved in the drive to create a circular economy for critical materials in the UK. The research will be informed by a system-wide perspective derived from a deep understanding of the industrial challenges for recycling of these materials and of the governance structures that drive the circular economy. This project will undertake low TRL transformative research to generate new knowledge in automated sorting, "short loop" recycling, pyrometallurgical and chemical processes with reduced environmental impact, biological processes which can enhance the behaviour of the extracted metals and new materials and products which are designed to make re-use or recycling easier.

PI name	Dr Michael Johnson
Lead institution	University of Nottingham
Je-S summary text	Reinforced polymer composites (or "composites") are increasingly replacing traditional structural materials like steel. This is because weight-for-weight, composites can be 5 times as strong as steel; meaning less weight of material is needed to do the same job. Saving weight means saving energy, particularly across the transport sector. Saving energy means less emissions and supports the global pathway to a sustainable net zero carbon future. Further, light weight makes it possible to build larger. Composites have enabled the production of huge wind turbine blades (larger blades are more efficient) that would be too heavy to install and would collapse under their own weight if made of metal. Composites are growing in use across multiple sectors including energy, aerospace, automotive, rail and infrastructure. Wind energy currently accounts for 20% of UK energy generation and the shift to electric and hydrogen fuels means composites are needed to offset the weight of batteries and the large size of hydrogen storage tanks in cars and planes. Unlike steel and aluminium, composites are not widely recycled. This is due to technical challenges and presently uneconomical means

	of recovery. In the UK, 110 kilotonnes of composites are produced annually but only 15% (17k tonnes) are currently recycled. The high growth in the use of composite materials (around 7.5%p.a. currently) presents a pressing need for the development and adoption of a circular economy for reinforced polymer composites. The Challenge is to make reinforced polymer composites last multiple lifetimes, fulfilling the vision of a circular economy. Composites follow a linear economy and are disposed of long before reaching the end of their useful material life. Net zero pledges and more stringent policy directives on recycling mean a circular economy solution is essential. Keeping the components of the composite within circulation for as many repeated product applications as possible is crucial to this goal. The focus is on efficient recovery through controlled disassembly rather than crushing and shredding, maintaining the components at the highest possible value. Such a solution is only achievable through an all-encompassing approach; employing inclusive, cross-disciplinary partnerships to form complete closed loop manufacturing and demanufacturing technologies. This must be developed alongside evolving policy and incorporate socioeconomic drivers to ensure a societal fitness for purpose. The solution is to create Full Loop Inversion Processes (FLIPs). These are imagined as circular loops that anticipate the entire life cycle of a composite component. There are 3 FLIPs to include the main starting materials used for composites: fabric, tape and filament. As loops, the FLIPs all break after the composite component has reached the end of its use as a product. There is no established means to demanufacture. The FLIP Programme will develop these demanufacturing process to complete FLIP loops. This includes selecting starting materials that facilitate demanufacture for re-use using low-energy manufacturing technologies. Embedded design practices need to assist economical material recovery and embrace modern techniques for traceability. Life extension features of maintenance and repair require consideration during the design phase. Required are simple separation of assemblies and processes to revert the composite component at the end of service into a feedstock for follow-on component manufacture. Completing the FLIP loops for circularity will be co-developed with industry, a Catapult, the third sector and government. Partnering with the National Composites Centre Catapult provides a clear translation pathway. A cross-disciplinary Team at the University of Nottingham provides critical mass and includes sustainable chemists, composites manufacturing engineers, life cycle analysists and business modellers, sociologists and policy forming specialists.

PI name	Dr Danielle Densley Tingley
Lead institution	University of Sheffield
Je-S summary text	The built environment is responsible for 30-42% of the UK's carbon emissions and produces over 60% of the UK's waste: 138 million tonnes

	of construction, excavation and demolition waste in 2018. At a global level, the built environment consumes approximately 50% of all extracted materials. The circular economy (CE) is an opportunity to turn waste into resource, and in doing so, minimise emissions. CE aims to keep materials at the highest value possible, via a hierarchy of strategies, e.g. prioritising building life extension, then element reuse, then element remanufacturing and finally material recycling. However, CE action to date has largely focused on individual projects or buildings, and often focuses on wasteful downcycling strategies. Current activities are therefore largely failing to capitalise on the full range of CE strategies available, and thus are not delivering the national-scale impact that is so desperately required. BuildZero proposes a much-needed radical vision for the UK's building stock: use of zero extracted materials, with production of zero waste and zero carbon. This transdisciplinary research programme will develop: 1) the first multi-scale, systems model of building and resource flows to quantify what is physically and technically possible at scale, 2) a suite of viable solutions based on two themes: making the best use of existing space, and making the best use of materials, and 3) backcasting and foresight scenario tools to test the extent to which this radical vision is achievable, and in what conditions it leads to favourable environmental, social and economic outcomes. Together these will provide the evidence base needed to catalyse changes in industrial practice, regional and national policy. Furthermore, we will use the scenario modelling tools employed in (3) to work with stakeholders to co-develop preferred pathways to BuildZero futures, and from these co-create a 10 year research agenda covering the remaining UK research required to reach BuildZero.

PI name	Professor Anthony Ryan
Lead institution	University of Sheffield
Je-S summary text	Nearly all sectors of the UK economy rely on plastic, from transport (1.36 M tonnes pa) to packaging (3.18 M tonnes pa), textiles (750,000 tonnes pa) to construction (1.65 M tonnes pa), and agriculture (40,000 tonnes pa) to electronics (450,000 tonnes pa). This plastic usually ends up in landfill or incineration, while only a fraction is recycled, and there is significant leakage into the environment. The lack of circularity of plastics contributes significantly to the consumption of resources (including water and energy), climate change, the pollution of ecosystems, and the production of microplastics. It also represents a financial and material loss to the UK economy of the order of £100 billion pa. Recent efforts have rightly focussed on plastic packaging, but packaging only accounts for 40% of global plastics and systemic challenges in plastic waste will not be solved through siloed projects as plastic flows encompass complex multi-material products embedded in every part of the economy. The UK is an international leader in plastic waste research but the focus on packaging has exposed the gaps in fundamental understanding, analysis and technological capability to move other generators of plastic waste into a circular economy. This project addresses the large sector

	of complex multi-material plastic products embedded in every part of the economy. We will help create a plastics circular economy system that meets government targets, e.g. halve residual waste by 2042 (Environmental Act 2021). Plastic has a role to play in delivering net zero, making plastics generates significant CO2 emissions and at the end of life its incineration is worse than burning coal soil and air pollution. If done properly plastics can even be net-negative at the end of life. Our consortium has the shared experience of working across industry, policy and academia delivering solutions of sustainable plastic packaging have developed valuable networks, trained 50+ young researchers and effective interdisciplinary methods. We have the momentum, highly trained teams and shared insight and vision needed to bring together a critical mass of researchers, industry, and policy makers to transform the plastics economy. We will deliver actionable change through our strong industry partnerships, as well as innovative solutions in strategic areas like healthcare, fast moving consumer goods (FMCG), appliances and construction & transport to drive economic benefit to the UK with considerable financial contributions from our industry partners. The legacy of this funding will be a self-sustaining community built on innovation in the Engineering and Physical Sciences, supported by interdisciplinary perspectives, and focussed on enabling systemic change in plastics circularity that creates impact by co-developing solutions with diverse industry and policy partners.

PI name	Professor Jhuma Sadhukhan
Lead institution	University of Surrey
Je-S summary text	The vision of this interdisciplinary programme is to deliver novel circular economy solutions for the UK's industrial clusters and boost their net zero transitions by circular economy approaches. Industrial clusters are concentrations of industrial sites where several resource-intensive and hard-to-decarbonise sectors, e.g., chemicals, cement, ceramics, paper, etc., are co-located. Enabling the sustainable transition of industrial clusters is the top priority of the UK's industrial mission. In the past, separate efforts have been put into (1) circular economy approaches to eliminate waste; and (2) industrial decarbonisation approaches via renewable energy, carbon capture and energy saving. However, these two objectives are often found in conflict with each other. To solve the dilemma, this programme brings together the UK's leading expertise in both areas of circular manufacturing and industrial decarbonisation into a single team with a fresh perspective of looking at the problem in a systemic approach. The programme will develop a cluster-level digital twin framework to enable us to understand the interactions between the energy flow and

	materials flow in complex industrial systems and explore the synergies and indeed any antagonistic effects between decarbonisation and circularity within the current infrastructure as well as in future scenarios. We will develop disruptive circular manufacturing technologies offering new possibilities for the utilisation of waste streams as secondary resources while minimising greenhouse gas emissions of the processes within the cluster. The programme will also implement Circular Cluster solutions in the real world by co-creating and co-delivering with project partners, supporting the UK industry to accelerate the pathway to circular and net zero manufacturing and increase our global competitiveness and expertise.