UK Research and Innovation

UKRI Interdisciplinary Circular Economy Centres

Outline proposals invited to full proposal stage

Contents

18 proposals have been invited to submit full proposals. Please note:

- The summaries contained in this document are those originally submitted through Je-S by the applicants at outline stage. These summaries were not part of the assessment process, and may therefore vary in the level of detail provided.
- Applicants are expected to develop their proposal between outline and full stage, and full proposals may differ from the outlines provided here.
- Interested parties are encouraged to approach the contacts listed in the document for further details, or to collaborate.

Textiles Circularity Centre (TCC): Circular Bioeconomy for Textile Materials

Name of Grant Contact: Professor Sharon Baurley

Summary: Most apparel and textiles in the UK are imported (£24.5bn); only £9bn of fashion and textiles are made in the UK. In 2018 clothing worth £60bn in the UK was consumed, of which cellulose and polyester accounted for the largest proportion at 90%, and the sector is responsible for over 1MT of material going to landfill and incineration each year. We therefore propose a CE Centre that will promote materials independence (in cellulose and polyester) for the UK by circularising the resource flow of textiles by using bio-based waste-derived feedstock (post-consumer textiles, agri-food industry by-products, and municipal solid waste). We will design and develop a supply chain for the circularity of materials for nonwoven, flexible composites and constructed textiles that are bio-based, and sourced from locally abundant low-carbon feedstock in the UK. Our transition strategy is based on using post-consumer textiles from the current textile system, towards a circular one that uses agri-waste, municipal waste, and eventually waste textiles that have been produced from these feedstocks. Our materials propose renewable alternatives to phase out imported cotton, wood pulp and synthetic polyester fibres and petrochemical finishes, and will be made accessible in an online 'biomaterials platform'. Our approach to circularity embraces the emergence of local flexible manufacturing hubs, comprising Additive Manufacture and 3D weaving and knitting. Together with these hubs and the materials platform, our circular and transparent supply chain of novel types of sustainable low carbon regenerated, semi-synthetic and bio-based synthetic fibre alternatives (combining biological and non-biological processes), as well as durable biologically fabricated materials, will catalyse significant growth in the UK textile manufacturing and SME apparel sectors. We will enact industrial symbiosis across sectors including agriculture, waste management, biorefining, biotechnology, manufacturing, design, SME apparel, retail, and consumers. TCC will provide SMEs with specifications for the design of consumption experiences that effect a coupling between the resource flow and human wellbeing and satisfaction. This will empower consumers to be a key node in the circular value chain, and enable a relationship of responsible and personalised engagement. Our approach will provide major reductions in waste, carbon emissions and environmental impacts for the textiles/apparel sector.

Centre for Circular Consumer Electronic and Electrical Products (CCEEP)

Name of Grant Contact: Professor Tracy Bhamra

Summary: The Centre for Circular Consumer Electronic & Electrical Products (CCEEP) will develop consumer-driven Circular Economy solutions for consumer electronic and electrical products. It will take a consumer-informed approach to investigate business models, materials, manufacturing processes, new and improvements to existing products, new technologies, services and systems that effectively contribute to the delivery of the circular economy. The interdisciplinary approach will explore how 'value' can be understood in terms of traditional material stocks and flows and beyond this to capture wider socio-economic impacts in partnership with key stakeholders from across the value chain. Circular business models will need to deliver customer requirements, within closed loops that enable products to be durable, remanufacturable and recyclable. This will include a shift away from the supply of products towards product service systems that meet consumer needs at the same time as radically reducing the system's environmental impact across the whole life cycle. Until recently, CE research and policy has broadly ignored the consumer or treated them as passive adopters. This timely Centre targets the application of CE principles in the business-to-consumer sector where significant theoretical and practical research involving multiple disciples is needed, focusing on the challenges of the mass market: a necessity if the CE is to have real and lasting impact.

UKRI Circular Economy Centre for Construction, Demolition and Excavation Waste

Name of Grant Contact: Professor Constantin Blome

Summary: Despite some recycling and reuse, construction, demolition and excavation (CDE) are a vast waste stream, some five times larger than household waste. Some 60% of the UK's annual waste (120m tons) comes from CDE, resulting in a large carbon footprint from the associated logistics alone. This presents a major challenge for infrastructure and urban projects in the era of achieving net zero emissions under a rapid timetable. A Circular Economy (CE) approach to CDE waste can aim to cut this impact and find more efficient and benign resource flow. However, in practice various factors hinder this. These include a need for new technology to enable recycling or reuse. Better data management about material use in construction and infrastructure projects is needed. Better supply chain and market analysis of who might be a buyer or supplier for such resource streams is required. Finally, economic modelling to help produce viable business cases is needed to attract investment and change performance.

The research team and their partners in local government and business have an established expertise in this topic, and working together in an interdisciplinary way, are able to help overcome these challenges. By focusing the research on the scale of a local city authority (Brighton), where there is policy being developed to encourage a Circular Economy in construction, the research proposal is timely and well-supported by key stakeholders.

The interdisciplinary research will work across schools of engineering and architecture, and business and management, to map existing resource flows in key construction sites, determine feasibility for change, and scalability to wider markets. Data analysis of CDE waste will help reduce waste, generate value and so create new employment. Such work would cover the whole value chain for construction, ranging from designers to contractors, physical skills in building deconstruction, civil engineering and construction product manufacturing, logistics and processing, and information technology and data services.

The Centre will focus on the transformation stages of resources in CE, namely, waste separation, recycling, remanufacturing, next-generation utilisation, and prevention. Via mapping existing pilot case studies, feasibility and foresight will be developed for digital resource management and supply network innovation. Business models based on value retention for CDE waste will inform new venture creation and policy making at local and national levels. Construction projects are all unique, so there is a particular challenge in assessing the quality and reuseability of construction materials. The distance of a supplier to a buyer can also result in prohibitive costs, the weight of the materials may be too great, or the timescales may not readily line up, and the pressure on firms to deliver projects at low cost and tight schedule can prevent reform.

However, the local context in Brighton is as favourable as may be hoped for to undertake this pioneering research. The Brighton & Hove City Council plan to build 1,000 new affordable homes (among other developments) using CE principles. The

City Council's 'Circular Economy Route Map' (to be published April 2020) focuses on the Construction and Visitor Economies. This aligns with national strategy on boosting the tourism sector in the UK along sustainable grounds, which will include changes to strategic infrastructure to enable more low carbon transport, and a substantial increase to visitor accommodation. This strategy aims to trigger a construction boom, so now is the time to develop the wider networks of business supply chains able to deliver a low carbon circular economy for new build, demolition, refurbishment and infrastructure. To do so will require undertaking research across economic modelling, digital systems for procurement and exchange, understanding regulatory barriers (such as taxation and liability), capacity building and employment needs.

Circular Nutrients Centre (CNC)

Name of Grant Contact: Professor Steffen Boehm

Summary: The Challenge
Nutrients (an essential substance in food production) are a fundamental and manageable, focal resource flow that is key to a more sustainable, low-carbon economy. Yet, nutrients are often overlooked by UK policymakers and rarely feature in national media and the public's consciousness. The UK's management of nutrients - mainly nitrogen (N), phosphorus (P) and potassium (K), as well as essential micronutrients such as zinc and molybdenum - has been ineffective: while many nutrients are lost across the entire value chain, creating negative environmental impacts, such as greenhouse gas and other gaseous emissions, poor water quality and biodiversity loss, farmers' cost of applying artificial fertilisers is growing, contributing to income and livelihood pressures.
The Solution
The Circular Nutrients Centre (CNC) is based on the premise that the most promising and enduring solutions to these multifaceted problems will only emerge by designing a circular nutrients system which, inspired by the principles of the circular economy (CE), works across economic, social and ecosystem dimensions, where waste loops are closed, surpluses shared and multiple forms of value are retained and circulated. Although agri-food systems are complex, nutrients are a fundamental resource flow that is key to, and must lie at the heart of, such a CE approach. A more restorative and regenerative nutrient system would lead to a healthier economy, society and environment. Such a circular nutrients system will (i) close loops of key nutrients by facilitating adoption and diffusion of regenerative practices; (ii) optimise the use of nutrients, facilitated by sharing platforms; and (iii) foster regenerative practices and diversity in the entire agri-food system.
Co-design and co-delivery
There is no blueprint for a circular nutrient system. Instead, the CNC will draw on skills and experiences from a broad range of experts to develop its vision. The CNC is led by the University of Exeter, collaborating closely with Rothamsted Research and Harper Adams University. Our world-class, interdisciplinary research team comprises engineers, agronomists, soil scientists, ecologists, geographers, business experts, economists and systems modellers. The CNC will closely involve a range of stakeholders from business, government and the NGO sector, setting up a joint Delivery Board that will co-design and co-deliver the Centre's programme. We already maintain good relations with Defra, WRAP, Lidl, National Trust, Dairy Crest and many other partners who will help the CNC to promote system change across the entire nutrients value chain. The CNC will have five inter-related themes, namely (1) Systems analysis for nutrient resilience and effectiveness; (2) New business models; (3) Governance and regulation; (4) Consumer and household dynamics; and (5) Technologies for nutrient reduction and recovery.
Funding and leadership track record
The University of Exeter is at the forefront of CE research. In 2017, it was designated a Global Pioneer University by the Ellen MacArthur Foundation, as Dame Ellen MacArthur launched the Exeter Centre for Circular Economy, which has grown a global reputation for CE thought-leadership. The CNC leadership team has a world-class track record in successfully delivering high-value research investments. For

example, Profs Boehm and Gaston co-lead a £3.4m EU project that delivers circular economy solutions. Prof Gaston is the founding director of the Environment and Sustainability Institute, which received £23m of initial EU investment. The Centre team has received large-scale investments from EPSRC, ESRC, NERC, BBSRC, Defra and other funders. The Exeter team will work closely with Rothamsted Research and Harper Adams University, which have agri-food research platforms with an unparalleled ability to study nutrient flows. They include the National Centre for Precision Farming, based at Harper Adams.

Centre for Circular Plastics Economy

Name of Grant Contact: Professor David Bucknall

Summary: We live in a world where plastics are ubiquitous, and in fact it is hard not to find any product where plastics are not included in some way. Plastics are so widely used for many reasons: they are relatively cheap to make and produce compared to some other materials; they are very adaptable giving huge design flexibility of products; they are light weight and very durable. Our reliance on plastics has led to a 300-fold increase in production and use over the last 50-60 years. The UK economy enjoys massive benefits not only from the money generated on production and sales of plastics of about £27 billion per year, but also from the huge number of jobs associated with the plastics industry.

However, the cheapness and durability of the plastics are also central to the problems associated with waste plastics that we are faced with not only nationally but globally. In the UK approximately two thirds of all plastics are discarded, some of which is incinerated, and the remainder is sent to landfill sites. Only one third of all plastics used are collected for recycling, and within the total collected less than one third is recycled, with a significant amount discarded or incinerated. One of the end results of this produce-use-discard approach to plastics (throwaway culture) is the loss of plastics to the environment, with visible litter and more insidious although less visible microparticles of plastics now widely found on land, rivers and seas.

This Centre will address the issues of end-of-life plastics and explore and develop methods to prevent these plastics ending up in landfill sites or the environment. The Centre will bring together an interdisciplinary team of academics from across many disciplines within seven universities to understand how to change the current usage of plastics into one where the end-of-life plastics are reused or recycled hugely more effectively. The Centre will undertake basic research into economic, environmental, societal as well as scientific and engineering approaches in critical areas of achieving a Circular Economy.

Interdisciplinary Circular Food Centre (iCFC)

Name of Grant Contact: Professor Dimitris Charalampopoulos

Summary: Food is ubiquitous and essential in everyday life providing not only individual nutrition but also an essential fabric to local communities and global trade. The Food and Farming sector is vital for the UK economy, contributing £121 bn to the Gross Value Added (including £22 bn of exports) and employing 4.2 million people (14% of UK employment), while it depends significantly on imports (~47%). The current food system is linear and with few exceptions it is typically based on a "take-make-dispose" model, often without considering the effective and restorative use of resources, resulting in degradation of natural capital, i.e. land, water, soil, finite resources and biodiversity. As a result, it contributes to considerable environmental impact, for example it is globally responsible for ~30% of the greenhouse gas (GHG) emissions. In the UK, about 30% of food is lost/wasted across the system, valued in excess of £20 billion a year and contributing >20Mt of GHG emissions, presenting significant opportunities for circularity. At the same time food related diseases have reached epidemic levels, with >20% of the UK population being overweight or obese.

There is significant impetus over the last 5 years by all actors across the food system for a transformation towards a more circular system. Consumers are drivers of this, as seen by significant changes in consumption patterns and social movements. Social media have also created the ability of groupings of consumers to organically collaborate and engage more actively with food producers and retailers. This has created the start of innovation in circular economy (CE) through collaborative consumption, food and produce sharing, redistribution channels and reduction of overconsumption and household waste.

Through the proposed Interdisciplinary Circular Food Centre (iCFC) we will embed CE thinking to recapture value across the whole system by understanding and promoting all actors' involvement (primary producers, consumers, food and non-food businesses, government) and implementing innovative digital and physical technologies to affect system's change. The iCFC brings together an interdisciplinary team from the Universities of Reading, Nottingham, Leeds, Cranfield, Brunel, Loughborough and Exeter working together in an open and collaborative way, which is important for ensuring that the iCFC's ambitious vision is realised. The team will be complemented by a network of 32 confirmed partners ranging from micro-SMEs to multinationals across multiple sectors including food & agriculture, manufacturing, logistics, IT & sensors, household & personal care and built environment, as well as local government, charities and NGOs.

Through this program of work, we will assemble a picture of what a future circular food system in the UK looks like, and most importantly what needs to change in terms of individual behaviours, digital infrastructure, technology and policy in order to get there. To achieve system transformation, the iCFC will address three interconnected challenges: (1) Enable actors' engagement and co-operation through digital technologies; (2) Implement circular principles within circular business models; (3) Advance scientific and technological innovations enabling circularity. In this future state, there is significant inter-connectivity between all actors and multiple sectors, through the multi-way flow of information and materials, creating new operating circles and new opportunities for Recycling, Recovery, Remanufacture & Refurbish,

Reuse & Redesign. The system will allow for flexibility and co-creation, and accommodate different business models, including manufacturing on-demand and distributed manufacturing. Its performance will be assessed not at an individual but at a system level, by measuring the net value added (e.g. resource effectiveness; waste, water and energy reduction; health gain; economic benefits) and the net gain to the environment and natural capital.

CircBE: Catalysing Circularity in the Built Environment

Name of Grant Contact: Dr Danielle Densley Tingley

Summary: The built environment is the largest producer of waste in the UK, and is equivalent to one third of UK greenhouse gas emissions. A growing proportion of these emissions are embodied in materials extraction, production and transportation. Improving our use of materials in the built environment is thus critical to ensure policies such as zero carbon by 2050 are met, and that wider plans in the Industrial Strategy such as doubling resource productivity by 2050 are achieved. The circular economy, which aims to keep materials at as high a value for as long as possible, is discussed as a way to achieve this. However, efforts to improve circularity remain niche or ineffective at reducing emissions. CircBE will address this by bringing together different disciplines to develop a novel framework that enables the testing, prioritisation and market acceleration of built environment circular economy strategies that operate within environmental limits and social thresholds.
Our research will establish different ways to allocate material and carbon budgets within the built environment, to be applied at different scales e.g. domestic construction, or a city's built environment. We will, for the first time, generate both a systems level understanding of built environment resource stocks and flows, alongside including public perspectives on the key values and priorities that will inform who gets what, and why, in a circular built environment. This cross-disciplinary approach is essential in assessing if different circular strategies deliver a built environment that is equitable and within carbon and material limits. From this assessment we will produce a prioritised list of CE strategies, investigating at a systems level which mix of strategies produce the lowest carbon and most circular built environment that equitably meets humanity's needs. We will explore, with industry stakeholders, the systems transformation required to deliver these strategies in practice, and take those key strategies with the potential for large scale impact to the next level by exploring knowledge transfer partnerships and working with partners to pursue Innovate UK funding.

Interdisciplinary Circular Economy Centre – CircularMetal

Name of Grant Contact: Professor Zhongyun Fan

Summary: In the 4.5 billion-year history of the Earth, humankind arrived late to a planet already functioning in a fully circular manner, and lived in harmony within the infinite cycles of the natural ecosystem until the intervention of the Industrial Revolution 200 years ago. Empowered by advancing science and technology, humankind exploited nature for more and more resources (biomass, fossil fuels, metal ores and non-metallic minerals) to meet the growing needs for housing and infrastructure, nutrition, mobility, communications, consumables, services and healthcare. Since 1970, the global population has doubled (7.2bn) and global economic activity (GDP) has grown fourfold (US$60.4Tn). Such rapid population expansion and economic growth were fuelled by a fast-growing extraction of natural resources from 26.7Gt in 1970 to 92.1Gt in 2017, which accounts for 50% of the global GHG emission and more than 90% of water stress and biodiversity loss due to land use. The International Resource Panel (2019) has forecast that by 2050, global resource extraction will increase to 177Gt/year, global population to 10.2bn and GHG emission to 60Gt/year. This is leading to a head-on collision between the shrinking global ecosystem (the parent system) and the expanding human economy (a subsystem). Urgent actions are required to mitigate this catastrophic collision. Circular economy approaches provide effective mechanisms to decouple economic growth and rising living standards from resource consumption and environmental damage.

Metallic materials are the backbone of manufacturing and the fuel for economic growth. The UK metals industry comprises 11,100 companies, employs 230,000 people, directly contributes £10.7bn to the UK GDP, indirectly supports a further 750,000 employees and some £200bn UK GDP. As a foundation industry, it underpins the competitive positions of every industrial sector, including aerospace, automotive, construction, electronics, defence and general engineering. Transformation of the metals industry from the current largely linear economy to a circular economy plays a critical role in delivering the government's industrial strategy for clean growth, doubling of resource productivity and reaching net zero carbon emissions in 2050. We propose to establish an Interdisciplinary Circular Economy Centre, CircularMetal, to accelerate this transformation. We have assembled a truly interdisciplinary academic team with a wide range of academic expertise (such as macroeconomics, industrial sustainability, business management, artificial intelligence, product design, metallurgical science and materials engineering) and a strong industrial consortium involving the full range of the metals supply chain with £2.5M financial support. As an integral part of the national circular economy community, our ambition is to make the UK the first country in the world to realise full metal circulation. We will conduct macroeconomic analysis of metal flow to identify circularity gaps and to develop pathways/policies/regulations to bridge them; we will develop circular business models, circular design principles and enabling technologies to underpin this transition; and we will also work closely with the wider academic and industrial communities, policy makers and the general public to deliver the widest possible impact of circular economy. The CircularMetal

programme will provide the capability and pathways to eliminate the need for metal extraction, resulting in an estimated £100bn addition to the UK economy over the next 10 years.

Agile Biorefining for a Competitive Economy

Name of Grant Contact: Professor Tim Foster

Summary: The UK has a treasure-trove of biological material that comes from the production associated with agriculture, food and textiles. This primarily comes in the form of waste residues from agriculture, factory co-products, forestry waste, and end of life imported sources e.g. textiles and packaging. Currently these are treated as waste products with no value and are a burden on society - filling up landfill and causing environmental damage, which is symptomatic of a linear, cradle to grave, economy. However, these waste products actually contain significant value and resources that can be extracted, re-used and re-circulated providing significant environmental, social and economic gains leading to the development of a circular bioeconomy. To date the technology to deconstruct and reconstruct is not sufficiently mature or integrated to make it economically viable to extract this value and utilise it in other products. We now have these technologies and through a collective effort we will be able to combine, integrate and connect technologies, and optimise the whole system to make the UK bioeconomy a leading example worldwide.
This Circular Bioeconomy Centre (CBC) will develop the technologies to deconstruct these biomaterial wastes into building blocks that can then be reconstructed judiciously (like Lego) to generate new products that feedback into our critical supply chains such as food/feed, pharmaceutical, personal products, fuel, agri-product and chemical sectors. This will be achieved by developing biorefineries that can be adaptable to the biomaterials that are available, and will adjust the products that will be generated, forming "agile biorefineries". Essential for success of this will be the development of a digital infrastructure that can integrate the biomaterials available and the agile biorefineries that can be utilised with an available market for the product. Currently the marketplace is devoid of innovation, as there is a lack of transparency for what building blocks are or could potentially be available. We will tackle these challenges by bringing together expertise from multiple disciplines and through working with stakeholders across the system (consumers, producers, manufacturers, retailers, policymakers) and will identify how to transform existing systems into future agile systems, including implementation in the near term and also futuristic biorefinery designs in the longer term, providing integration across the system. The established centre of excellence will therefore transform our national bioeconomy through the adoption of these technologies and the implementation of a National Plan for a Zero Waste Bioeconomy.

Future Fibres Circular Economy Research Centre

Name of Grant Contact: Professor Tamara Susan Galloway

Summary: The trillion pound per year global fibres industry is a resource flow of strategic national importance to the UK Economy as a key input to multiple commercial sectors, value chains and products. The UKRI Future Fibres Circular Economy Centre will be the first of its kind internationally to address the global challenge presented by current linear fibres resource flows. It will provide outstanding national leadership to address systematically the accumulation, impact and heavy costs to the environment of key synthetic and renewable fibre resource flows, whilst maintaining and supporting applications of fibres for multiple high value purposes. We bring together four Universities and an extensive (inter)national network of collaborators across multiple sectors and all stages of the Fibres resource flow. Our team includes world-leading experts in circular economics, environmental and social science, technology and design, all actively working in fibre-related fields or research to support the circular economy. The team is ideally positioned to lead National circular economy interventions in this field within the UK hubs of design (University of the Arts, London), fibre and textile manufacturing (West Yorkshire: Universities of Leeds and Huddersfield) and environmental impact and circular economy research (South West: University of Exeter). We will build a systematic understanding of the current leakage points across significant fibre applications exemplified by relevant signature products/service. The Centre will research and promote the best safer-by-design materials, business model, technical, managerial, consumer/citizen and enabling conditions to and recapture current leakage points and redesign future systems to design out waste and environmental impact. To build legacy and long term impact we will construct a lasting innovation platform to present case studies, proof of concept, standards, tools and techniques needed to build a UK fibres circular economy fit for the future. We will build an active interdisciplinary community of academics, experts, industrial organisations, government, policy makers and user groups to position the Centre at the heart of the UK Industrial Strategy and create a new, world-leading, competitive advantage for the UK economy.

The Circular Bioeconomy Centre

Name of Grant Contact: Dr Louise Horsfall

Summary: The Circular Bioeconomy Centre will use the unavoidable waste and by-products from food & drink production to power a more circular and more bio-based economy in the UK. There are many products - chemicals, materials, coatings and devices, for example - whose current manufacture could be improved by adopting a bio-based strategy. Not only are these products more sustainable in terms of renewable feedstocks and end-of-life degradability, the processes used for their production are capable of remediating current & legacy contaminants. Circular Bioeconomy Centre research will examine environmental impact, economic performance, analysis of dependencies and impacts of processes and products on natural capital and policy frameworks in conjunction with analysis of the complete, full-cycle value chain. The aim will be to reintroduce biological components back into the economy earlier whilst minimising the use of additional resources, with the potential to also valorise components through efficient isolation or bioprocessing. Furthermore, while the Circular Bioeconomy Centre will develop processes focusing on the food & drink resource flow, we envision that the results derived are likely to be common to other biological resources and thus technologies and models developed could also be applied more widely to other bio-based resource streams.

Protein Resources in the Circular Economy (PRICE)

Name of Grant Contact: Professor Alan Raybould

Summary: A Circular Economy is defined by Zero Waste Scotland as "... an all-encompassing approach to life and business where everything has value and nothing is wasted". Our research will apply these principles to the production of protein for human consumption.

Protein for human consumption is provided by a variety of foods, including red meat, dairy products, poultry (meat and eggs) and certain vegetables. Production of some of these foods can lead to undesirable consequences; in particular, intensive red meat production uses large quantities of grain, which may be grown on recently cleared forest, and require large amounts of nitrogen fertiliser produced with energy from fossil fuels. Producing red meat may also emit large quantities of greenhouse gases, such as methane, and pollute waterways with slurry. These problems, and related concern about animal welfare, is leading many people to limit or eliminate animal products from their diets.

The purpose PRICE's research is to treat the discrete methods of protein production as a single system and thereby maximise the use of waste products and minimise emissions in the system as a whole. Taking the example of intensive animal production, circularity would be increased by using manure from cattle to fertilise land that will grow cattle feed; this reduces the need for fertiliser, and hence energy, and reduces or eliminates pollution from slurry. Even more circularity would be achieved by raising cattle on pasture, which sequesters CO2 from the atmosphere and reduces the import of animal feed. Another example would be to use waste food to rear insects for processing into feed for farmed fish; waste from producing, processing and consuming the fish could be used to rear more insects. With sufficient swapping of waste products among the various methods of producing protein, we can create a "protein circular economy" that consumes far fewer resources and produces far less unused waste than do present methods of protein production.

Achieving a circular protein-economy will require technical innovation to turn currently unused waste into a valuable input to a protein-production system. It may also reduce production of a waste product that currently has no value, or is difficult to reuse using today's technology. Innovation may come from many areas of science and technology, including robotics, artificial intelligence and biotechnology. Part of the Centre's work will be to identify opportunities for increased circularity in protein production created by technical advances.

Technical innovation must be complemented by economic and policy innovation; hence the PRICE Centre will develop economic models that allow accurate valuation of all the changes brought about by technical innovation. For example, an increase in fish farming may lead to a reduction in livestock farming. This may have benefits in terms of reduced GHG emissions, but, depending on the type of farming replaced, it may have adverse effects on landscapes and biodiversity. Accurately pricing the balance of benefits and harms of each change will allow better decision-making.

The final area of innovation is policy. Beneficial technical innovation may be blocked if regulations prevent its use or policy creates incentives against its use. For

example, if regulations ban the use of fish by-products in rearing insects for fish food, no amount of technical or economic innovation will enable this potentially valuable contribution to circularity. A key research aim of the centre will be to create policy, regulations and standards that help to deliver economically valuable technical innovations that increase circularity in protein production. Finally, PRICE will undertake citizen engagement to ensure that the proposed approaches to protein production are acceptable to society generally.

Seaweed Circular Economy Centre (SEA-CEC)

Name of Grant Contact: Professor Michele Stanley

Summary: The oceans encompass approximately 70% of the surface of our planet. The marine environment is rich in biodiversity with unparalleled potential for biotechnological applications, including the sustainable production of food, chemicals and fuels. Combining marine resources with sustainable processes can make significant contributions to achieving UN Sustainable Development Goals, particularly limiting climate change. Producing products using renewable marine resources will benefit the UK in achieving the country's legally binding target of net zero CO2 goals by 2050. In order for the UK to meet this goal, it needs innovations in biomass production, which are sustainable and do not require substantial amounts of productive land. Seaweed growth requires only CO2, sunlight and the nutrients present in natural seawater, where seaweeds act as the natural filters of the ocean. Properly managed seaweed farms produce biomass rapidly, support biodiversity and mitigate CO2 acidification of the ocean. CO2 concentrations in the oceans are 50 times higher than in the atmosphere; favouring fast growth of aquatic biomass. Seaweed cultivation requires no fertilizer, pesticide or herbicide use and places no demands on fresh water supplies.

Large-scale cultivation of seaweeds has been practiced across Asia for decades, amounting to 29.4 million tons in 2018 with an annual growth of 8%. Norway alone is predicting an annual production of 20 million tonnes of seaweed biomass by 2050 and there is an opportunity for the UK to significantly expand on its current small-scale sites. Cultivation of seaweeds, as opposed to harvesting wild seaweed, offers an alternative to crop cultivation on arable land, making marine biomass a serious contender in a circular economy context. Both high value and high volume products can be produced from seaweed, thereby extracting maximum economic value for coastal communities.

The Seaweed Circular Economy Centre or SEA-CEC has the production and the integrated utilisation of seaweed biomass as a renewable feedstock at its core. The SEA-CEC will bring together biologists, ecologists, chemical engineers, social scientists, commercial expertise and companies in order to meet the centre's two principal challenges (1) establishing the feasible of seaweed-based manufacturing facilities, limiting climate change; and (2) uplifting coastal communities through the introduction of this new sustainable industry producing multiple products.

Interdisciplinary Circular Economy Centre for Mineral-based Construction Materials (ICEC-MCM)

Name of Grant Contact: Professor Julia Stegemann

Summary: 177 million tonnes of virgin aggregates, 15 million tonnes of cement and 2.4 billion bricks were used to build houses, civic and commercial buildings, roads and railways, etc., in the UK in 2016. At the same time, 64 million tonnes of waste arose from construction and demolition. This waste was mainly managed by down-cycling with loss of the value imparted to the materials by energy-intensive and polluting manufacturing processes; for example, high value concrete was broken down into low value aggregate. Environmental damage is associated with the whole linear life cycles of mineral-based construction materials, and includes scarring of the landscape and habitat destruction when minerals are extracted from the earth; depletion of mineral and energy resources; and water use and emission of greenhouse gases and other pollutants to air, land and water, during extraction, processing, use and demolition. It is important to take action now, to return materials to the resource loop in a Circular Economy, and reduce the amount of extraction from the earth, as the amount we build increases each year, for example, the UK has planned to spend £600 billion to build infrastructure in the next 10 years.

This UKRI Interdisciplinary Circular Economy Centre therefore aims to do more with less mineral-based construction materials, to reduce costs to industry, reduce waste and pollution, and benefit the natural environment that we depend on. There is potential for mineral-based construction materials to be reused and recycled at higher value, for example, by refurbishing rather than demolishing, or by building using reusable modules that can be taken apart rather than demolished, so all the energy that went into making them isn't wasted. It may also be possible to substitute minerals from natural sources by recycling other types of mineral wastes, such as the 76 million tonnes of waste arising from excavation and quarrying, 14 million tonnes of mineral wastes that come from other industries, or 4 billion tonnes of historical mining wastes. We can also be more frugal in our use of mineral-based construction materials, by designing structures to use less materials, last longer, and be suitable for repurposing rather than demolition, and using novel manufacturing techniques.

Firstly, our research will try to better understand how mineral-based construction materials flow through the economy, over all the stages of their life cycle, including extraction, processing, manufacture, and end-of-life. The Centre will work to support the National Materials Database planned by the Office of National Statistics, which will capture how materials are used and waste arises over time and space in the UK, so that we have the information to improve how materials are used. We will also study how any changes we might make to practices around minerals use would affect the environment and the economy, such as how they affect greenhouse gas emissions, how much they will cost businesses, or how they will affect jobs.

Secondly, we will work on technical improvements that we can make in design of mineral-based products and structures, and in all the life-cycle stages of mineral-based construction materials. Thirdly, we will look at how changes in business

practices could support use of less mineral-based construction materials, such as how they might be able to move more quickly to new technologies, or how they might use digital technologies to keep track of materials. We will explore how the government can support these changes, and how we can provide education so that everyone working in this systems understands what they need to do.

Circular Economy Centre for Foundational Materials

Name of Grant Contact: Dr Vera Trappmann

Summary: Much of human activity is impacted by basic materials ("foundational materials"), such as steel, cement and glass. These are used in sectors as diverse as appliances, homes, commercial and industrial buildings; vehicles and industry. Steel and cement also find application in renewable energy technologies such as onshore and offshore wind power, wave and tidal energy. The production of these materials currently involves digging raw materials out of the ground, processing them, using them and, in some cases, recycling them. This is not environmentally sustainable as there is very extensive use of energy and extremely large emissions of greenhouse gases. With this Research Centre, we seek to fundamentally change how these materials are produced so the production is cleaner, to ensure that these materials are used more efficiently, and that materials and components at their end-of-use are reused so that we need less new raw materials. We understand that this is not just a question of technological change but it can affect jobs, communities and the quality of their living environment.

Change for these foundational materials is complex. Their production is already energy efficient and if we burden these industries with major additional costs, we will drive production out of the UK, resulting in both loss of good jobs and production moving to locations that have lower environmental standards than the UK does. We don't want to repeat what happened in previous rounds of deindustrialisation, when well paying secure jobs were replaced by worse paying, insecure ones. So what to do?

We recognise that any one academic discipline doesn't have the answer and that the challenge we face with foundational materials cuts across social, economic, business, engineering and cultural considerations. We are therefore taking an approach that brings all of these together and focuses on how they interact, to shape the outcomes for foundational materials industries, their workers and users of these materials from major companies to individual people.

We seek to identify what can change with foundational materials, when and how. We will translate this into effective actions. In doing this, we consider:

1. How these materials can be designed and used differently;
2. How digital technologies can help to make reuse possible and easier;
3. How value is destroyed financially by not reusing or repurposing the foundational materials;
4. How other forms of values, such as environmental and social costs and benefits, are neglected by producing foundational materials just for single use;
5. How to prepare companies for the necessary changes in the foundational materials industries and use of these materials;
6. What role the general public can play and how people feel about this;
7. How workers affected by changes in the foundational materials industry can have a voice, be re-skilled, and protected from job loss;
8. What sort of industrial strategy is needed for the future of foundational materials.

Sustainability Circular Economy Centre (SCiEnCe)

Name of Grant Contact: Professor Nick Voulvoulis

Summary: The Sustainability Circular Economy Centre (SCiEnCe) at Imperial College London will be a cross-faculty, cross-disciplinary initiative that will use the College's expertise in science, engineering, business and policy, and extensive links to industry, to accelerate understanding and solutions to enable circularity and servitisation of consumer goods. Consumer Goods sit at the centre of a resource flow that starts with the mining of resources to the management of wastes and end-of-life disposal, and spans across multiple sectors of the UK and Global economy. The Consumer Goods and Services sector consists of companies that manufacture and sell Durable Goods (such as automobiles, furniture, radios, TV, communication hardware, office machinery, computers and medical equipment) as well as Fast-Moving Consumer Goods, including food and beverages, household care and personal care products.

The Centre will engage directly with businesses, policy-makers, the third sector, consumers and other relevant stakeholders, and support the sector's transition towards sustainability, increased productivity and improved customer satisfaction. It will investigate opportunities for the servitisation of consumer goods and the type of systemic changes required for sustainability to emerge. In a circular economy, 'Servitisation' is the practice of reducing material needs by changing a product's ownership or its presence altogether in favour of providing a service or solution. It offers a unique opportunity for the sector to address the needs of the rapidly expanding global middle class impelled by the emerging world view that sustainable economic growth needs to be fully aligned with sound environmental stewardship and social development.

The Centre will deliver the evidence base and technical know-how to support the sector with product rethink for selling outcomes and services; business models for a sharing economy; and innovations that go beyond improved material productivity, towards opportunities that amplify positive impact through symbiotic relationships, closed-loops and efficiencies. These will require a fusion of physical, digital, and biological technologies, supported by research activities that aim to shift the deeper structures of consumption towards sustainable commons and user access and to decouple economic activity from natural resources through dematerialised services provision and symbiotic relationships.

Imperial College is in a unique position to deliver such interdisciplinary research through the collaboration of academic teams from several disciplines across the College. A team of 12 investigators from five academic departments has come together to address the complexity of the circular economy concept and to contribute techniques, tools, perspectives, concepts, and theories that will lead to a more complete, holistic and integrated understanding of the challenges and opportunities. SCiEnCe will be supported by a range of partners and collaborators whose involvement will be formalised at the full proposal stage. An external advisory group will also offer advice and provide appropriate and constructive challenges to the assumptions and operating routines of the Centre, as well as opportunities for knowledge transfer and application for the outputs of the research. It will also help

with fundraising and identifying opportunities for collaborative research and development. Our overall vision for SCiEnCe is one that is inclusive and empowering and that requires engaging with businesses and stakeholders, and opening an ongoing dialogue with customers, citizens and users as part of designing a sustainable future that will benefit everyone.

Technology metals for a Circular Economy (TechMet)

Name of Grant Contact: Professor Frances Wall

Summary: The Circular Economy (CE) is a revolutionary alternative to a traditional linear, make-use-dispose economy. It is based on the central principle of maintaining continuous flows of resources at their highest value for the longest period and then recovering, cascading and regenerating products and materials at the end of each life cycle. Metals are ideal flows for the circular economy. With careful stewardship and good technology, the metalliferous raw materials mined from the Earth can be kept and reused indefinitely.

Technology metals (techmetals) are an essential, distinct, subset of specialist metals. Some such as lithium have become 'household names', others such as neodymium are less well-known. Although they are used in much smaller quantities than major industrial metals such as iron and aluminium, each techmetal has its own specific and special properties that give it essential functions in devices ranging from smart phones, batteries, wind turbines and solar cells to electric vehicles.

Techmetals are thus an essential enabler of a future circular and low carbon economy. Demand for many of them is increasing rapidly. For example, to meet the UK's 2050 ambition for offshore wind turbines will require 10 years' worth of global neodymium production. Just to replace all UK-based vehicles today with electric vehicles would require 200% of total annual world cobalt production, and 75% of the world's lithium production. The UK is 100% reliant on imports of techmetals including especially imports from China and also the Democratic Republic of the Congo (DRC), which represent geo-political risks. A number of techmetals are therefore also referred to as Critical Raw Materials (i.e., they have high economic importance and high risk of supply disruption). Only 12 of the 43 raw materials considered critical by the EU have an end-of-life recycling input rate of 10% or higher.

Our UKRI TechMet CE Centre brings together for the first time world-leading researchers to maximise opportunities around the provision of techmetals from primary and secondary sources, and lead materials stewardship, creating a National Techmetals Resource Security Roadmap and accelerating a future Techmetals Circular Economy. This will help UK manufacturing take advantage of opportunities in decarbonisation and digital economy, with secure and environmentally-acceptable supplies of techmetals.

There are many challenges to a future Techmetal circular economy. With growing demand, new mining is needed and we must keep the environmental footprint of this primary production as low as possible. Materials stewardship of techmetals is difficult because the fate of most is difficult to track. Many are embedded in products not designed for re-use, disassembly remanufacture, or recycling. Collection is inefficient, policy and legislative initiatives such as extended producer responsibility (EPR) focus on the large volume metals rather than the small quantity techmetals. Currently there is a lack of end-to-end visibility and connection between different parts of techmetal value chains.

The TechMetal consortium brings together UK research teams already working on how to improve and assure the mining of raw materials, how to manufacture goods to be re-used and recycled, and how to recycle complex goods such as batteries.

One of the first things we need to do is track the current flows of techmetals through the UK economy, which although fundamental, is poorly known. The Centre will conduct new interdisciplinary research on key interventions to improve each stage in the cycle and join the different stages of the value chain together - raw materials can be newly mined and recycled, manufacturing technology can be linked directly to re-use and recycling. Business and social experts will research how best the UK can put all these stages together to make a new Techmetals circular economy and produce a roadmap for its implementation.

Centre for Circular Chemical Economy

Name of Grant Contact: Professor Jin Xuan

Summary: The UK chemical sector has an annual turnover of over £40 billion with 99,000 direct jobs in 2016. Olefins, particularly ethylene and propylene, are an essential feedstock for the chemical industry, accounting for >70% of all organic chemical production. The Centre will transform the UK's chemical industry into a fossil-independent, climate-positive and environmentally-friendly circular chemical economy. The aim is to transform currently linear Olefins supply-demand network to a circular system (e.g., using waste streams as alternative feedstocks). The whole system approach will include key sectors of production, transportation/distribution, refinery/downstream and waste recycling, to reduce fossil reliance and improve productivity and sustainability of whole process industry.

The Centre will generate a cross-disciplinary platform combining synergistic innovations in science/engineering with social scientists to comprehend the whole system industrial symbiosis and market/policy/incentive design. The research is organised around three interconnected themes: (1) Key technologies to enable olefin production from alternative/recycling wastes streams and design more reusable chemicals via advanced catalytic processes; (2) Process integration, whole system analysis and value chain evaluation, and (3) Policy, society and finance. Through detailed process modelling, economic analysis and environmental assessment of technology solutions along the supply chain, accelerated understanding, opportunities and optimum solutions to achieve circularity of Olefin-derived resources flow will be attained. These activities are embedded with stakeholders involving all affected groups, particularly local SMEs and downstream users, and will provide evidence and data for policymakers.

The centre will engage with users through social studies and organised events, and exploit consumer/business behavioural change related to chemical systems enabling a sustainable community and society with innovative technologies.