Manufacturing a Circular Economy

A position statement on circular economy research in the UK

Summary

This position statement sets out a synthesis of views on publicly-funded research being done in the UK relevant to the circular economy. It summarises the opportunity for the UK and identifies the research communities contributing to this area as well as key stakeholders across the research and innovation landscape.

Aimed at academics, industrialists, policy makers and funders it identifies a number of research challenges highlighted by stakeholders and recommends some approaches to take these forward.

Views were gathered from a broad range of academics and experts in the area across multiple disciplines as well as input from BBSRC, ESRC, NERC, Innovate UK, KTN, Ellen MacArthur Foundation and the Green Alliance.

This document will inform EPSRC strategy going forward as EPSRC develops its delivery plan priorities and is placed to contribute to a wider discussion across the research councils and Innovate UK.

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1 Introduction

A circular economy is an alternative to a traditional linear economy (make, use, dispose) in which we keep resources in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life (Figure 1).¹

The market for clean and sustainable technologies has grown in recent years building on decades of public and private investment in research and development. The ideas and concepts that make up the circular economy have always been a part of this but it is only relatively recently, with growing interest from industry and a number of third sector organisations such as the Ellen MacArthur Foundation that interest in the circular economy has grown significantly.

This interest, in part, has been sparked by a number of economic factors such as rising input costs, resource volatility and an increased focus on reducing energy usage in the extraction of raw materials.

The UK’s prosperity and national security depend heavily on global stability and access to reliable sources of resources. As such, processes, technologies and whole systems that enable the circulation of valuable resources, such as recycling, re-use and remanufacture will become ever more important.

Interest is also growing internationally. China implemented a circular economy promotion law in 2008² and the European Commission recently launched a circular economy package.³

Circular economy is part of the ongoing narrative on industrial sustainability covering resource efficiency, reduced energy and water use, food security and increasing the efficiency of land use. The UK has research expertise in a broad range of areas relevant to the circular economy and, as this document identifies, nearly £200 million from the research councils and Innovate UK is currently invested.

¹ Definition from Waste and Resources Action Programme (WRAP)
² Article: http://europesworld.org/2014/06/15/chinas-policies-and-instruments-for-developing-the-circular-economy/#.VmVV_3bhCUk
Figure 1 – Illustrations of the traditional linear economy model (top) and a circular economy model separated into biological and technical cycles. *Source: Ellen MacArthur Foundation*
2 The Opportunity for the UK

Economic Growth through Sustainable Innovation

The transition towards a circular economy has the potential to drive growth and productivity in the UK as evidenced by a number of recent reports. Accenture estimate that worldwide the circular economy will be worth $4.5 trillion in the next 15 years, referring to it as the biggest revolution in the global economy in 250 years⁴. For the UK, the Next Manufacturing Revolution (NMR) report conservatively predicts a £10 billion profit increase, 4.5% GHG reduction and 300,000 jobs created from only partial implementation of circular economy approaches⁵.

As well as generating new business opportunities circular economy approaches save industry money through reduced cost of resources and energy, generated revenue from waste streams and retention of value in existing infrastructure and assets through new business models such as leasing. For example, it is estimated that remanufacture and refurbishment could save EU manufacturers $380 billion p.a. in material costs in a transition scenario and up to $630 billion p.a. in an advanced scenario⁶.

Resilience and Competitiveness

The security of supply of materials and price volatility are growing concerns among businesses with 80% of manufacturing executives seeing raw materials shortage as a key business risk.⁷ In addition 29% of profit warnings by FTSE350 companies in 2011 were for rising resource prices.

The Government Office for Science Foresight report⁵ highlighted concern for the security of supply of materials with the circular economy approach being viewed as necessary from 2025 to prevent serious material input disruption.

The British Geological Survey’s risk list highlights a number of elements critical to maintain our economy and lifestyle with rare-earth elements, tungsten, antimony and bismuth topping the list.⁸ There is also an overwhelming reliance on fossil fuels to make both chemicals and fuels, which will eventually need to be addressed in terms of security of supply, rising energy costs, water requirements of production, rising costs of remote extraction and in reducing GHG emissions.

As well as increasing security, circular economy approaches allow increased competitiveness. Companies who maintain the productive value of their assets can add 20 – 30 times more value to their business than recycling (e.g. Michelin). Furthermore, the use of intelligent components, e.g., implanted sensors, enables organisations to use big data methods to better understand their material flows through becoming less reliant on virgin production.

It is also estimated that a reduction of total material requirement by 1% is accompanied by a rise of GDP between €12-23 billion and a rise of employment between 0.04% and 0.08%, which for the EU countries equates to between 100,000 and 200,000 people.⁹

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⁵ Lavery, G., Evans, S., 2013. Next manufacturing Revolution - report on the opportunity for profit, jobs and environmental benefits from non-human resource productivity improvements
⁶ Ellen MacArthur (2013), Towards the Circular Economy
⁸ http://www.bgs.ac.uk/mineralsuk/statistics/risklist.html
⁹ Meyer, B. (2011), Macroeconomic modelling of sustainable development and the links between the economy and the environment,
Waste and the Environment

Waste production is a critical issue that, despite a number of measures, still has many problems that need to be solved as highlighted by the following trends:

- Projected 40% increase in consumer waste by 2020
- Landfill full/approaching capacity
- 93% of production materials never used in final product
- 80% of products discarded after single use
- 80% of materials used in manufacturing products end up as waste
- 2/3 of mixed plastic household waste is landfilled

As well as reducing impact on the environment there is an opportunity for the UK to build value chains based on waste. The waste sector in the UK was valued at over £12bn in 2011, with an annual growth rate of between 3% and 4%. According to WRAP only around 22% of the resource flows in the UK are fed back in to the economic cycle, and more than £5bn worth of recovered materials are sent abroad for reprocessing.

Examples of industries where there are sizeable opportunities to use waste include the construction industry, where construction and demolition waste recycling could by itself replace 25% of current consumption of construction minerals and the consumer goods industry where linear production, worth approximately $3.2 trillion, has remained largely unchanged.

Creation of New Industries

The transition towards a circular economy offers exciting opportunities for innovation, new business sectors and increased competitive advantage within UK manufacturing. Remanufacturing alone in the UK is worth £2.4 billion with a potential to increase to £5.6 billion alongside the creation of thousands of skilled jobs.

Other specific industrial opportunities include:

- Green technologies and the transition towards more sustainable feedstocks
- Transport fuels and high-values products from green chemistry and bioprocesses, CO$_2$ capture and using biomass to clean water
- New recycling businesses, e.g., composites

There are also opportunities to offer consultancy and management tools as evidenced by leading UK consultancies in the sustainable built environment (ARUP, WSP). Other opportunities include the multiple organisations that are moving towards servitisation and delivery of product-service systems.

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10 Communication from the EU Commission on Resource Efficiency Opportunities in the Building Sector (2014)
3 Current Investment and the UK Research Portfolio

Nearly £200 million of research council and Innovate UK funding is invested in programmes relevant to the circular economy. Research council investment is spread across EPSRC, BBSRC, NERC and ESRC with a number of cross-council and council/Innovate UK joint investments. (Figure 2 and Tables 2-6).

Figure 2 – Key Research Council investments by broad themes. A – Materials manufacturing, B – Bioeconomy, C – Crosscutting projects, D – Recycling technologies, E – Value from waste. For the purpose of this document projects have been assigned to each theme and are described in the tables below.

The majority of these research investments focus on a particular technology, aspect or part of the circular economy while some aim to tackle more cross-cutting challenges in the area. The spread of investments draws on the UK’s capability and expertise in the following disciplines: biochemical feedstocks, catalysis, circular business models, design, gas fermentation, industrial biotechnology, materials design, materials discovery, process systems, recycling of composite materials, recycling of metals, remanufacturing, sustainable chemistry, synthetic biology, waste management research and waste technology.
A – Materials manufacturing

| Investment |
|-----------------|-----------------|-----------------|
| Centre for Industrial Energy, Materials and Products – Leeds University |
| Materials substitution for Safety, Security and Sustainability - EPSRC Call |
| G8 Material Efficiency Programme |
| Materials Demand Reduction – University of Cambridge |
| Security and Supply of Mineral Resources |

| Description |
|-----------------|-----------------|-----------------|
| EPSRC and ESRC centre for End Use Energy Demand reduction, £2.9M |
| £17.9M over 7 projects, manufacturing challenges associated with replacements for materials |
| £2.1M over 6 grants |
| EPSRC and ESRC investment in reducing materials and energy demand, £1.7M |
| Interdisciplinary programme of research focusing on the science needed to sustain the security of supply of strategic minerals. NERC led with funding from EPSRC, £8.7M |

| Link to the circular economy |
|-----------------|-----------------|-----------------|
| Reducing Industrial Energy & Material Use |
| Sustainable materials and new materials for sustainable products |
| Materials sustainability |
| Reducing Industrial Energy & Material Use |
| Materials mining, environmental impact. |

Table 2 - A – Materials manufacturing, total of the above investments is £34M.

B – Bioeconomy

| Investment |
|-----------------|-----------------|-----------------|
| Scaling up synthetic biology - Imperial College London |
| Centre for Innovative Manufacturing in Food, University of Nottingham |
| Sustainable Chemical Feedstocks – EPSRC call with BBSRC funding |
| Industrial Biotechnology Catalyst – BBSRC, Innovate UK and EPSRC |
| Centre for Doctoral Training in Bioprocess Engineering Leadership – University College London |
| Networks in Industrial Biotechnology and Bioenergy (BBSRC NIBB) |

| Description |
|-----------------|-----------------|-----------------|
| EPSRC Frontier Engineering Grant, £5.1M |
| EPSRC investment in sustainable food processing, £4.5M |
| £13.7M over 6 projects, cost-effective production of chemicals and materials from sustainable and renewable feedstocks |
| Collaborative R&D in the development and scale-up of new processes and products, £59M |
| EPSRC Centre for Doctoral Training, £4.4M |
| 13 unique collaborative Networks in Industrial Biotechnology and Bioenergy with some co-funding from EPSRC, £18M |

| Link to the circular economy |
|-----------------|-----------------|-----------------|
| Enabling production from biochemical feedstock |
| Sustainable food production |
| Production of chemicals and materials from sustainable chemical feedstocks |
| Significant aspects relevant to development of the bioeconomy |
| Bioprocessing in the bioeconomy |
| A range of topics relevant to the bioeconomy |

Table 3 - B – Bioeconomy, total of the above investments is £105M.
### C – Crosscutting projects

<table>
<thead>
<tr>
<th>Investment</th>
<th>Description</th>
<th>Link to the circular economy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre for Innovative Manufacturing in Industrial Sustainability – University of Cambridge</td>
<td>EPSRC investment cutting across all of industrial sustainability. <strong>£5.2M</strong></td>
<td>Covers all aspects of CE as well as reducing use of energy, water and land.</td>
</tr>
<tr>
<td>Centre for Doctoral Training in Sustainable Materials and Manufacturing – Warwick University</td>
<td>EPSRC Centre for Doctoral Training, <strong>£3.6M</strong></td>
<td>Natural or recovered materials as feed-stocks, reducing process inputs and outputs without compromising performance or economic viability, extracting high value materials from waste.</td>
</tr>
<tr>
<td>CLEVER - Closed Loop Emotionally Valuable E-waste Recovery – Bath University</td>
<td>EPSRC Resource Efficiency sandpit project looking at new product-service systems, <strong>£1.3M</strong></td>
<td>Re-use/refurbishment/recycling</td>
</tr>
<tr>
<td>EXHUME, Efficient X-sector use of HeterogeneouS MatErials in Manufacturing – University of Birmingham</td>
<td>Novel recycling and re-manufacture processes, to provide a step-change in composites resource efficiency. Resource Efficiency sandpit project <strong>£1.4M</strong></td>
<td>Re-use, re-processing and remanufacture as well as energy efficiency</td>
</tr>
<tr>
<td>RECODE, Re-distributed manufacture, big data, and consumer goods – Cranfield University</td>
<td>EPSRC funded network in redistributed manufacturing looking at big data in the Circular Economy. <strong>£500k</strong></td>
<td>Overarching</td>
</tr>
<tr>
<td>CORE, Creative Outreach for Resource Efficiency – University of Loughborough</td>
<td>EPSRC sandpit project looking at public engagement with resource efficiency. <strong>£300k</strong></td>
<td>Overarching</td>
</tr>
<tr>
<td>CUSP, Centre for Understanding Sustainable Prosperity – University of Surrey</td>
<td>CUSP aims to explore the concept of sustainable prosperity and understand people’s aspirations for living sustainably, <strong>£6M</strong></td>
<td>Socio-economic understanding</td>
</tr>
</tbody>
</table>

| **Table 4** – C – Crosscutting projects, total of the above investments is **£18M** |

### D – Recycling technologies

<table>
<thead>
<tr>
<th>Investment</th>
<th>Description</th>
<th>Link to the circular economy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latest2 – University of Manchester</td>
<td>EPSRC programme grant looking at light alloys towards environmentally sustainable transport, <strong>£5.8M</strong></td>
<td>Materials manufacture/ process and recycling</td>
</tr>
<tr>
<td>DARE – University of Sheffield</td>
<td>EPSRC grant designing Alloys for Resource Efficiency, <strong>£3.2M</strong></td>
<td>Manufacture, recycling and remanufacture</td>
</tr>
<tr>
<td>LiME, EPSRC Liquid Metal Engineering Future Manufacturing Research Hub – Brunel University</td>
<td><strong>£10M</strong> over 7 years manufacturing challenges associated with replacements for materials.</td>
<td>Materials manufacture/ process and recycling</td>
</tr>
</tbody>
</table>

| **Table 5** – D – Recycling technologies, total of the above investments is **£19M** |
E – Value from waste

<table>
<thead>
<tr>
<th>Investment</th>
<th>Description</th>
<th>Link to the circular economy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cleaning Land for Wealth – Warwick University</strong></td>
<td>EPSRC sandpit project looking to reclaim value from</td>
<td>Recovering value from waste</td>
</tr>
<tr>
<td></td>
<td>contaminated land, <strong>£3.1M</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Resource Recovery from Waste</strong></td>
<td>NERC-funded programme <strong>£7.2M</strong></td>
<td>Recovering resources from waste</td>
</tr>
<tr>
<td><strong>Innovate UK Collaborative R&amp;D grants – Value from Waste</strong></td>
<td>CR&amp;D projects, co-funding from EPSRC, <strong>£4.2M</strong></td>
<td>Recovering value from waste</td>
</tr>
</tbody>
</table>

**Table 6 – E – Value from waste, total of the above investments is **£15M**.**

Better integration of these disciplines is required if the benefits from a circular economy are to be fully realised and many of these research activities would benefit from a common approach.

Collaborative working across disciplines is key to achieving this and there is already precedent where this has worked well, one example being the EPSRC resource efficiency sandpit where engineers, social scientists, life cycle analysts, chemists and product designers were brought together.

Research expertise in these various disciplines is spread across a number of UK academic institutions. Some of these are identified in **Table 7**.

This spread of expertise puts the UK in a unique position to exploit opportunities related to the circular economy and build a national community in the area. However, in order to fully realise these opportunities the community needs to be better networked. This could be realised, for example, through networking activities or via a research hub and spoke type model.
<table>
<thead>
<tr>
<th>Key Centre</th>
<th>Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bradford University</td>
<td>Host of the £6M re:centre - a hub for research, knowledge transfer, education and business activities around the circular economy</td>
</tr>
<tr>
<td>Brunel University</td>
<td>Host of EPSRC Centre for Innovative Manufacturing in Liquid Metal Engineering and Centre for Sustainable Energy Use in Food Chains</td>
</tr>
<tr>
<td>Cranfield University</td>
<td>Cross-cutting across multiple departments including design, engineering, environmental science and management.</td>
</tr>
<tr>
<td>Imperial College</td>
<td>Sustainable Chemistry, Environmental business models</td>
</tr>
<tr>
<td>Loughborough University</td>
<td>Sustainable construction, sustainable manufacturing, sustainable engineering</td>
</tr>
<tr>
<td>Strathclyde University</td>
<td>Host of Scottish Institute of Remanufacture</td>
</tr>
<tr>
<td>University College London</td>
<td>Sustainable chemical feedstocks, sustainable materials, Industrial biotechnology</td>
</tr>
<tr>
<td>University of Birmingham</td>
<td>Low Carbon Technologies, recycling</td>
</tr>
<tr>
<td>University of Bristol</td>
<td>Composites manufacture</td>
</tr>
<tr>
<td>University of Cambridge</td>
<td>Host of the cross-cutting EPSRC Centre for Innovative Manufacturing in Industrial Sustainability, Materials demand reduction</td>
</tr>
<tr>
<td>University of Durham</td>
<td>Sustainable Chemical Processes</td>
</tr>
<tr>
<td>University of Exeter</td>
<td>Low-carbon manufacturing and sustainable technologies</td>
</tr>
<tr>
<td>University of Leeds</td>
<td>Host of End Use Energy Demand Centre in Reducing Industrial Energy &amp; Material Use</td>
</tr>
<tr>
<td>University of Liverpool</td>
<td>Sustainable chemical feedstocks</td>
</tr>
<tr>
<td>University of Manchester</td>
<td>Industrial Biotechnology, Advanced Materials</td>
</tr>
<tr>
<td>University of Northampton</td>
<td>Sustainable Wastes Management</td>
</tr>
<tr>
<td>University of Nottingham</td>
<td>Sustainable Chemistry, Industrial Biotechnology, Manufacturing</td>
</tr>
<tr>
<td>University of Sheffield</td>
<td>Metals manufacture and recycling</td>
</tr>
<tr>
<td>University of Surrey</td>
<td>Environmental Technology and Management, Sustainable Systems</td>
</tr>
<tr>
<td>University of Warwick</td>
<td>Host of the Centre for Doctoral Training in Sustainable Materials and Manufacturing</td>
</tr>
<tr>
<td>University of York</td>
<td>Sustainable Chemical Technologies</td>
</tr>
</tbody>
</table>

*Table 7 – Key centres conducting research relevant to the circular economy.*


4 Innovation

There are a growing number of companies, especially large companies that see environmental sustainability as a key priority. Since its inception the EPSRC Centre for Innovative Manufacturing in Industrial Sustainability has had interactions with over 100 companies providing tools for business to enable them to benefit from the opportunities and competitive advantage that a sustainable approach can bring. One key example of leadership comes from Unilever, who have a goal to halve their impact on the environment by 2020 and achieved zero waste to landfill in 2014.

Other examples of industrial leadership in this sector include:

- Philips refurbished systems factory
- Caterpillar remanufactured and rebuild business
- Rolls-Royce Power by the Hour
- Jaguar Land Rover reclaimed and recycled Aluminium processing

There are also a growing number of supply chain organisations, re-processing firms and consultancies enabling the sector to grow including Axion Polymers, Recycling Technologies, Ultromex, Tetronics, Granta Design and Oakdene Hollins.

In the public and third sector there are several organisations providing strategic direction in this area. These are:

- The Ellen MacArthur Foundation
- Forum for the Future
- Green Alliance
- WRAP
- Zero Waste Scotland
- High Speed Sustainable Manufacturing Institute (HSSMI)
- RSA (The Great Recovery)

Innovate UK is looking to embed sustainable approaches across sectors and has invested as part of its Resource Efficiency programme including the following competitions:

- Recovering valuable materials from waste call (with EPSRC).
- Supply Chain Innovation for Resource Efficiency
- Design Challenges for Resource Efficiency
- Design Challenges for a Circular Economy
- New Designs for a Circular Economy
- Business models pilot competition with a view to fund 2-3 bigger demonstrator projects

The High Value Manufacturing Catapult has a focus on sustainability and efficiency providing access to equipment and knowledge to help partner companies improve the efficiency and sustainability of their processes.

The UK has the correct mix of skills, workforce and industry to benefit from a transition towards a circular economy. In order to realise this more collaboration between businesses, along the supply chain and with government and academia will be required.

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12 EPSRC Centre for Innovative Manufacturing in Industrial Sustainability Annual Review 2014-2015
5 Research Challenges

There are many research challenges associated with the successful development and implementation of a circular economy. Below is a list of research challenges identified by a survey of key stakeholders. They have been classified by theme, while recognising their cross-cutting nature.

It should be noted that work towards many of these challenges is already under way and that the challenges themselves overlap. As part of ongoing strategy development in the circular economy these challenges should be expanded upon and prioritised.

Understanding the Circular Economy

- Integration of the circular economy approach with other approaches such as industrial sustainability, industrial symbiosis, the “Five Capitals” schema and resource efficiency
- Systemic methodology – nexus approach, methodologies to account for interconnections across the various themes and issues relevant to circular economy
- Understanding the current landscape in terms of linearity and circularity/ metrics of “circularity”
- Characterisation of resource challenges
- The potential impact of a circular economy
- How the two sides of the circular economy butterfly diagram (Figure 1) interact

Implementing a Circular Economy

Design

- Better design of products for sustainability/circularity; new design approaches, i.e., design for re-use, repair, maintenance and remanufacture. E.g., products manufactured to allow easier separation of materials, reducing complexity.
- Design of products to influence consumer behaviour. Opportunities with the retailer, household.
- Getting consumers involved in design, e.g., why do consumers throw away so much food?
- Design of supply chains
- Service design

Society, Regulation and Business Models

- Research into regulation that could create the right customer and business behaviours informed by a clear vision of what is technically possible.
- How to develop the required new products, services and innovative business models
- Alternative models, e.g., community, collaborative consumption.
- How to undertake the complex collaborations required to develop the new products
- Institutional psychology and sociology – there is an “activation energy” required to get businesses to change, how does this affect adoption of the circular economy?
- Understanding the supply chain
- Development of standards
- When and where can technologies be deployed for sustainability? There are lots of technologies but it is hard to identify the wider impacts.
- Incentives for manufacturers and retailers, especially supply chain owners.
- Challenges relating to societal issues and behaviour change
Modelling and Understanding Whole Systems

- Traceability of resource streams
- Energy and material flows modeling
- Identification of system connections and feedbacks
- How do cascades operate?
- Potential for amplifying mistakes – e.g. BSE crisis when herbivores were fed to herbivores, and the consequences of that
- Interdependencies – market failures, supply failures
- Issues in the segregation of waste streams and the value of doing this
- Process systems modelling to identify where improvements are needed.
- The interaction between the circular economy and Industrie 4.0
- The use of life cycle analysis for circular economy decision making
- Macro economy modelling for the circular economy
- Use of data on materials contained within products
- Data on distribution of products within the economic system
- Use of open data

Remanufacturing

- Research into remanufacturing, e.g., inner loops, disassembly, flexible remanufacture.
- How reverse logistics can be harnessed to increase productivity
- Active disassembly for more efficient component recovery (e.g. In2Tec dissolvable PCBs)
- Tracking/tracing technologies for keeping track of assets in the system, e.g. product passports
- Access to data to enable repair and re-use

Recycling

- Assessing the benefits of reclaiming materials
- Evaluation of the performance of products made from reprocessed materials.
- Use of waste materials as raw materials
- Redistributed manufacturing and waste, e.g., reduced movement of waste
- Feedstock recycling (mixed plastic waste to chemicals / oils), for example recycling technologies and biodegradability in plastics
- Potential improved sorting technologies (e.g. spectroscopic tags/dyes/markers embedded in packaging)
- Substitution of toxic for non-toxic additives to aid recycling

Materials

- Understanding of recycled material properties and the effect of process conditions on such materials
- Materials design for recyclability
- Introduction of new (advanced) materials into current processes
- Choosing materials based on first principles of why they are needed
• Recycling of current/next-generation materials, e.g., resin in composites
• End of life solutions for novel materials, e.g., sensors in Internet of Things, biopolymers, additively manufactured components, advanced magnetic materials (e.g., NdFeB), composites and Graphene.
• Developing manufacturing processes for substitution of critical materials combined with life cycle analyses of ore extraction to end product.
• Up scaling of sustainable technologies and processes
• Health and safety in recovery of new materials
• Using novel materials to capture waste/ GHG, e.g., building materials for carbon capture
• Regenerating starting materials, e.g., returning polymers to monomer
• Packaging / coatings solutions to extend the life of degradable and durable products

Bio-cycle

• Producing sustainable feedstocks for materials in use
• Cost effective removal of oxygen from biomass
• Cleaning up biomass, e.g., dealing with volatile compounds
• Using supercritical CO2 as a chemical feedstock
• Understanding processes in biomass through enhanced instrumentation, throughput and data processing.
• Novel ways of treating organic waste, e.g., Elemental Digest’s work on abattoir waste.
• Symbiosis recovery of value from different streams, e.g., waste and feedstocks, CO2, energy and water e.g., nitrates from water.
• Scaling up biomass fuels for boats and planes
• Novel reactor design for upscaling process technologies
• Waste to fuel technologies, e.g. pyrolysis, enzymatic conversion
• Scaling up gas fermentation

Challenges and Opportunities Identified by Industry

Industries face a large and diverse set of challenges when moving towards more circular approaches. These challenges can be sector and business specific. Through surveying key stakeholders a snapshot of these challenges and opportunities were identified, listed below:

• Knowing where the waste/by product is being produced and in what quantities
• Obtaining data, e.g., recycled carbon fibre and renewable polymers
• Creating or changing standards for products with recycled content
• Understanding how to maintain a consistent supply of waste
• The need for new waste management licenses to be obtained and understanding new health and safety requirements
• Justifying investment for potentially low-profit margin products
• Product/market development for “circular” products
• Small volume, high value waste valorisation
• “Distributed/localised” waste valorisation avoiding transport costs and regulatory issues
• Specific technology problems – for example, making clothing with fewer finishing chemicals so that they can be re-used, robot technologies to dis-assemble vehicles at volume
• Barriers to implementation (as identified in the TSB (now Innovate UK) 2014/15 delivery plan\textsuperscript{13}:
  o Weak information flow along supply chains
  o Lack of understanding and exploitation of life-cycle thinking
  o Lack of visibility of projected resource crunches; especially for smaller players
  o Lack of systems and established business models to get ‘stuff’ (products, components and materials) back for manufacturers and retailers
  o Poor understanding of the importance of system-level thinking and the interrelation of different resource types

\textbf{Cross-Disciplinary and Collaborative Working – Accelerating Impact}

In order to address the above challenges, partnership with industry and other stakeholders such as government organisations is essential (see section \textbf{6 Key Stakeholders}). Co-creation of projects and programmes with these stakeholders will inform research and facilitate its translation.

Many of the challenges transcend disciplines requiring cross-disciplinary approaches in order to be addressed so experts from different disciplines such as process modelling, engineering, economics, materials science, social science and environmental science will need to work together. In order to facilitate this, a challenge-led approach may be required.

Technologies that aim to move the economy towards more sustainable circular approaches will have to operate in complex manufacturing systems, with many interactions and interdependencies. As well as co-creation approaches more work will need to be done to understand the broader impact these approaches are likely to have. The energy efficiency rebound effect has been well documented\textsuperscript{14} and attempts should be made to understand the potential consequences of interventions made in the transition towards a circular economy.

An example of this type of approach is that used by the Sustainable Materials group at Warwick who have been looking at the technical, social and economic factors of using sustainable nanoparticles in fuels. This type of life-cycle analysis (LCA) approach alongside cost/benefit analyses can focus research efforts, allowing more promising avenues to be explored and reducing the time taken.

Research into more effective areas of intervention can also inform what research needs to be done.

Research proposals in the area should consider stakeholder mapping and developing communication plans as part of an enhanced pathway to impact.

Learning should be drawn from reviews of previous initiatives such as the EPSRC Review of the SUE and ARCC Programmes\textsuperscript{15} and the Review of Networks in Sustainable Use of Materials\textsuperscript{16}.

\textsuperscript{13} TSB Delivery Plan 2014/15 – page 60
\textsuperscript{14} Gillingham, Rapson and Wagner, 2015 – The Rebound Effect and Energy Efficiency Policy
\textsuperscript{15} https://www.epsrc.ac.uk/newsevents/pubs/sueurccreview/
\textsuperscript{16} EPSRC (2006): Available on request.
6 Key Stakeholders

Government

Government support has been instrumental in driving growth in parts of the circular economy. The triple win report on remanufacturing\textsuperscript{17} reported government support leading to a 300\% growth in the recycling industry since 2005. By comparison, without government support, the remanufacturing sector has only grown by 15–20\% despite the significant opportunity for economic growth, job creation and CO\textsubscript{2} savings. Remanufacturing is currently at below 2\% for durable products in the UK.

In order to take advantage of the benefits of a circular economy industry needs practical support from the government. Such government policy and regulation should be informed by research into understanding the circular economy providing the evidence needed for legislation.

Examples of specific government actions already identified by researchers include:

- Funding for training/education at tertiary level to raise standards of expertise within the industry.
- Establishing mechanisms to facilitate the complex collaborations required. E.g., centres of expertise that can enable effective collaboration between stakeholders (industry, academia & policy makers) to develop required tools, techniques, business models.
- Pro-product recovery policy e.g. tax breaks, legislation to support uniformity of standards in the reuse sector thus raise customer confidence and Government offices setting an example by purchasing reuse rather than new equipment.
- Modified legislation to recover waste focusing on value recovery.
- Concerted efforts to develop the supply chain.
- Economic drivers to aid the transition to sustainable feedstocks. E.g., charging a premium for bio-sourced chemicals.
- Extending 2\textsuperscript{nd} generation biofuel subsidies to other sustainable sources.
- Changing the definition of CO\textsubscript{2} footprints to include the embedded energy of imported commodities.
- Investing in efforts to track materials, e.g., knowing what goes into products.
- Consideration of existing subsidies (ROCs) favouring waste to fuel technologies / business models over waste to platform chemical approaches.

Regulators and Third Sector Bodies

As mentioned in section 4 Innovation a number of third sector organisations are involved in furthering progress towards a circular economy.

The Ellen MacArthur Foundation has built an internationally respected network and are driving academic research in the circular economy, conducting literature reviews and developing hotlists of research topics relevant to industry. They also have sector foci including food, carpet, remanufacturing and built environment, and are looking at cross-collaborative projects.

Important work has also been done by WRAP, for example working with the Concrete Centre on Resource Efficiency Action Plans and the Green Alliance is currently conducting a study co-funded by EPSRC and Innovate UK into novel materials and the circular economy.

The British Standards Institute is also involved, aiming to implement principles and frameworks into companies with DEFRA, RSA, Tata and various Trade associations. The group are convening standards due to emerge in late 2017.

The RSA runs a project called The Great Recovery\(^{18}\) which looks at the challenges of waste and the opportunities of a circular economy through the lens of design.

In December 2015 the European Commission launched a Circular Economy Package looking to facilitate the move towards a more circular economy. This includes revised legislative proposals on waste, as well as a comprehensive action plan.\(^{19}\)

**Funding Bodies**

As mentioned in section 4 Innovation, Innovate UK is looking to embed sustainable approaches such as remanufacturing across sectors. They have also invested in the circular economy as part of their resource efficiency programme and have significant programmes in agrifood, energy storage and the waste bioeconomy.

In the KTN (Knowledge Transfer Network) circular economy is seen as a subset of sustainability with resource efficiency as a cross-cutting business priority and the KTN has been active in building business-led collaborations to develop and implement circular economy solutions.

Current research council investment has been covered in depth in section 3 Current Investment and the UK Research Portfolio.

Continued investment will be needed and the research challenges identified are especially relevant to the remits of EPSRC, BBSRC, ESRC and NERC with links to AHRC.

**Universities and Other Research Organisations**

Research organisations should develop appropriate training/education at tertiary level to raise standards of expertise within the industry. There are already a number of courses, for example, the MSc in Technology, Innovation and Management for a Circular Economy at Cranfield University.

**Industry**

The transition to a circular economy will be realised by industry. Big companies are already investing in circular economy approaches across many sectors but SMEs in several sectors are behind.

Encouraging SMEs to become more involved will open up the many symbiotic relationships and ecosystems required to embed circularity across supply chains.

\(^{18}\) http://www.greatrecovery.org.uk/

There is also a need for engagement of key interlocutors and trusted intermediaries e.g. consulting firms are engaged to look across the whole business while academic researchers can be limited by only looking at specific technologies or individual products. Engaging the advisory consultancies could embed the circular economy across the businesses and sectors that they are active in.

**Society**

Societal participation and public engagement are key to the success of a number of approaches to the circular economy. Circular economy research should therefore be conducted under the principles of responsible innovation.\(^{20}\)

All the aforementioned stakeholders need to work together in order to move society towards a more circular economy. There are already a number of examples of cross-stakeholder partnerships but more need to be encouraged.

\(^{20}\)EPSRC Responsible Innovation Framework: [http://www.epsrc.ac.uk/research/framework/](http://www.epsrc.ac.uk/research/framework/)
7 Next Steps

This position statement has set out a synthesis of views on publicly-funded research being done in
the UK relevant to the circular economy. It has summarised the opportunity for the UK and
identified the research communities contributing to this area as well as key stakeholders across the
research and innovation landscape.

It has also identified a number of research challenges highlighted by stakeholders, which will inform
EPSRC strategy going forward as EPSRC develops its delivery plan priorities and will aim to contribute
to a wider discussion across the research councils and Innovate UK.

Below are some next steps on how the UK research community can contribute to a transition
towards a circular economy and how some of the research challenges may be addressed:

The UK has a broad research expertise putting it in a unique position to exploit opportunities
related to the circular economy and build a national community in the area. In order to fully
realise these opportunities the community needs to be better networked. This could be realised,
for example, through networking activities or via a research hub and spoke type model.

The UK has the correct mix of skills, workforce and industry to benefit from a transition towards a
circular economy. In order to realise this more collaboration between businesses, along the supply
chain and with government and academia will be required.

There are many research challenges associated with the successful development and
implementation of a circular economy. Work towards many of these challenges is under way and
the challenges themselves overlap. As part of ongoing strategy development in the circular
economy the challenges identified in this document should be expanded upon and prioritised.

In order to address these research challenges, partnership with industry and other stakeholders
such as government organisations is essential. Co-creation of projects and programmes with these
stakeholders will inform research and facilitate its translation. Research proposals in the area
should consider stakeholder mapping and developing communication plans as part of an
enhanced pathway to impact.

Many of the challenges transcend disciplines requiring cross-disciplinary approaches in order to be
addressed so experts from different disciplines such as process modelling, engineering, economics,
materials science, social science and environmental science will need to work together. In order to
facilitate this, a challenge-led approach may be required.

Future research investment relevant to the circular economy should look to understand the
potential consequences of any technological development and interventions made through, for
example, life cycle and cost-benefit analyses.

This position statement was prepared by the EPSRC Manufacturing the Future theme - any questions
should be addressed to manufacturing@epsrc.ac.uk.