MICROBIOLOGY SOCIETY

# A Sustainable Future

*Transitioning to a Circular Economy: Opportunities and Challenges for Microbiology Research and Innovation*

Published by the Microbiology Society

# Foreword

Step by step and year after year, the health, wealth, and well-being of the global population is improving. Not on every single measure every single day, but as a rule. However, many challenges remain. Extreme weather events, biodiversity loss and forced displacement are affecting tens of millions of people worldwide every year. These catastrophic events generate headlines and grab our attention in ways that progressive improvements rarely do. When things get better, such as the decrease in child mortality across the world, it is because lots of people are working together on the frontlines every day, over the long term, to bring about the changes that constitute progress. Through the discovery of antibiotics and vaccines, water sanitation and hygiene, bioremediation and food security, to name but a few contributions, microbiology's impact has been profound.

The United Nations, 17 Sustainable Development Goals, including 'good health and well-being', 'gender equality' and 'affordable and clean energy', build on the success of the Millennium Development Goals to close the gap and cement hundreds of years of incremental human progress with the support of a strong international community. The Global Goals are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity by 2030.

Microbiology is essential to achieving the Sustainable Development Goals. The ocean and soil microbiomes, for instance, act as natural carbon sinks and could be used to further sequester carbon and mitigate the effects of anthropogenic climate change. Microbial technology can be used to produce sustainable clean energy in the form of biofuels. Microbial secondary metabolites could provide novel antimicrobials to tackle the pressing issue of antimicrobial resistance. Many of the steps that will be taken on the long road towards achieving the Sustainable Development Goals will involve microbial processes. The major policy decisions needed to set us on this journey require knowledge of relevant microbial activities and how these can be channelled for the greater benefit.

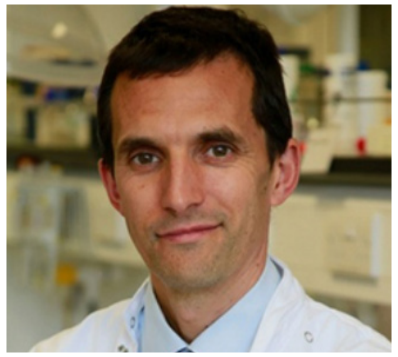
Microbiology has made our present better than our past, and can make our future better still. Policy decisions based on knowledge of underlying microbiological processes will be the basis of future progress, well-being and, ultimately, sustainability. With this project we hope to share our excitement for the profoundly positive effects that microbes have on human beings, the biological world and the entire planet and its atmosphere. Microbiologists, policymakers and others must work together to propel us towards the global goal: a sustainable future.

**Emeritus Professor Judith Armitage**
Professor of Biochemistry
*University of Oxford*

President of the Microbiology Society

# Contents

# 1. Executive summary



Microbiology has a critical role to play in the transition of our society from a linear to a circular economy, which is interlinked with the challenge of achieving climate neutrality. Micro-organisms are already helping us to deal with waste and recycle nutrients. The ability of microbes and the knowledge of microbiologists can help society to become sustainable now and into the future. The circular economy fits perfectly with the ambitions of several United Nations (UN) Sustainable Development Goals (SDGs).

Investment in infrastructure and innovations in industry (SDG 9) will help society achieve circular resource efficient production cycles, which complements SDG 12 (responsible consumption and production), but also help us to prevent waste getting into the waterways and seas (SDG 14; life below water). Industry and governments need to build infrastructure so that society can move away from linear fossil fuels and towards the circular economy. Microbiology will play a key role in the circular economy, allowing the use of renewable bio-based resources (e.g. agricultural side streams and food processing side streams) and their conversion to products of value using microbial enzymes and whole-cell processes such as anaerobic digestion and other fermentations, addressing SDGs 9 and 12, as well as 7 (affordable and clean energy). Microbes in soil can contribute to soil health and regenerative agriculture addressing SDG 15 (life on land). The circular economy is not just rural, but also urban, and the use of home and industrial composting to deal with waste arising from food and gardens will contribute to sustainable cities and communities (SDG 11). Microbes are needed to treat wastewater, which can be supplied back to society. Microbiologists and chemical engineers collaborate to make wastewater treatment less energy-intensive. Together, they can reduce water wastage and help achieve SDG6 (clean water and sanitation).

Open and broad collaboration is essential to realising change and impact. This brings with it many challenges, but the Microbiology Society can play a critical role in the structuring of these collaborations. Microbiologists must engage the wider public, policymakers and industry to inform the debate on addressing grand challenges and showcase the outputs, outcomes and positive impacts of microbes and microbiologists for society as a whole.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# 2. Recommendations

## Microbiology research in the circular economy

1. Sustained microbiology research and innovation in the field of the circular economy is imperative to help deliver the SDGs, particularly goals related to the environment (SDGs 6, 14 and 15), sustainable production and consumption (SDGs 9, 11 and 12) and economic growth (SDGs 7 and 8).

## Scaling up microbiology research and innovation

2. Microbiologists working in the circular economy field should seek collaboration outside of their core research expertise and realise how it applies to big global challenges. By collaborating with industry and funders, microbiologists should also advocate for flexible funding schemes, which would allow researchers to achieve longer-term research aims and to bring new expertise in to manage evolving challenges and work towards impact.

## Enabling a collaborative community

3. A physical or virtual space fostering non-competitive communication and showcasing the practical benefits and economic outcomes of successful circular economy projects is needed to encourage more research and industry collaboration.

## Developing a sustainable policy framework

4. While progress is being made, with governments adopting new policies, innovators developing new technologies and industry committing to transform their business models, large-scale action and impact is still lacking. Further effort to shape policy that meets societal, environmental and economic needs will be essential in ensuring the transition to a circular economy.

## Facilitating greater multi-sector engagement

5. Greater societal engagement could be gained by creating a coalition-building initiative to bring together representatives of the population to hear balanced evidence on the choices the UK and Ireland face and make recommendations about what should be done in order to transition to a circular economy.

6. Without a significant shift in human behaviour, technological solutions will be ineffective at transitioning to a truly circular economy. The use of sustainably managed bio-based resources proposed by expert scientists is only one part of the culture change we must undergo as a, technological society.

# 3. The circular economy and the Sustainable Development Goals

> Humans and micro-organisms have central roles to play in enabling a circular economy in which wastes are the key resources for new processes, technologies and innovation. Only by embracing this collaboration, in which all citizens are stakeholders, can societal, economic and environmental resilience be ensured for future generations."
> *Dr Maria Tuohy, National University of Ireland, Galway*

In an increasingly expanding global economy, within a resource-constrained environment, concerns over the exploitation and possible future scarcity of natural resources are rising rapidly. In recent years, interest in a circular economy model that looks beyond the current linear 'take–make–dispose' industrial model has surged among scientists, policymakers and business actors.

**The circular economy aims to redefine growth, focusing on positive society-wide benefits. It entails gradually decoupling economic activity from the consumption of finite resources, and designing waste out of the system. Underpinned by a transition to renewable energy sources, the circular model represents a systemic shift that builds long-term resilience, generates business and economic opportunities, and provides environmental and societal benefits [1].**

In 2015 the United Nations (UN) adopted the Sustainable Development Goals (SDGs), a collection of 17 goals and 169 associated targets. Wide-ranging and ambitious, the goals are a blueprint for transforming our world by 2030. They are interconnected and address economic, social and environmental challenges crucial to a better and more sustainable future for all. (More information on the UN SDG framework is available in Appendix 1)

The circular economy is tightly connected to many of the 17 SDGs; indeed, implementing the circular economy and the SDGs at large must go hand in hand.

Microbiology can help to achieve the SDGs by facilitating the transition to a circular economy. For example:

- Micro-organisms are crucial in creating a circular production cycle for plastics, where these can be reused, recycled and upcycled through their conversion into biodegradable polymers (SDGs 12 and 13).
- Microbial components affect anaerobic digestion – the process by which organic matter such as animal or food waste is broken down to produce biogas and biofertiliser (SDGs 2, 14 and 15).
- The nutritional versatility of micro-organisms can be exploited for biodegradation of pollutants, a process termed bioremediation (SDGs 13, 14 and 15).
- Soil microbes influence nutrient availability. They can solubilise organic and inorganic compounds that are largely unavailable to plants, and make them available for uptake by a plants, root system, allowing the plant to put more energy into growth (SDGs 2, 13 and 15).
- By considering the entire lifecycle of products and creating an effective after-use plastics circuit, the circular economy can drastically reduce the leakage of plastics into natural systems. This in turn can reduce the negative impact of microplastics and other pollutants on biodiversity (SDGs 14 and 15).

[1] **Ellen MacArthur Foundation.** *What is a circular economy? A framework for an economy that is restorative and regenerative by design. https://www.ellenmacarthurfoundation.org/circular-economy/concept*




**SDG 6:** Sustainable sanitisation, soil enhancement, nutrient recovery and water recycling and reuse can help increase access to safe drinking water, reduce pollution and improve water quality.

**SDG 7:** Waste heat recovery from industrial processes offers potential to improve industrial energy efficiency. Anaerobic digestion and biogas utilisation can contribute to increasing the share of renewable energy in the global energy mix.

**SDG 8:** Remanufacturing, recycling and closed loop supply chains can support higher resource efficiency in production. New circular opportunities and associated green jobs can also contribute to economic growth.

**SDG 9**: Circular economy practices contribute to making industries more resilient and sustainable. Achieving targets under this goal will enable a circular economy.

**SDG 11:** Circularity principles such as balancing local production with global supply chains can help foster resilient cities and improve their efficiency and environmental impact.

**SDG 12**: Decoupling economic development and human well-being from resource depletion and waste production is at the core of both the circular model and the transition to sustainable consumption and production.

**SDG 14:** Recovering nutrient from wastewater streams and preventing waste generation and leakages from land-based activities can directly reduce waste entering the oceans.

**SDG 15:** Circularity practices such as adopting regenerative agricultural practices that protect biodiversity and returning biological material back to soils as nutrients are fundamental for restoring terrestrial ecosystems.

# 4. Circular economy research spotlight

Microbiology plays a critical role in transitioning to a circular economy. Microbiologists working in research laboratories and in industry settings contribute to the three founding principles of circularity: design out waste and pollution, keep products and materials in use, and regenerate natural systems.

Microbiologists working in the field of the circular economy have the potential to help progress the UN SDGs, particularly goals related to the environment (SDGs 6, 14 and 15), sustainable production and consumption (SDGs 11 and 12) and economic growth (SDGs 7 and 8).

## 4.1. Design out waste and pollution


The SDGs related to the environment (SDGs 6, 13, 14 and 15) and to sustainable consumption and production (SDG 12) will not be met unless pollution and waste management are addressed as key priorities. The prevailing 'take–make–dispose' linear economic model consisting of voracious depletion of natural resources in both production and consumption patterns has proved to be one of the world's main killers due to the huge pollution it causes for air, land, soil, and marine and freshwater.

The circular economy seeks to reveal and design out the negative impacts of economic activity that cause damage to human health and natural systems. This includes the release of greenhouse gases and hazardous substances, the pollution of air, land and water, and structural waste such as traffic congestion [2].

Microbiology is opening up a vast range of opportunities supporting the shift to sustainable forms of production and consumption (SDG 12). Micro-organisms have the capacity to restore the original natural surroundings and prevent further pollution (SDGs 6, 13, 14 and 15). Microbiological methods of waste management using micro-organisms in techniques such as composting, activated sludge, trickling filters and oxidation ponds play an important role in treating and converting waste streams into value-added products [3]. However, more research is needed to fully understand the interplay between micro-organisms and waste. For example, biomass pretreatment is an area in need of improvement for economical production of biogas from complex organic matter such as lignocellulosic material.

[2] **Ellen MacArthur Foundation.** *The circular economy in detail*
*https://www.ellenmacarthurfoundation.org/explore/the-circular-economy-in-detail*
[3] Fatimat O. Adebayo, Obiekezie Smart, Microorganisms in Waste Management, *Research Journal of Science and Technology*, 2018, 10, https://doi.org/10.5958/2349-2988.2018.00005.0*nt*

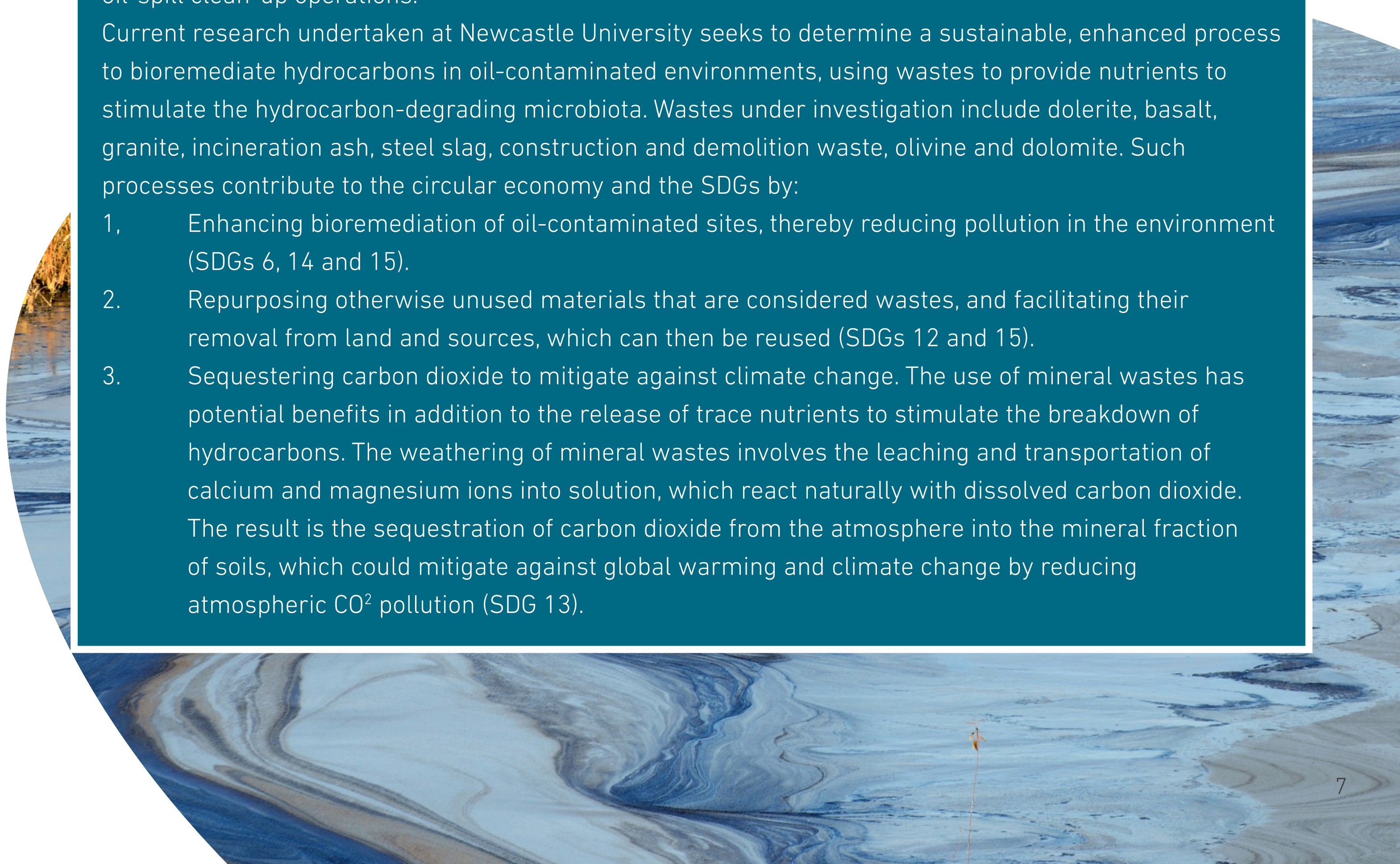


Promising microbial processes used for industrial purposes also include:

- Anaerobic digestion – a technology that uses micro-organisms to break down organic matter to reduce the amount of waste, make it harmless and recover energy materials such as short-chain fatty acids, hydrogen and methane. In order to allow anaerobic digestion to meet its full potential, we must have a standardisation process that encourages the redirection of waste from landfill to reuse.
- Bioremediation – a treatment technique for organic fuel-based contaminants using naturally occurring bacteria and fungi to degrade or detoxify substances hazardous to human health and the environment.
- Biofiltration – a separation process relying on bacteria and fungi immobilised on a biofilm to remove organic pollutants from air, water and wastewater.
- Biotechnological fermentation – a process through which micro-organisms produce organic acids (useful as starting materials for food supplements, bio-based materials and chemicals and biodegradable polymers), replacing petroleum-based processes.

**Using wastes to enhance bioremediation of oil-contaminated sites – Sola Olawuyi (PGR student, Newcastle University), Dr Angela Sherry (VC Senior Research Fellow, Northumbria University).**
Oil pollution is a worldwide problem and will continue to be so for the foreseeable future. The addition of nutrients into oil-contaminated sites provides a successful strategy for the stimulated bioremediation of oil-spill clean-up operations.
Current research undertaken at Newcastle University seeks to determine a sustainable, enhanced process to bioremediate hydrocarbons in oil-contaminated environments, using wastes to provide nutrients to stimulate the hydrocarbon-degrading microbiota. Wastes under investigation include dolerite, basalt, granite, incineration ash, steel slag, construction and demolition waste, olivine and dolomite. Such processes contribute to the circular economy and the SDGs by:

1, Enhancing bioremediation of oil-contaminated sites, thereby reducing pollution in the environment (SDGs 6, 14 and 15).
2. Repurposing otherwise unused materials that are considered wastes, and facilitating their removal from land and sources, which can then be reused (SDGs 12 and 15).
3. Sequestering carbon dioxide to mitigate against climate change. The use of mineral wastes has potential benefits in addition to the release of trace nutrients to stimulate the breakdown of hydrocarbons. The weathering of mineral wastes involves the leaching and transportation of calcium and magnesium ions into solution, which react naturally with dissolved carbon dioxide. The result is the sequestration of carbon dioxide from the atmosphere into the mineral fraction of soils, which could mitigate against global warming and climate change by reducing atmospheric $CO^2$ pollution (SDG 13).



## 4.2. Keep materials in the materials cycle for longer

The continued expansion of global resource consumption poses a number of challenges for the achievement of SDGs 7, 8, 11, 12 and 13. The efficient management of our shared natural resources and the way we manage waste and pollutants are important targets to achieve a sustainable future.

The circular economy favours activities that preserve value in the form of materials, energy and labour. This means designing for durability, reuse, remanufacturing and recycling to keep products, components and materials circulating in the economy [4].

The recycling of plastics as an option remains largely underexploited in circular economy thinking, likely due to the high price and low quality of the recyclate. In addition to providing enzymes for biological depolymerisation and bio-recycling of plastics, micro-organisms have evolved to utilise a wide range of carbon and energy substrates, including plastics or plastic-derived molecules. Use of post-consumer plastic as a non-conventional feedstock with the capacity of micro-organisms to produce value-added molecules, such as biodegradable plastics and chemicals, should be a perspective of the circular economy of plastics [5]. By seeking a better understanding of the interactions between micro-organisms and plastics, scientists may make significant contributions to the way we design, use and reuse plastics. For example, scientists are investigating:

- A plastic degrading enzyme isolated from *Ideonella sakainensis*, a bacterium isolated from a dumping site. Unlike natural degradation, which can take hundreds of years, the 'super-enzyme' is able to convert the plastic back to its original materials in just a few days [6]. The next step is to get this enzyme to be able to degrade plastic in hours.

- Monomers arising from polymer degradation by enzymes that can be re used to re make polymers. In the longer term, the process would allow plastics to be made and re used endlessly, reducing our reliance on fossil resources.

- Anaerobic digestion could be a future end-of-life management option for biodegradable plastics. During the anaerobic process, a methane-rich biogas is produced, which could be used to make green electricity or transport fuel. A nutrient-rich 'digestate' remains at the end and can be collected and used as a fertiliser.

[4] **Ellen MacArthur Foundation.** *The circular economy in detail https://www.ellenmacarthurfoundation.org/explore/the-circular-economy-in-detail*
[5] **Microbiology Society.** *Bio-upcycling of plastic waste, Dr. Tanja Narancic https://microbiologysociety.org/our-work/75th-anniversary-a-sustainable-future/circular-economy/circular-economy-case-studies/bio-upcycling-of-plastic-waste.html*
[6] Harry P. Austin, Mark D. Allen, Byron S. Donohoe, *et al.*, Characterization and engineering of a plastic-degrading aromatic polyesterase, *PNAS*, 2018, 115, https://doi.org/10.1073/pnas.1718804115



**MIXed plastics biodegradation and UPcycling using microbial communities (MIX-UP) – Dr Tanja Narancic (Assistant Professor, School of Biomolecular and Biomedical Science, University College Dublin)**
Almost 350 million tonnes of plastics are produced worldwide and 800 million tonnes are forecasted to be produced by 2050. As part of the EU Horizon 2020 project MIX-UP, a team of researchers at University College Dublin are working with universities, research centres and industry partners from around the world to showcase a novel approach to the circularity of the plastic life cycle and therefore address one of the greatest challenges of our time: the establishment of a circular bio-economy for plastics.
The objective of MIX-UP is to use plastic waste as a valuable resource for the future by sustainable, biotechnological conversion of unsorted, mixed plastics into ecological, value-added biomaterials using heavily engineered enzyme mixtures and mixed microbial communities. A combination of enabling technologies, such as systems and synthetic biology, and non-conventional feedstocks for micro-organisms, such as mixed plastic waste, will be used to develop bioprocesses to not only reduce, but valorise plastic waste. By tackling the issue of downstream processing and recovery of the product, MIX-UP will be showcasing a novel, complete approach to the circularity of plastic – contributing to addressing SDGs 12, 14 and 15.

## 4.3. Regenerating natural systems

Natural resources are essential inputs for economic and social development. However, overexploitation and unsustainable use have led to the degradation and depletion of natural capital, threatening the achievement of SDGs 12, 13, 14 and 15. Central to the notion of sustainable development is the requirement that resources should be utilised in ways that do not diminish their capacity for renewal, so that they will always be present for future generations.

The circular economy provides a framework for the management of natural resources by avoiding the use of non-renewable resources and preserving renewable ones, for instance by returning valuable nutrients to the soil to support regeneration, or using renewable energy as opposed to fossil fuels [7].

Soils are one of the most biodiverse habitats on Earth, with an estimated 40,000 to 50,000 species of micro-organism per gram of soil. The soil microbiome governs biogeochemical cycling of macronutrients, micronutrients and other elements vital for the growth of plants and animal life [8]. Research has shown that soil micro-organisms can be harnessed to draw carbon out of the atmosphere and sequester it in the soil, providing a significant means of reducing atmospheric greenhouse gases and helping to limit the impact of greenhouse gas-induced climate change [9]. Many micro-organisms can contribute to the regeneration of natural systems, including:

- Nitrogen-fixing bacteria, micro-organisms capable of transforming atmospheric nitrogen into fixed nitrogen usable by plants, which in turn sustain all animal life.
- Bacteria that use pollutants as carbon sources, allowing them to decontaminate dangerous chemicals in the environment, thereby helping to regenerate natural resources.
- Micro-organsims regulation biogeochemical systems, a pathway by which a chemical element (such as carbon, nitrogen or phosphorus) circulates through and is recycled by an ecosystem in virtually all of our planet's environments.
- Cyanobacteria, or 'blue–green algae', are responsible for almost all of the production of oxygen on Earth today.

[7] **Ellen MacArthur Foundation.** *The circular economy in detail https://www.ellenmacarthurfoundation.org/explore/the-circular-economy-in-detail*
[8] Janet K. Jansson, Kirsten S. Hofmockel, Soil microbiomes and climate change, *Nature Reviews Microbiology,* 2020, 18, https://doi.org/10.1038/s41579-019-0265-7
[9] Himangshu Dutta, Angshu Dutta, The microbial aspect of climate change, *Energy, Ecology and Environment*, 2016, 1, https://doi.org/10.1007/s40974-016-0034-7



**London 2012: contaminated soil treatment at the Olympic Park**
The grounds that hosted the 2012 Olympics had previously been heavily polluted, after hundreds of years of industrial activity. Bioremediation cleaned 1.7 million cubic metres of heavily polluted soil to turn this brownfield site into one containing sports facilities surrounded by 45 hectares of wildlife habitats. Groundwater polluted with ammonia was cleaned using a new bioremediation technique that saw archaeal microbes breaking down the ammonia into harmless nitrogen gas. The converted park marked the London 2012 Olympic and Paralympic Games as the 'greenest' and most sustainable games ever held, only possible with bioremediation techniques. It is also considered one of the most successful remediation projects undertaken in the UK over the last decade, having warranted further development of previous widely used remedial methods and technologies.

**Recommendation 1:**
Sustained microbiology research and innovation in the field of the circular economy is imperative to help deliver the SDGs, particularly goals related to the environment (SDGs 6, 14 and 15), sustainable production and consumption (SDGs 9, 11 and 12) and economic growth (SDGs 7 and 8).

## OPINION PIECE

# Circularising the bioeconomy – Louise Horsfall, Professor of Sustainable Biotechnology, University of Edinburgh

Covid-19 has had a severe impact on the economy, with public debt now larger than the size of the UK's economy. However, it has also provided us with a massive opportunity to effect real environmental change. Developing a circular economy would lead to a 48% reduction in carbon dioxide emissions by 2030 and provide a host of opportunities for the expanding bioeconomy. The food and drink production industry is vital to the UK economy but creates unavoidable bio-based waste that largely goes to landfill, resulting in methane gas production, causing environmental pollution and contributing to climate change. Food and drink manufacturing waste and by-products therefore constitute a vast resource that is currently underutilised. They have the potential to power a circularised bioeconomy, whilst also relieving tensions in the food-versus-fuel debate and supporting efforts to achieve targets in climate change, sustainability and food security.
The circular economy model may be bioinspired, but the biological cycles and cascades are somewhat underdeveloped and oversimplified. What is needed is a multidisciplinary research approach that incorporates new technologies able to utilise the waste and by-products of food and drink production to their full potential. Three areas of technical development could improve resource flow and circularity within a bioeconomy powered by waste from the food and drink sector:

1. Separation of valuable by-products, e.g. the removal of proteins for animal feed.

2. Biological transformation of by-products into new products, with concomitant redesign of biological systems and processes to minimise waste, e.g. the production of high yields of enzymes using microbes engineered for increased lifespan to reduce washing, sterilisation and waste.

3. Conversion of biomass, including that resulting from biological processes, into carbon products and chemicals through thermochemical processing or anaerobic digestion – thereby providing an alternative route, by which even the treated biomass of genetically modified micro-organisms could be used to regenerate natural systems through thermochemical conversion to useful soil additives.

The interdisciplinary challenge of circularising the bioeconomy is clearly enormous and expertise in the field of microbiology is key to overcoming it. There are specific challenges associated with using complex industrial by-products and wastes as feedstocks, instead of comparatively pure commercial growth media for microbial growth. Impurities that can accumulate in the growth medium to inhibitory or toxic levels, as well as unfavourable consequences of harsh raw material pre-treatment conditions, such as very low pH, represent chemical stresses for the microbial production strains. Whether it be a source of new genes or as alternative 'chassis', we will be reliant on a diverse range of micro-organisms to adapt the current microbial production platforms to better tolerate unfavourable conditions and impurities. New bio-based products will be produced from food waste by moving away from our 'go to' hosts, *Escherichia coli* and *Saccharomyces cerevisiae*, and diversifying the pallet of tools available to biotechnology.

As climate change imposes further stresses on land use, food security will depend on our ability to control our own supply chains. The UK currently imports 50% of its food and feed. A circular bioeconomy would reduce our demand for imports, lowering carbon footprints and environmental pollution. Valorisation of waste is critical to the maintenance of our limited arable land and marine resources, while still protecting the UK's natural environment.

# 5. Moving forward in transitioning to a circular economy

There is an opportunity to unlock the potential of microbiology to transition to a circular economy and therefore help to achieve the SDGs. In order to explore the challenges and opportunities for microbiology in the field of the circular economy, the Microbiology Society held a series of online workshops, which collectively brought together circular economy researchers from different fields, along with representatives from industry, funders and government agencies. In this section, we discuss what more could be done if there were fewer barriers, and the interventions needed to achieve a sustainable future.

## 5.1 Scaling up microbiology research and innovation

Scaling up industrial microbial processes is vital to develop sustainable technologies that can help to achieve a circular economy. Technological innovations have significant potential to accelerate the transition to the circular economy by combining digital, physical and biological technologies at scale.

- Scaling-up microbial processes for commercial production requires time and investment in infrastructure and people. Microbiologists need to consider this early on in the development process and create partnerships so that processes can withstand scaling up and increase the chances that they will be resilient and robust.
- Microbiologists should seek to develop a network beyond microbiology and gain advice from those who have successfully executed scale-up.
- Flexible funding deadlines with a clear plan and potential to work towards impact are required in order to bring new expertise in to manage the challenges as they evolve.
- Microbiologists must move away from a narrow view of their research and realise how it applies to big global challenges to effectively communicate messages across to industry and wider society. More sophisticated bioinformatic tools allowing large-scale dataset analyses as well as training could help microbiologists think about the bigger picture earlier on.
- Emerging methods such as DNA sequencing are enabling an increase in innovation, which may help to develop novel strategies for a circular economy. Methods such as smart search algorithms have the potential to find new biocatalysts, and synthetic biology provides opportunities to improve the efficiency of micro-organisms. These new methods are transforming the possibilities in this sector and should be supported by appropriate funding to enable implementation.
- Most efforts to achieve a circular economy have so far centred on the 'trash' part of the circle, through recycling and waste management programmes. While this is important, there needs to be more focus on the 'take': reducing the amount of materials that we remove from nature to begin with.



**Global alliance of Biofoundries – Professor Paul Freemont (Imperial College London, Co-Director of the London Biofoundry) and the London Biofoundry team**

Synthetic biology is a rapidly growing area of interdisciplinary research that aims to provide a systematic framework for the engineering of living systems at the genetic level. The potentially transformative nature of the field is addressing many different application areas of societal and industrial importance, including new materials, pharmaceuticals, therapeutics, diagnostics and biomanufacturing. However, the artisanal processes of research and development in this growing field are slow, expensive and inconsistent, representing a key obstacle in biotechnology production processes.

In recent years, biofoundries have been developed to automate the engineering biology design–build–learn-test cycle in an effort to accelerate the translation of synthetic biology as a platform technology. With this in mind, the Global Alliance of Biofoundries (GBA) was created to bring together the world's leading non-commercial biofoundries and academics; coordinating activities between universities and institutions worldwide. Each facility is unique and typically has a degree of specialisation in the organism type and process it employs. For example, the London Biofoundry (LBF) provides a suite of state-of-the-art robotic machinery supplying automated end-to-end design, construction and validation of large gene constructs.

As new automated workflows are being developed, the GBA is allowing their rapid implementation due to its collaborative and open-source culture. With the rapid development of technologies in synthetic biology, regular investment in this infrastructure is necessary to keep innovating at the forefront of the field.

Find out more about the LBF here: **www.londonbiofoundry.org**.

**Recommendation 2:**

Microbiologists working in the circular economy field should seek collaboration outside of their core research expertise and realise how it applies to big global challenges. By collaborating with industry and funders, microbiologists should also advocate for flexible funding schemes, which would allow researchers to achieve longer-term research aims, and to bring new expertise in to manage evolving challenges and work towards impact.

## 5.2 Enabling a collaborative community

At the heart of the circular economy is the ambition to collaborate in order to keep resources in use for as long as possible, extract the maximum value from them while in use and then regenerate natural systems. However, collaboration between academic scientists and industry within the field has been hampered by intellectual property (IP) issues:

- Complex IP agreements at university-level are costly and time-consuming. Consortium agreements in the spirit of responsible partnering, such as the Development of a Simplified Consortium Agreement (DESCA) model in the EU [10], make it possible to balance and protect the interests of all participant categories: universities, public research institutes, and large and small firms. A similar model, settled across the UK, would provide more freedom and opportunities for microbiologists working in the circular economy field to partner-up and share their work.

- The lack of resources in universities to manage IP portfolios can also lead to the premature development of companies and the licencing of IP at a too early stage. There could be value in consolidating resources and focusing support to enable the transition from good ideas to viable businesses.

Collaborative networks of experts achieve more impact when they are given access to dynamic infrastructures that enable knowledge exchange rather than when operating in isolation. Whilst workshop attendees welcomed UK Research and Innovation's support for the creation of five Interdisciplinary Circular Economy Centres [11], they regretted that not one includes a bio-based resource stream.

- The Microbiology Society and its members must continue to promote the vital role microbiology should be playing within multisectoral endeavours.

- There is a need for a strategic framework that enables the development of a circular economy by allowing academia and industry to grow together. The creation of a physical or virtual space fostering non-competitive communication and showcasing the practical benefits and economic outcomes of successful circular economy projects could help to encourage more research and industry collaboration.

[10] **DESCA.** *DESCA 2020 Model Consortium Agreement http://www.desca-agreement.eu/*
[11] **UKRI.** *Circular economy centres to drive the UK to a sustainable future https://www.ukri.org/news/circular-economy-centres-to-drive-uk-to-a-sustainable-future/*



**The Environmental Biotechnology Network – Professor Frederic Coulon (Cranfield University, Co-Investigator of the Environmental Biotechnology Network) and the Environmental Biotechnology Network team**

The Environmental Biotechnology Network (EBNet) is one of six 5-year Networks in Industrial Biotechnology and Bioenergy (NIBB) funded in 2019 by the BBSRC, with support from EPSRC. The aim of the network is to provide funding and opportunities to foster collaborations between academia, industry, policymakers and NGOs in order to find new approaches to tackle research challenges and to translate research towards industrial application.

The current revolution in biosciences is creating new tools that offer the chance to optimise existing processes and create more sustainable 'future-proof' technologies in new areas of application. But successful exploitation depends on combining an enhanced understanding of the fundamental science with an ability to apply this in full-scale engineered systems. EBNet aims to strengthen the links between those working at the forefront of microbial genomics, metabolic capabilities and community interactions; and those designing next-generation environmental protection technologies based on sustainable bioprocesses. Combining the complexities involved in these microbial systems with their wider context – process and chemical engineering, life cycle and sustainability analysis, social science issues, etc. – paves the way for a more holistic understanding of their capabilities; an otherwise mammoth task for any one individual. By providing significant funding to support the implementation of new technologies and help move laboratory findings closer to industrial application, the network is aiming to foster the necessary collaborations that may one day make microbial communities behave on demand.

Find out more about the EBNet here: **https://ebnet.ac.uk/**.

**Recommendation 3:**
A physical or virtual space fostering non-competitive communication and showcasing the practical benefits and economic outcomes of successful circular economy projects is needed to encourage more research and industry collaboration.

## 5.3 Developing a sustainable policy framework

Sustainable solutions that harness microbiology to transition towards a circular economy already exist and are close to breakthrough. However, for the technologies to be commercialised, a policy framework should be developed to influence the market and incentivise breakthrough of technology. For example, extracting products from waste sources is feasible but, for the process to be implemented, clarity from policy perspective is needed.

- The circular economy will be truly sustainable only if it helps contribute to a transformation of society. From a policy point of view, major changes are needed in global, regional and national frameworks. Policies at different levels of government need to be aligned and work in harmony to advance meaningful progress. An ambitious systems approach, bringing different actors and systems together, is needed to bridge multiple contexts rather than relying on solutions generated in silos.

- There is a need for better policy coherence and integration between food and agriculture, energy, waste and trade sectors in order to enable the transition to a circular economy. The Well-being of Future Generations Bill [14], which has garnered cross-party support in its call for public bodies to act in pursuit of the environment, social, economic and cultural well-being of the UK, is recognised as a positive step towards beginning to address the greatest threats facing future generations.

**Recommendation 4:**
While progress is being made, with governments adopting new policies, innovators developing new technologies and industry committing to transform their business models, large-scale action and impact is still lacking. Further efforts to shape policies that meet societal, environmental and economic needs will be essential in ensuring the transition to a circular economy.

[14] **UK Parliament.** *Wellbeing of Future Generations Bill https://services.parliament.uk/Bills/2019-21/wellbeingoffuturegenerationsbill.html*



**Ireland's Waste Action Plan for a Circular Economy [12]**
In Ireland, the Waste Action Plan for a Circular Economy published in September 2020 sets out strategic objectives and a framework to give direction to waste planning and management over the coming 5 years. Its overarching aim is to shift away from the current focus on waste disposal and treatment to ensure that materials and products remain in productive use for longer. This is intended to prevent the build-up of waste and support the re use of goods and materials in line with the EU directives and the promotion of the circular economy. With over 200 actions, it echoes many of the ambitions committed to in the European Commission's Green Deal, particularly the goals of the 2020 Circular Economy Action Plan 'For a cleaner and more competitive Europe'. Among other things, the plan intends to halve the amount of food waste by 2030, introduce environmental levies for waste recovery and single-use coffee cups, and standardise bin colours across the state.

**The UK's Circular Economy Package Statement [13]**
The UK's own Circular Economy Package (CEP) was published in July 2020 by the UK, Welsh, Scottish and Northern Ireland governments. In the statement, the UK commits to moving towards a more circular economy that will keep resources in use as long as possible, extract maximum value from them, minimise waste and promote resource efficiency. Primarily the same as the European CEP, it includes objectives such as sending no more than 10% of municipal waste to landfill by 2035.
Other key policies includes the UK's 25 Year Environment Plan and its objective to reduce all single-use plastic and unavoidable plastic waste by 2042. The Welsh Government's strategy, Beyond Recycling, sets out its aim of making a circular, low-carbon economy in Wales a reality. The Scottish Government's circular economy strategy, 'Making Things Last', sets out a vision and priorities for action to move towards a more circular economy. In Northern Ireland, the Department of Agriculture, Environment and Rural Affairs is currently developing the 'Environment Strategy for Northern Ireland', which will consider the main long-term environmental priorities for Northern Ireland.

[12] **Government of Ireland.** *Waste action plan for a circular economy* https://www.gov.ie/en/publication/4221c-waste-action-plan-for-a-circular-economy/
[13] **UK Government.** *Circular economy package policy statement https://www.gov.uk/government/publications/circular-economy-package-policy-statement/circular-economy-package-policy-statement*

## 5.4 Facilitating greater multisector engagement

The coronavirus pandemic has highlighted the crucial role of microbiology research and innovation in tackling global challenges. However, microbiology is not limited to global health issues and has the power to provide solutions to transition towards a circular economy. Microbiologists should seek to communicate the benefits of understanding microbes to stakeholders and showcase the growing role of microbes in nature-based solutions.

COVID-19 has also revealed issues with supply chains in certain sectors and this has created a renewed interest from the public in localised production and more sustainable supply chains. Using the momentum of the 'build back better' campaigns, there is now an opportunity for policymakers and microbiologists to engage with the public in this area and encourage behavioural change to adopt a more circular economy.

- Greater societal engagement could be gained by creating a coalition-building initiative similar to Climate Assembly UK [15]. Such an assembly would bring together representatives of the population to hear balanced evidence on the choices the UK and Ireland face, discuss them and make recommendations about what should be done in order to transition to a circular economy.

When developing innovative solutions for a circular economy, the importance of behavioural change for implementation of the technologies should not be underestimated. Microbiologists have warned that we should not look upon biodegradable plastics as a magical solution that excuses us from our environmental responsibility. The use of sustainably managed bio-based resources is one part of the culture change we must undergo as a society.

- A successful circular economy involves a huge network of actors collaborating together. The Alliance to End Plastic Waste [16], for example, works to end the leakage of plastic waste into the environment; its members include consumer brands, resin producers, packaging producers, recyclers and solid waste management companies. Whilst the story of the circular economy is ongoing, complex and has many iterations, such public–private partnerships demonstrate the collective responsibility needed to develop meaningful solutions for a sustainable future.

**Recommendation 5:**
Greater societal engagement could be gained by creating a coalition-building initiative to bring together representatives of the population to hear balanced evidence on the choices the UK and Ireland face and make recommendations about what should be done in order to transition to a circular economy.

**Recommendation 6:**
Without a significant shift in human behaviour, technological solutions will be ineffective at transitioning to a truly circular economy. The use of sustainably managed bio-based resources proposed by scientists is only one part of the culture change we must undergo as a society.

[15] **Climate Assembly UK.** *https://www.climateassembly.uk/*
[16] **Alliance to End Plastic Waste.** *https://endplasticwaste.org/*



**Resource Recovery from Waste – Dr Anne Velenturf (University of Leeds)**
Resource Recovery from Waste (RRfW) was a £7M strategic investment by NERC, ESRC and DEFRA. The programme included six diverse projects spanning the recovery of metals and organic resources, as well as novel approaches for participatory sustainability assessments.
One of the main issues in enabling decision-making for better policies and to unlock investments is the limited information on the volumes and qualities of resources and wastes. RRfW has been a strong contributor to generate momentum for a national data system for material stocks and flows. Impacts from the programme included the establishment of an environment in which government policy could become more integrated, and continuous targeted engagement and communications shaping the public narrative on the circular economy. These impacts were enabled by an integrated approach to research, engagement and impact. Important to the success of RRfW was the recognisable image, which included consistency in the main messages of the programme targeting key stakeholders in the system. Understanding the diverse stakeholder perspectives on the circular economy, their interests and concerns, and their preferred methods for learning and innovating was also crucial for successful engagement. But ultimately, it was the vibrant and diverse community that created an environment within which novel and radical ideas could emerge and fuel transformative change to transition towards a circular economy.
Find out more about RRfW: **https://rrfw.org.uk/**.

# 6. Acknowledgements

The Microbiology Society would like to thank the A Sustainable Future Expert Working Groups, who helped identify major issues and developments, assisted with producing this report and advised on other aspects of the Society's A Sustainable Future policy project. The Society would also like to thank all of the experts who participated in its A Sustainable Future in June and July 2020 for sharing their perspectives, which also helped to inform this report and other outputs from the project.

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### Other acknowledgments

Professor Judith Armitage, President of the Microbiology Society; the members of the Microbiology Society Impact and Influence Committee; Professor Paul Kellam, Microbiology Society Impact and Influence Committee Co-chair; Dr Chloe James, Microbiology Society Impact and Influence Committee Co-chair; and Professor Charles Dorman, Microbiology Society Council Member, for reviewing the report.

Professor Paul O'Toole and Dr Max Paoli for providing video content to support the A Sustainable Future Workshops.

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# Appendix


The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries – developed and developing – in a global partnership. They recognise that ending poverty and other deprivations must go hand in hand with strategies that improve health and education, reduce inequality and spur economic growth – all while tackling climate change and working to preserve our oceans and forests. For more information please visit: **https://sdgs.un.org**.

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Page 23: Participants at Annual Conference 2019 – Ian Atherton

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The Microbiology Society is a membership charity for scientists interested in microbes, their effects and their practical uses. It is one of the largest microbiology societies in Europe with a worldwide membership based in universities, industry, hospitals, research institutes and schools.

Our members have a unique depth and breadth of knowledge about the discipline. The Society's role is to help unlock and harness the potential of that knowledge.