ROYAL SOCIETY OF CHEMISTRY

A Circular Economy for polymers in liquid formulations

A synergy report on the opportunities for collaboration in the chemical sciences

January 2019

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Recommended readers of this report

This report is for participants of the Synergy programme and colleagues within their organisation. Technical managers interested in this topic, working in businesses across the polymer supply chain will also benefit from reading this report, to understand our current and future work in this area. This report may also be of interest to academia, government and NGOs working in this area.

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Executive summary

Transitioning the production of polymers in liquid formulations from a 'take, make, dispose' model to one that reuses resources and waste (Circular Economy model) could improve the environmental and economic sustainability of these materials. It also presents a significant innovation opportunity for UK businesses. Proactive, early stage collaboration across the chemical science community in this topic could advance scientific knowledge and accelerate innovation. Without it, businesses and the government could face longer timeframes and higher costs for innovation.

Polymers are functional materials that provide properties such as thickeners, emulsifiers and coatings to liquid formulations in pharmaceuticals, energy, paints and coatings, personal care and agriculture. Industry often source these materials from fossil-derived feedstocks and they enter waste streams at the end of their life. This could contribute to climate change, waste generation and environmental pollution. Consumers are becoming increasingly concerned about the environment and demanding more sustainable products which could drive innovation in this space.

The Royal Society of Chemistry has brought together a diverse group of stakeholders including academics, SMEs, large companies, government agencies and NGOs through our Synergy programme. Together we identified four opportunities for the chemical sciences to help transition these materials to a Circular Economy model:

1. The modification and development of new monomers and polymers
2. Life cycle analysis and models and methods to design sustainable materials
3. Manufacturing scale up of sustainable monomers
4. The recovery and reuse of polymers

Collaboration is critical to progressing these opportunities. It can de-risk the economic burden of research and development and reduce the potential for duplicating work. It can also leverage multidisciplinary skills to address knowledge gaps and deliver solutions faster. Key findings from this work highlight the need for wide collaboration to advance our understanding of these materials to overcome technical feasibility and economic challenges of integrating solutions in industry. It will also be critical for influencing key areas of funding, regulation and policy that may affect innovation. Recommendations made by participants for supporting the chemical science community to progress these opportunities in the next stages of Synergy are:

1. Gaining a baseline understanding of currently used polymers in liquid formulations across chemistry-using industries
2. Addressing gaps in technical knowledge
3. Identifying mechanisms that stimulate collaboration on this topic in academia, industry and the wider ecosystem

In 2019, we want to engage with large companies across the supply chain interested in this topic, to help us build a programme that facilitates collaboration. *A Circular Economy for polymers in liquid formulations* presents a significant opportunity for the UK chemical sciences community to collaborate. Early engagement in the Synergy programme will enable businesses to build relationships with a wide network of academics and other companies concerned with this topic, advance knowledge required to find solutions and gain external support for innovation.

If you are interested in being involved in the next phase of Synergy, please contact:

Jenny Lovell, Synergy Programme Manager, Royal Society of Chemistry (**email: synergy@rsc.org**).

Contents

1 Participants

We would like to thank the following organisations for their contributions to this early stage work.

Anglian Water
Biorenewables Development Centre
BP
British Coatings Federation (BCF)
Centre for Ecology and Hydrology
Centre for Process Innovation (CPI)
CustoMem
DEFRA
Durham University
Ellen MacArthur Foundation
Itaconix
Lubrizol
Marine Conservation Society
PRA World Ltd
Sanofi
Syngenta
Synthomer
Thomas Swan
Unilever Research
University of Bath
University of Birmingham
University of Nottingham
University of Surrey

2 Context to this report

2.1 Collaboration to advance the chemical sciences

Innovation is a key driver for UK growth and is a priority for the chemical industry in doubling its contribution to the economy by 2030.[1] Innovation can not only increase process efficiency and create new products that improve daily life and wellbeing, but also contribute to solving persisting problems. We believe that collaboration is essential for advancing the chemical sciences to help address these problems.

Problems such as antimicrobial resistance (AMR), climate change and waste are often difficult to solve because they are multifaceted, interconnected with other issues and have no sector boundaries. There is no single approach for tackling these types of problems, nor is there one solution available to eradicate them. The extensive number of people affected by these problems make them impossible for any organisation to solve in isolation.

There is a strong demand from academia, industry and the wider innovation ecosystem to leverage the capabilities of different communities to tackle these problems. However, collaboration at this scale does not happen spontaneously, it requires coordination. A structured and managed approach to collaboration could significantly reduce the barriers to innovation for individual organisations and accelerate the development of solutions to these problems. The Joint Programming Initiative on Antimicrobial Resistance (JPIAMR)[2] is an example of such a collaboration that has supported 62 collaborative projects and 340 research groups with €67 million to advance innovation for AMR.

2.2 Synergy

We understand that the chemical science community contributes to solving these types of problems, which is why we are setting up a pilot programme called Synergy to support this. The purpose of the programme is to solve chemical science-based challenges in persisting problem areas. We will do that by facilitating collaborations across the UK chemical sciences community.

We expect that Synergy will advance chemical science knowledge, reduce barriers for innovation in industry and achieve results faster than if the community addresses these challenges in isolation.

In 2015, our *Future of the chemical science report* highlighted that the role of the chemical sciences is changing with a shift from fundamental to problem-driven research.[3] Several interviews and workshops with experts in our industrial community since then identified a strong need for a consortium for the UK chemical science community to stimulate collaboration for innovation. As an independent organisation with a community of over 54,000 experts, our industrial community recognised a key role for the Royal Society of Chemistry to facilitate this.

Figure 1: Introduction to the Synergy programme at a workshop

2.3 The case of polymers in liquid formulations (PLFs)

The United Nations 17 sustainable development goals highlight the areas required to create a sustainable planet,[4] which 60% of the businesses in the UK are actively reporting on.[5] The Circular Economy is a key concept, which could help address four of these challenges: a) responsible consumption and production; b) climate action; c) life below water and d) life on land, by reducing waste and pollution and keeping products and materials in continuous use.[6]

In addition, the Circular Economy could also create significant economic benefits in Europe, worth approximately €320 billion.[7] The EU action plan for the Circular Economy[8] and initiatives led by the Ellen MacArthur Foundation are examples of the work already going on at an international level. Several initiatives, like the New Plastics Economy[9] and the launch of the UK's £20 million Plastics and Research Innovation Fund,[10] direct efforts towards a Circular Economy by stimulating action in the research and business community.

In 2018, the formulated products sector, which contributes £129 billion Gross Added Value to the UK economy, identified greener formulation as a strategic priority to address current sustainability pressures on industry.[11] Polymers are typical ingredients used in formulations in multiple applications. Thickeners in cosmetics and personal care, coagulants in water treatment and emulsifiers in paints and coatings are all examples of PLFs.

However, there is limited work going on in this space, which highlights a significant opportunity to advance the chemical sciences. These materials often fall out of the scope of reports that deal with solid polymer particulates but a UNEP report on plastics in cosmetics highlighted the need for further research to evaluate liquid-phase and soluble polymers.[12]

The first theme that our industry community selected to focus on is **A Circular Economy for polymers in liquid formulations (CEPLFs)**. This theme is highly relevant to the plastics and formulation work that already exists in the UK and it is an emerging area of interest for many industry sectors. While sectors know a lot about their specific materials, knowledge exists in silos. This creates a huge opportunity for the chemical science community. This initial piece of work explores potential opportunities for the chemical science community to collaborate to advance this theme.

3 Goals, focus and scope

The goal for the early stage work outlined in this report is to identify potential opportunities for industry-led collaborations in the context of CEPLFs for the Synergy pilot programme. In this report, we consider biological based and synthetic based polymers to reduce the consumption of non-renewable resources, reduce waste generation and maximise value obtained from PLFs.

This work does not focus on plastics and their degradation products, because of the significant work already going on in this area and potential to duplicate efforts with other organisations. However, we will be drawing on similarities that may exist with these materials.

The timeframe chosen for this topic is 2018–2043 to align with the 25-year Environment Plan from the UK government.[13] The initial scope of this work is the UK because of our connections and knowledge of the innovation ecosystem. However, we recognise that this is a global topic so in the future we may expand the scope.

4 Methodology

We employed an iterative approach of engaging with our industrial and academic community to better understand PLFs and integrate as many perspectives as possible. In the following paragraphs, we describe the range of consultation techniques that we used. As this was the pilot for Synergy, the methodology provides a comprehensive overview of the topic and engages a wide stakeholder group in the creation of well-defined collaborative opportunities to take forward.

4.1 Process

We combined desk-based research, interviews and workshops as per Diagram 1 below.

The first stage consisted of desk-based research, literature reviews and one-to-one interviews with practitioners from large companies to better define the topic. We invited a small number of representatives from industry to define the scope and aims of this work in a workshop.

In the second stage of the process, we invited 25 people representing academia, industry, NGOs and government agencies to a second workshop. The aim of this was to understand the high-level trends and drivers that could affect this area over the next 25 years. We also identified chemical science-based challenges, which are common across industry sectors and created collaborative opportunities for the chemical sciences to solve them. This workshop comprised individual pre-work, small and large group activities and review and feedback sessions to validate results and opinions among the delegates.

In the final stage of the process, we held a follow-on workshop to validate each of the opportunities and identify research, collaborations and additional support required to deliver them.

4.2 Roadmapping

We used strategic roadmapping, a technique developed by the Institute for Manufacturing's Department of Engineering at the University of Cambridge,[14] throughout the process. The output of this process is a series of roadmaps that define the current situation, what the future state might look like and how we get there in a given timeframe. For complex themes like sustainability, which involve multiple stakeholders, strategic roadmapping creates a common approach to planning activities.

We selected this technique because it is a widely tested approach, encourages collaboration and produces detailed and structured outputs. Strategic roadmapping also engages a wide stakeholder group, generates consensus for next steps and creates visual outputs, which enable easy communication.

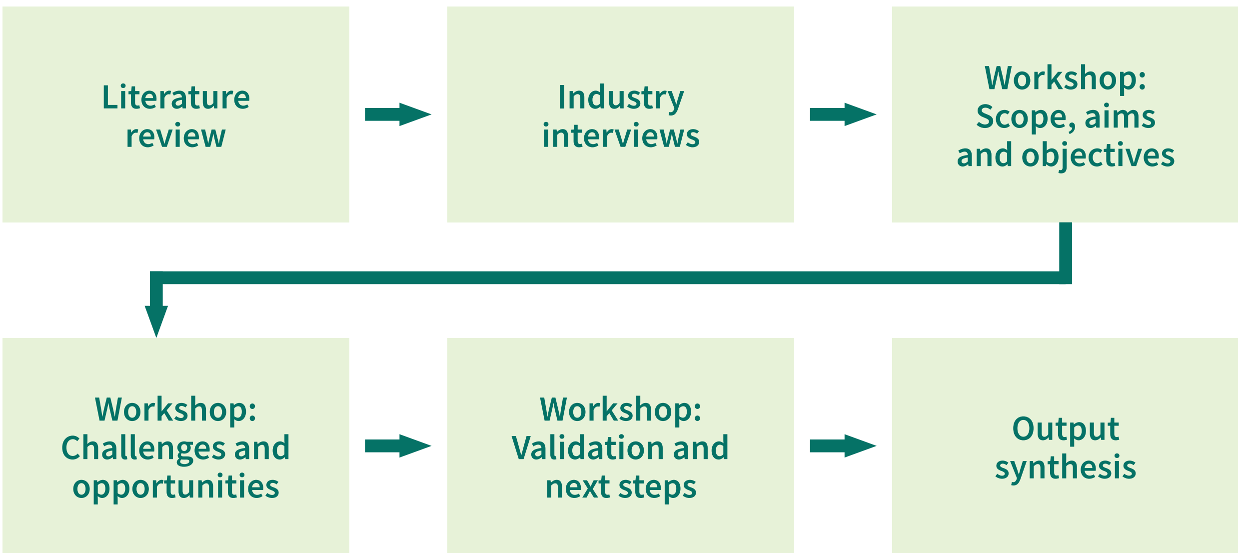

Diagram 1: The process

5 Data analysis and conclusions

We considered the following questions to explore opportunities for the chemical sciences to collaborate on this theme:

1. What are the high-level trends and drivers that may influence polymers in liquid formulations over the next 25 years?
2. What technical challenges could concern industry?
3. What collaborative opportunities are there for the chemical science community to solve these challenges?
4. How could we deliver these opportunities?

The sections below summarise the outcomes of this work.

5.1 Trends and drivers

We used the PESTLE tool to analyse the potential political, economic, social, technological, legal and environmental factors affecting this theme. Participants discussed the effect of funding, skills, the population growth, increasing consumer concern for the environment and the regulatory landscape on the direction of innovation for PLFs over the next 25 years. The following section provides a high-level view of the landscape provided by participants and literature evidence that further validates the points raised.

5.1.1 Political and economic trends

The government is a potential driver of political and economic trends that could affect skills and funding for innovation in this space. Currently, 96% of chemicals manufacturing and pharmaceutical companies in the UK are SMEs.[15] Despite employing 60% of the UK workforce,[16] they often require support for training their employees due to time and cost constraints of running a small company. The UK already invests in several successful schemes that develop skills in academia and industry. Catapults, for example, operate £968 million of open access research and demonstration facilities[17] and EPSRC invested £506 million in Centres for Doctoral Training in 2013.[18] However, changes in government priorities could affect skills support available for SMEs and, therefore, the development of early stage technology for PLFs.

In a similar way, government priorities for funding could also affect innovation in this space. The industrial strategy challenge fund, for example, provides funding for academic and business collaborations to address large scale challenges. However, government prioritises funding for topics like driverless cars and healthy ageing that will raise UK productivity and earning power. Further changes in these priority challenges could affect the amount of funding available for research and development and collaborations.

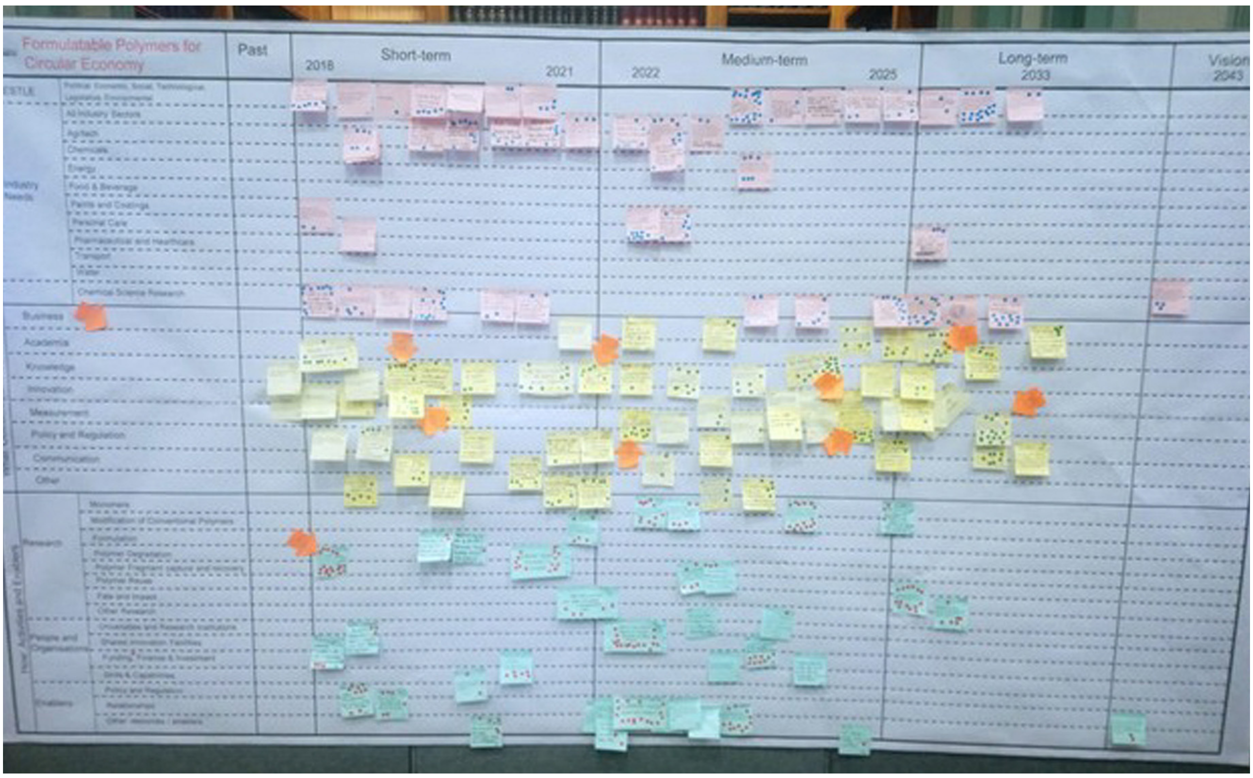

Figure 2: Landscape produced by workshop participants

5.1.2 Societal and environmental trends

Changes in society and the environment are two key factors that could influence PLFs over the next 25 years. In the 20th century, global population grew by 400%,[19] doubling our material footprint[20] and waste generation in recent years.[21] In addition, greater public concern for the environment is driving our need to reduce our consumption of virgin raw materials and maximise the lifetime of materials we use.

Some sectors, such as cosmetics and personal care, are particularly observing the effects of this. Consumers are increasingly scrutinising ingredients in the products they buy and actively seeking products that contain natural and biodegradable materials in favour of seeking potential environmental and health benefits. However, rising temperatures and higher probabilities for extreme weather due to climate change could affect the production of natural and bio-based raw materials. There may be increasing competition with land used for farming and food production, which could influence the quantity of renewable raw materials available. Consumers could have the power to shift markets and influence the direction of innovation in other sectors too.

5.1.3 Regulatory trends

The regulatory landscape is another factor that we investigated. The European Union already has an action plan in place for implementing Circular Economy concepts,[22] but their two objectives; improving the uptake of secondary raw materials and substituting substances of concern may conflict with each other.[23] Little information is currently available on the potential environmental concerns of PLFs, but as our knowledge and understanding improves, clarity over this legislation will be important for the direction of innovation.

In addition, current regulation restricting the use of hazardous materials such as volatile organic compounds (VOCs) could also affect the direction of innovation. A review by the Paints and Coatings Industry brought attention to how businesses are increasing their use of water-based and low-solvent based paints as a result in this regulatory change.[24]

Restricting or banning materials could also increase the risk of introducing alternative materials that have more damaging consequences than those they replace. An example is EU regulation restricting the use of bisphenol A (BPA) in certain food contact materials.[25] Scientists found that an alternative to BPA, bisphenol S (BPS), also had serious health concerns and was more persistent in the environment,[26] which highlights the need for thorough screening of new chemicals before they enter the marketplace. Sudden changes in regulations for materials used in liquid formulations could be a driver for innovation.

5.2 Challenges

Participants also discussed the potential challenges industry and the wider chemical science community could face in advancing our understanding in this theme over the next 25 years. These challenges highlight the gaps in current knowledge and understanding about these polymers and their life cycles, technical challenges that could inhibit the transition to a Circular Economy and finally the downstream economic challenges that this could bring to industry. The following paragraphs describe these challenges in more detail.

5.2.1 Knowledge and understanding

According to the Ellen MacArthur Foundation, transforming materials from a linear to Circular Economy requires changes in production, manufacturing and disposal.[27] PLFs are highly diverse materials with wide ranges of polymer types, uses and applications, which makes understanding their life cycle, global flow and supply chains complex. While organisations have information on materials used in their own sector, to the best of our knowledge there is limited information on these materials as a whole. Without a baseline understanding of the PLFs currently used and information on their potential environmental fate and impact, it may be difficult to prioritise which materials have the greatest opportunity for the Circular Economy.

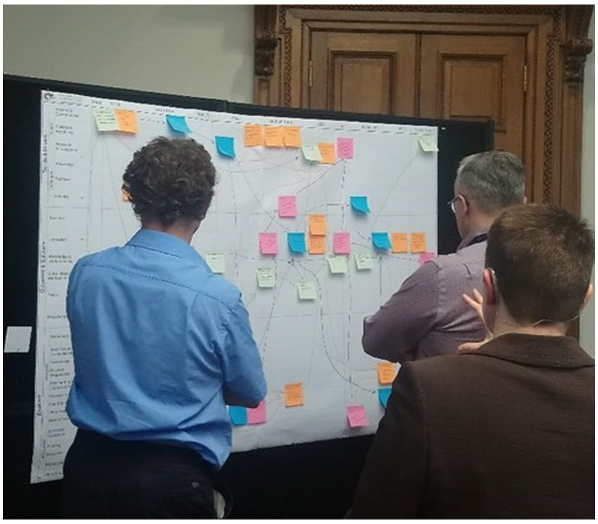

Figure 3: Participants discussing challenges at a workshop

Differences in terms used for sustainability could be another challenge we face. Academia, industry, the government and public use a variety of expressions like *bio-based, biodegradable and environmentally benign* to express similar views, which could inhibit our deeper understanding of the technical challenges and opportunities in this space. WRAP identified that this could also be a problem for plastics and have since produced information on the different definitions,[28] which goes some way to bridging this gap. However, participants recognised the importance of addressing gaps in knowledge and understanding early on in this work.

5.2.2 Technical feasibility

In addition to gaps in knowledge and understanding, there could be several technical feasibility challenges that could affect transitioning PLFs to a Circular Economy. Firstly, using renewable raw materials to reduce our consumption of fossil-derived materials could increase the likelihood of introducing contaminants and impurities into final formulations. Natural and bio-based materials may not be as durable as synthetic materials and could degrade throughout their lifetime. In addition, producing raw materials from natural and bio-based materials is a less controlled process than for synthetic materials. Not only could this affect product quality, but it could also create problems for product repeatability. To overcome these risks, the supply chain may need to introduce additional processes to refine these materials, adding costs to production.

Secondly, recovering polymers from waste and reformulating them to reduce our reliance on virgin raw materials may also be technically challenging. As previously discussed, PLFs are highly diverse which could mean that each polymer type would need to be collected, separated and reformulated separately. Polymers are also not the only ingredient in a final liquid formulation; industry blends them with other materials to create the final product. The supply chain will need to implement processes and technology to separate them from these materials at the end of their life to recover and reuse them.

PLFs also have different entry points in the waste stream at the end of their life, eg marine environmental, landfill and wastewater treatment facilities. These materials may degrade throughout their lifetime and therefore be a mixture of different degradation products. Recovering them would not only require coordination between many different stakeholders and infrastructure to collect them, but also technology to extract them from dilute solutions and sort them into different polymer types.

Finally, making these into useful secondary products for industry would require further processes to reformulate them at scale. Current recycling schemes are limited to easily recoverable materials such as plastic, paper and glass, and economically viable processes to reuse them. For PLFs, this would require significant advances in technology, changes to infrastructure and significant opportunities to reuse them in industry.

5.2.3 Industrial systems and supply chains

Modifying or replacing conventional polymers with materials that are suitable for the Circular Economy could be risky for manufacturing and end user industries. Potential costs, available volumes and effects on performance could influence the uptake of sustainable polymers over conventional materials. Previously discussed, the risks associated with natural or bio-based raw materials on final formulated products could create additional costs for end users. In addition, there could be additional risks associated with sourcing, refining and processing renewable raw materials, especially as production relies on seasonal dependencies, climate stability and available land. Participants also highlighted the potential versatility and performance limitations of renewable raw materials compared with fossil-derived materials.

Furthermore, changes in legislation and regulation could affect industry. For example, developing and approving new materials and adapting or installing new infrastructure to improve Circular Economy acceptance will be time consuming for industry. Without a secure supply chain to reduce these potential risks, participants recognised that these processes might not be competitive with existing ones.

5.3 Opportunities

The main intent of this work is to identify a range of possible opportunities for the chemical science community to collaborate and solve key challenges. Early in this process, the opportunities were broad and included knowledge and understanding activities, research and development, development of new technologies, methods and processes, communication and regulation and legislation. Throughout the process, we refined these opportunities to focus on technical challenges.

Participants selected eight opportunities to explore further, based on their relevance to multiple industry sectors, the opportunity for the chemical-sciences and feasibility to deliver solutions through collaboration:

1. The modification of existing materials for the Circular Economy
2. New materials for the Circular Economy
3. Open access life cycle analysis tools
4. Multidisciplinary capability building
5. New standard methods for environmental fate
6. Understanding chemical degradation and mixed products
7. The scale up of processes for sustainable high-purity raw material production
8. Polymer separation and reuse

Participants defined the scope and deliverables of these opportunities in small groups, which resulted in four clustered opportunities that had similar or linked deliverables to ensure further work is comprehensive. We outline these opportunities in the following section.

5.3.1 Modification and development of new monomers and polymers

Consumers are increasingly seeking products that are less harmful for the environment. Modifying existing and synthesising new monomers and polymers could be a route to competitive products that comply with Circular Economy principles. Multidisciplinary research and development for polymer synthesis, characterisation and formulation could develop generic processes for designing, modifying and developing functional polymers for wide a variety of applications.

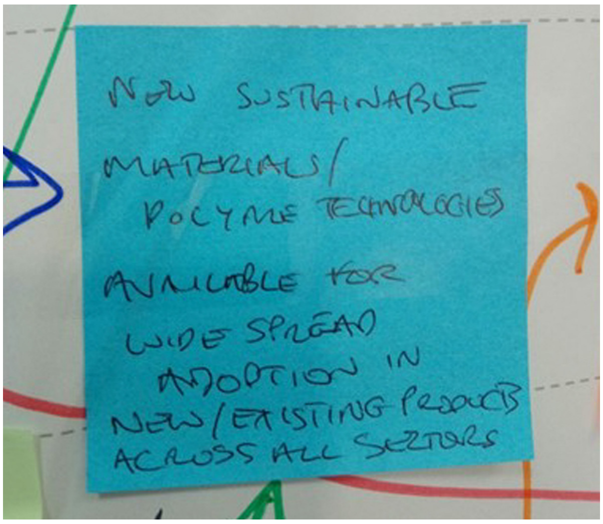

Figure 4: Sticky note capturing idea

5.3.2 Life cycle analysis models and methods to design sustainable materials

Developing materials that can naturally degrade and become less harmful for the environment could be a significant consumer driver for developing new polymers. Creating open access tools can accelerate and improve our understanding of chemical degradation in different scenarios. Developing models of degradation pathways, identifying degradation products and assessing their environmental fate would enable industry to assess the potential of inducing degradation by design for different PLFs.

5.3.3 Manufacturing scale up of high-purity sustainable monomers

Consumers are increasingly demanding natural ingredients and products. Scaling up high-purity sustainable monomers would produce natural feedstocks at high volume, reducing the risk for industry to take up these materials. Developing generic scale up processes for continuous manufacturing could produce a portfolio of commercially available monomers at multi-tonne scale, enabling industry to diversify their raw material sources.

5.3.4 Recovery and reuse of polymers

Recovering and reusing polymers from waste streams could be a potential way of maximising the value of durable polymers that cannot degrade. Developing separation and recycling techniques and identifying outputs for recycling products in industry, could potentially expand current recycling capabilities. Scale up processes that deliver useful ingredients to industry at scale could create an attractive opportunity for industry to use secondary products.

5.4 Enablers

As well as identifying collaborative opportunities, participants explored the key enablers and barriers for progressing them. Innovation across the entire value chain is a key concept within the Circular Economy. Strengthening relationships and initiating collaborations between raw material processors, manufacturers, end users and recyclers, and wastewater treatment facilities could be critical for polymers. In addition, extending this to academia, regulators, NGOs and the government would create high-level changes in the system that are much needed. Aspects such as regulation to support the implementation of new materials, policy for recycling and communication to inform public awareness, are all aspects that are key to enabling the delivery of technical solutions.

The following paragraphs outline the fundamental and applied research, multidisciplinary skills base and collaborative funding that we need to develop over the next 25 years.

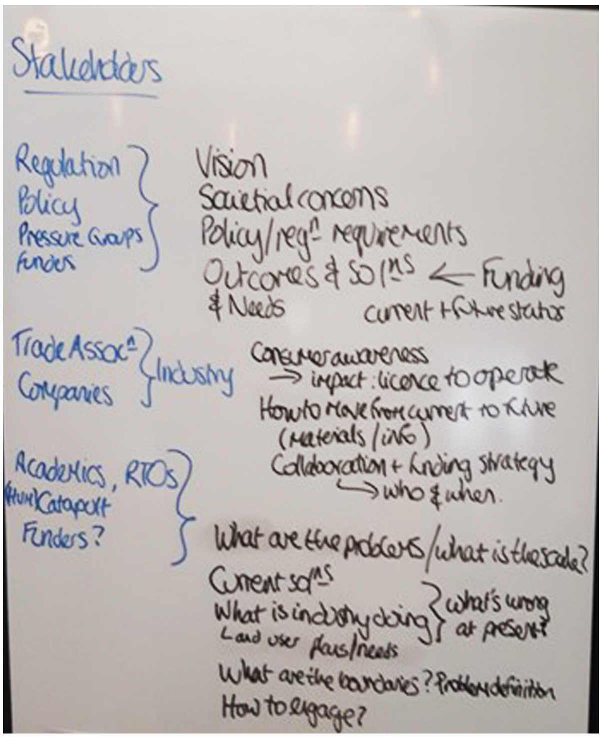

Figure 5: List of stakeholders

5.4.1 Research and development

A key theme for chemical science research and development needed for developing sustainable novel polymers is backbone chemistry, which is important for functionality. Investigating ways of developing these backbones from natural or bio-based monomers, like peptides, could create a range of renewable-derived polymers suitable for diverse applications. In addition, polymer backbones could also be key for designing polymers that degrade in different environmental conditions. Exploring ways to control degradability could enable the creation of polymers that are stable in formulations in use, but degrade at the end of their life. Literature highlights examples of degradable linkages for polymers in controlled drug release,[29] which could be a good starting point for this research.

Another key research theme that is important to investigate for inducing degradation of polymers is blending them with catalysts. Research on this topic already exists for waste plastics; one example is the application of catalysts to degrade polyethylene used in agricultural waste and household food packaging into hydrocarbons for gasoline.[30]

Another research theme is exploring the potential of capturing polymers from organic and inorganic waste to improve recycling opportunities. One area of potential exploration could be capturing and recovering polymers from wastewater using existing water treatment solutions that capture specific chemicals.

5.4.2 Skills base and funding

Another key enabler is maintaining and expanding the skills set for progressing these opportunities. We require a whole system understanding of technologies, applications and the social needs in order to tackle this challenge. Comprehensive knowledge and understanding is particularly important for limiting negative consequences in other parts of the system. Specific skills that the UK needs to maintain and enhance includes formulation science, polymer chemistry and engineering. Supporting training and skills development in SMEs and leveraging existing schemes discussed in the trends section are particularly important.

In addition to skills, funding at all levels is important for stimulating fundamental and applied research, commercialisation of new technology, process and technology scale up, and the development of open access capability building tools. Developing strong networks and relationships for knowledge sharing is also important. The UK Circular Plastics Network[31] is one example of how the government is raising awareness, encouraging the sharing of best practice and highlighting emerging innovation to address the plastics challenge. Without a range of funding mechanisms available, the community could lose momentum.

6 Conclusions

In this report, we discuss the initial work we carried out through Synergy on CEPLFs. The community highlighted four opportunities for the chemical sciences to collaborate over the next 25 years:

1) The modification and development of new monomers and polymers
2) Life cycle analysis and models and methods to design sustainable materials
3) Manufacturing scale up of high-purity sustainable monomers
4) The recovery and reuse of polymers

We identified a sizeable opportunity to advance the chemical sciences through collaboration. Currently our knowledge of PLFs as a whole is limited but understanding the diversity of the different types and uses of polymers across different sectors and their life cycles could create significant multidisciplinary research opportunities. These could potentially include natural feedstocks, degradation by design and recycling processes.

Advancements in research and development and technology can also create a significant opportunity to accelerate innovation in industry. Novel polymers, diverse feedstocks and opportunities to reuse waste can provide competitive advantages for businesses. Implementing these solutions will also have a wider positive impact on society and the environment as we reduce our reliance on fossil-derived resources, reduce waste and limit negative influences on the environment.

6.1 Next steps

Progressing any of the opportunities that we identified requires wide collaboration and significant long-term effort from academia, industry and the government. Building relationships and initiating collaboration at this scale does not take place spontaneously. As discussed at the beginning of the report, multidisciplinary and multi-stakeholder collaboration requires facilitation to manage the different perspectives, opinions and people, and coordination to create action. The Royal Society of Chemistry is an independent organisation that can facilitate and coordinate this type of collaboration to advance the four opportunities identified and transition PLFs towards a Circular Economy.

So far, we have brought together a small multidisciplinary and cross-sector group to identify early stage opportunities for collaboration. In the next phase of the programme, we need to engage a wider stakeholder group to gain a baseline understanding of the materials currently used.

This will be important for making the case for a collaborative effort on this topic and creating a mechanism to initiate collaborations. We also need to build knowledge and capability in the chemical science community to address current gaps in knowledge and understanding of PLFs so that we can prioritise materials to focus on. Finally, we need to build an expert network of academics and businesses to influence the wider ecosystem to support innovation in the long term.

6.2 Recommendations for 2019

To summarise, recommendations made by participants for supporting the chemical science community to progress this topic are:

1. To gain a baseline understanding of the materials currently used by engaging with a wider industry group
2. To build on the technical knowledge that we already have and address gaps by creating a community of experts to build knowledge in the topic area
3. To create mechanisms that stimulate collaboration in academia, industry and the wider ecosystem

We are now seeking input from businesses that are interested in this topic for the next stages of the programme. If you are nterested in being involved, please contact:

Jenny Lovell

Synergy Programme Manager,
Royal Society of Chemistry

Email: synergy@rsc.org

7 References

1 Chemistry Growth Partnership (2013). *Strategy for delivering chemistry-fuelled growth of the UK economy*. [pdf] p.3. Available at: http://ukchemistrygrowth.com/Portals/3/Downloads/Growth%20Strategy_Oct13_FINAL.pdf [Accessed 3 Dec. 2018]

2 Swedish Research Council (2018). *JPIAMR Official Website*. [online] Available at: https://www.jpiamr.eu/ [Accessed 3 Dec. 2018]

3 Royal Society of Chemistry (2015). *Future of the Chemical Sciences*. [pdf] p.8. Available at: https://www.rsc.org/globalassets/04-campaigning-outreach/campaigning/future-chemical-sciences/future-of-the-chemical-science-report-royal-society-of-chemistry.pdf [Accessed 3 Dec. 2018]

4 United Nations (2018). *Sustainable Development Goals*. [online] Available at: https://sustainabledevelopment.un.org [Accessed 3 Dec. 2018]

5 Consultancy UK (2018). *Consultancy UK Official Website*. [online] Available at: https://www.consultancy.uk/news/16521/just-40-of-global-companies-reporting-on-un-sustainable-development-goals [Accessed 3 Dec. 2018]

6 Ellen MacArthur Foundation (2017). *Ellen MacArthur Foundation Official Website*. [online] Available at: https://www.ellenmacarthurfoundation.org/circular-economy/concept [Accessed 3 Dec. 2018]

7 Systemiq, SUN Institute and Ellen MacArthur Foundation (2017), *Achieving 'Growth Within'*. [pdf] p.4. Available at: https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Achieving-Growth-Within-20-01-17.pdf [Accessed 3 Dec. 2018]

8 European Commission (2018). *European Commission Official Website*. [online] Available at: https://ec.europa.eu/info/strategy/priorities-2019-2024 [Accessed 3 Dec. 2018]

9 Ellen MacArthur Foundation (2017). *New Plastics Economy Official Website*. [online] Available at: https://newplasticseconomy.org/ [Accessed 3 Dec. 2018]

10 GOV.UK (2018). *UK Government Official Website*. [online] Available at: https://www.gov.uk/government/news/reducing-plastic-waste-in-the-environment-apply-for-funding [Accessed 3 Dec. 2018]

11 Knowledge Transfer Network (2018). *UK formulated products sector strategic priorities 2018*. [pdf] p.3. Available at: https://admin.ktn-uk.co.uk/app/uploads/2018/07/Formulated-Products-Sector-Strategic-Priorities-2018-Final.pdf [Accessed 3 Dec. 2018]

12 UNEP (2015). *Plastics in Cosmetics*. [pdf] p.1. Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/9664/-Plastic_in_cosmetics_Are_we_polluting_the_environment_through_our_personal_care_-2015Plas.pdf [Accessed 3 Dec. 2018]

13 HM Government (2018). *A Green Future: Our 25 year plan to improve the environment*. [pdf] p.4. Available at: https://www.gov.uk/government/publications/25-year-environment-plan [Accessed 3 Dec. 2018]

14 University of Cambridge (2018). *Institute for Manufacturing Official Website*. [online] Available at: https://www.ifm.eng.cam.ac.uk/ifmecs/business-tools/roadmapping/roadmapping-at-ifm/ [Accessed 3 Dec. 2018]

15 Chemicals Sector Report. *A report for the House of Commons re exiting the EU*, https://www.parliament.uk/globalassets/documents/commons-committees/Exiting-the-European-Union/17-19/Sectoral-Analyses/7-Sectoral-Analyses-Chemicals-Report.pdf

16 Federation of Small Businesses (2018). *Federation of Small Businesses Official Website*. [online] Available at: https://www.fsb.org.uk/media-centre/small-business-statistics [Accessed 3 Dec. 2018]

17 Catapult Centres (2018). Catapult Official Website. [online] Available at: https://catapult.org.uk [Accessed 3 Dec. 2018]

18 EPSRC (2016). *EPSRC Official Website*. [online] Available at:https://epsrc.ukri.org/skills/students/centres/monitoringevaluation201617/ [Accessed 3 Dec. 2018]

19 Roser, M (2018), *Future population growth*. [online] Available at: https://ourworldindata.org/future-population-growth [Accessed 3 Dec. 2018]

20 United Nations (2018). *Sustainable Development Goal 12*. [online] Available at: (https://sustainabledevelopment.un.org/sdg12 [Accessed 3 Dec. 2018]

21 The World Bank (2012). *What a waste. A global review of solid waste management*. [pdf] p.8. Available at: https://openknowledge.worldbank.org/handle/10986/17388 [Accessed 3 Dec. 2018]

22 European Commission (2018). European Commission Official Website. [online] Available at: http://ec.europa.eu/environment/circular-economy/index_en.htm [Accessed 3 Dec. 2018]

23 European Commission (2018). European Commission Official Website. [online] Available at: https://ec.europa.eu/docsroom/documents/27321 [Accessed 3 Dec. 2018]

24 Ruckle, B, Wilkowski, S and Wilson, D (2015). *Regulation-driven innovation*. [online] Available at: https://www.pcimag.com/articles/101171-regulation-driven-innovation [Accessed 1 Dec. 2018] 25 European Commission (2018). Use of bisphenol A. [online] Official Journal of the European Union. Available at: http://data.europa.eu/eli/reg/2018/213/oj [Accessed 1 Dec. 2013]

25 European Commission (2018). *Use of bisphenol A*. [online] Official Journal of the European Union. Available at: http://data.europa.eu/eli/reg/2018/213/oj [Accessed 1 Dec. 2013]

26 Trasande,L (2017). *Exploring regrettable substitution: replacements for bisphenol A.* [pdf] *The Lancet Planetary Health, p.88. Available* at: https://www.thelancet.com/pdfs/journals/lanplh/PIIS2542-5196(17)30046-3.pdf [Accessed 1 Dec. 2018]

27 Ellen MacArthur Foundation (2018). *Lesson 2 Exploring the circular economy.* [pdf] Available at: https://www.ellenmacarthurfoundation.org/assets/downloads/Schools-Colleges-WLL-Lesson-Plan-2-F.pdf [Accessed 1 Dec. 2018]

28 WRAP (2018). *Understanding plastic packaging and the language we use to describe it*. [pdf] Available at: http://www.wrap.org.uk/sites/files/wrap/Understanding%20plastic%20packaging%20FINAL.pdf [Accessed 1 Dec. 2018]

29 Siegel, R and Rathbone, R (2012). Fundamentals and applications of controlled release drug delivery. [pdf] Springer Chap. 2. Available at: https://pdfs.semanticscholar.org/b7cb/79e0aa5449ebdb77d6074736e41e434d4812.pdf [Accessed 1 Dec. 2018]

30 Ratnasari, D, Nahil, M and Williams, P (2017). *Catalytic pyrolysis of waste plastics using staged catalysis for production of gasoline range hydrocarbon oils.* [online] Elsevier: Journal of Analytical and Applied Pyrolysis. Available at: https://www.sciencedirect.com/science/article/pii/S0165237016306015 [Accessed 1 Dec. 2018]

31 Knowledge Transfer Network (2018). *Knowledge Transfer Network Official Website.* [online] Available at: https://ktn-uk.co.uk/news/ktn-presents-the-uk-circular-plastics-network [Accessed 1 Dec. 2018]

ROYAL SOCIETY
OF **CHEMISTRY**

Thomas Graham House
Science Park, Milton Road
Cambridge CB4 0WF, UK
T +44 (0)1223 420066

Burlington House
Piccadilly, London
W1J 0BA, UK
T +44 (0)20 7437 8656

International offices
Beijing, China
Shanghai, China
Berlin, Germany
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