ROYAL SOCIETY OF CHEMISTRY

SUSTAINABILITY

Polymers in liquid formulations

Opportunities for a sustainable future

Acknowledgements

We would like to acknowledge the contributions made by the Royal Society of Chemistry project team. In particular, Jenny Lovell for establishing the Synergy programme and leading the project with support from Aurora Antemir, Richard Holliday, Lampros Litos and Andrew Waterworth. We also acknowledge the significant efforts made by Neil Clark, Julian Roberts, Claire Southgate, Karen Stroobants and Kathy Page. We are grateful to Lynsey Thorpe for her help in shaping this report and to Chris Gooch for the design work.

In addition, we thank the support of the Royal Society of Chemistry leadership team, in particular Jo Reynolds and Helen Pain.

We would also like to thank all external contributors to the technical report *Polymers in liquid formulations: A landscape view of the global PLFs market*, upon which this summary report was based.

Introducing our new perspectives series

In a world where global challenges and advances in technology bring both uncertainty and new possibilities, the chemical sciences have a critical role to play. But what will that role be? How can we maximise the impact we make across academia, industry, government and education? And what actions should we take to create a stronger, more vibrant culture for research that helps enable new discoveries?

Our perspectives series addresses these questions through four lenses: talent, discovery, sustainability and research culture. Drawing together insights and sharp opinion, our goal is to increase understanding and inform debate – putting the chemical sciences at the heart of the big issues the world is facing.

Sustainability

Our planet faces critical challenges – from plastics polluting the oceans, to the urgent need to find more sustainable resources. But where will new solutions come from? How can we achieve global collaboration to address the big issues? And where can the chemical sciences deliver the biggest impacts?

Talent

Talent is the lifeblood of the chemical sciences. But how do we inspire, nurture, promote and protect it? Where will we find the chemical scientists of the future? And what action is required to ensure we give everyone the greatest opportunity to make a positive difference?

Discovery

Chemistry is core to advances across every facet of human life. But where do the greatest opportunities lie? How will technology and the digital era shape the science we create? And what steps should we take to ensure that curiosity-driven research continues to unlock new opportunities in unexpected ways?

Research Culture

Globally, scientific research in academia and industry fuels both progress and innovation. But how do we create more inclusive, diverse and vibrant environments for research, that lead to better, more open science? And how should we recognise the breadth and diversity of the people, contributions and achievements that enable new discoveries?

Find out more at **www.rsc.org/new-perspectives**

Foreword

Solving every global challenge needs a starting point, and I believe this report should mark a new paradigm in global sustainability efforts.

Very few outside of the chemical industries will have heard of Polymers in Liquid Formulations – or PLFs – but almost everyone in the world interacts with them daily.

Found in millions of consumer and industrial products, they truly are an intrinsic part of our everyday lives – from the paints on our walls to the shampoo and detergents in our cupboards. In fact, 36 million tonnes of these materials – enough to fill Wembley Stadium 32 times over– are made and sold for $125bn each year.

Despite their importance, the way that PLFs are made, used and disposed of is putting unnecessary strain on the environment by releasing carbon dioxide into our atmosphere, using up the earth's finite resources and generating physical waste. These issues create risks for all parts of the value chain, from monomer producers to product formulators and waste management companies.

It's hard to say why PLFs haven't had enough attention over the years – perhaps it is because they are ingredients rather than products, which come with a host of technical challenges. Regardless, the fact that these issues are not widely known outside of the industry has left researchers and businesses only able to tackle part of the problem.

In the past year, our sustainability campaigns have successfully highlighted the threat to the supply of a number of elements we use in our technology every day, as well as exploring the complexities, opportunities and threats presented by plastics. Like those initiatives, finding innovative solutions to tackling problems created by PLFs will rest on collaboration between academia, industry, government and the wider public. That's why this report identifies common issues across eight key markets which only the chemical sciences can address – collaboratively.

To this end, we have launched a PLFs task force with a number of companies who produce some of the many products that rely on these materials, dedicated to outlining the next steps forward. But these are just first steps – solutions will only come through concerted action, with support from academia, industry and civil society.

Together, we must develop innovative new technologies and apply circular economy principles to collect PLFs, reuse them as new products and raw materials, and offer further bio-based and biodegradable alternatives. Together, we have a fantastic opportunity to make real and lasting change.

Professor Tom Welton OBE CChem FRSC, President, Royal Society of Chemistry

Introduction

Polymers in liquid formulations (PLFs) are found in millions of household and industrial products. They play a vital role in our society by improving food productivity, treating wastewater, protecting buildings, infrastructure and transport, as well as creating consumer products that promote health and wellbeing.

It is a sector that few people have heard of, and yet PLFs are a high value and critically important class of speciality chemicals worth **$125.2 billion** to the global economy annually.*

What are PLFs?

A polymer is a general term for large molecules consisting of repeating units (monomers).

A Polymer in Liquid Formulation (PLF) is a broad group of polymers that are used in a formulation that is liquid in manufacture or point of application.

PLFs are typically used as thickeners, emulsifiers and binders and have wide applications; from ingredients in household cleaning and personal care products to industrial applications including agriculture, automotive, construction, lubricants and wastewater treatment. Despite their importance to society and the global economy, and in contrast to the intense recent focus on the sustainability of plastics, there has been very little coordinated effort to highlight the sustainability of PLFs.

*$125.2 billion in 2019 (see page 4 of *Polymers in liquid formulations: A landscape view of the global PLFs market*)

What do we address in this report?

More than **36.3 million metric tonnes** of PLFs are made and used every year, enough to fill over 14,500 olympic sized swimming pools or Wembley Stadium 32 times. Currently, the most likely destination at the end of their life is waste, which means that the value of PLFs are lost after use.

To ensure that the PLF sector is economically and environmentally sustainable in the future, new approaches to PLF production, use and end-of-life treatment are needed. It is a challenge that is bigger than any single organisation, market or academic research group.

This report is an important first step in addressing the challenges of sustainability and the opportunities to maximise the economic value of PLFs and reduce their impact on the environment.

For a deeper dive into the PLF landscape, sustainability issues and recommendations for change, please download the technical report *A landscape view of the global PLFs market*.

Who should read this report?

Tackling the challenges around PLF sustainability will take collective effort. This summary report is a rallying call to all those who have the power to influence and effect change. Primarily:

- **Industry** – producers and manufacturers of polymers; those who create polymer-using products; and those who are developing emerging technologies and solutions
- **Academia** – researchers who are working on fundamental and applied research in this area
- **Governments and policymakers** – those responsible for policies and regulation that support and enable researchers and businesses to tackle the problem
- **Funding bodies** – whose interests are in funding current and future research and collaborative projects, backed by industry, to develop sustainable solutions for PLFs
- **Waste management organisations** – that collect, recycle and dispose of PLF products

Case studies in this report

This report contains several case studies to showcase existing technologies that are being developed to provide solutions to specific sustainability challenges of PLFs. Each case study includes its technology readiness level (TRL), indicating its current level of maturity (Figure 1).

Figure 1. Technology Readiness Levels

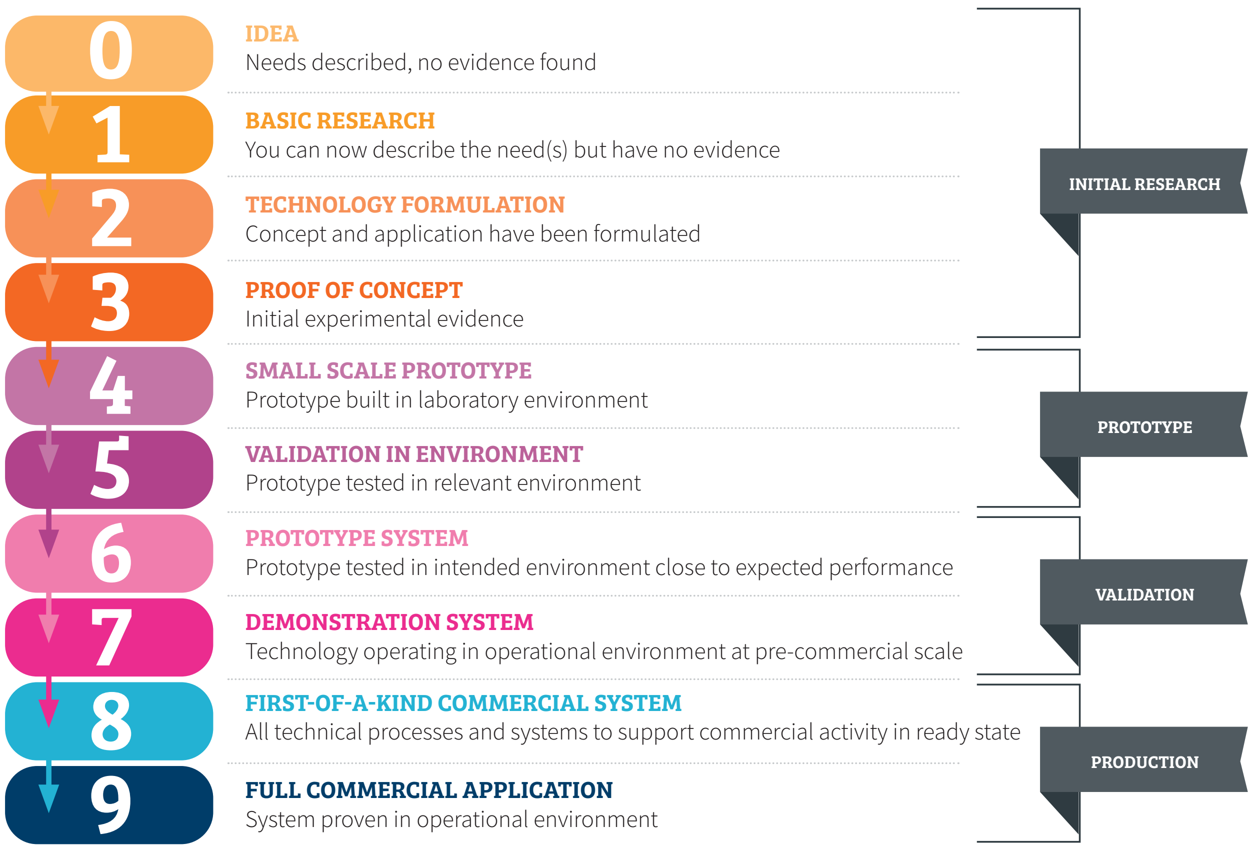


Figure adapted from the CloudWATCH2 project[1]

Our action plan

Chemistry plays a fundamental role in developing sustainable solutions. That is why the Royal Society of Chemistry has identified **five key opportunities** to galvanise industry, academia, policymakers and funders into action.

In 2021 we will establish a PLF task force that will convene key industry partners to prioritise and progress these opportunities.

1. **Establish** new innovation networks that promote collaboration between industry, academia, and policymakers
2. **Identify** and champion key research themes and priorities that will support businesses and researchers to tackle PLF innovation challenges
3. **Explore** the emerging need for a consistent approach to PLF biodegradability and stability testing
4. **Investigate** opportunities for chemistry-based innovations in developing circular economy solutions in key markets such as paints, adhesives and sealants
5. **Engage** with key stakeholders to ensure that a science- and evidence-based approach is used to develop future policy for PLFs

This piece of work is part of Synergy, the Royal Society of Chemistry's collaborative programme bringing together businesses working in different industries to tackle complex chemistry topics.

If you would like to work with us to help develop these opportunities, please contact Jenny Lovell, Programme Manager, at **synergy@rsc.org**.

Glossary and key principles

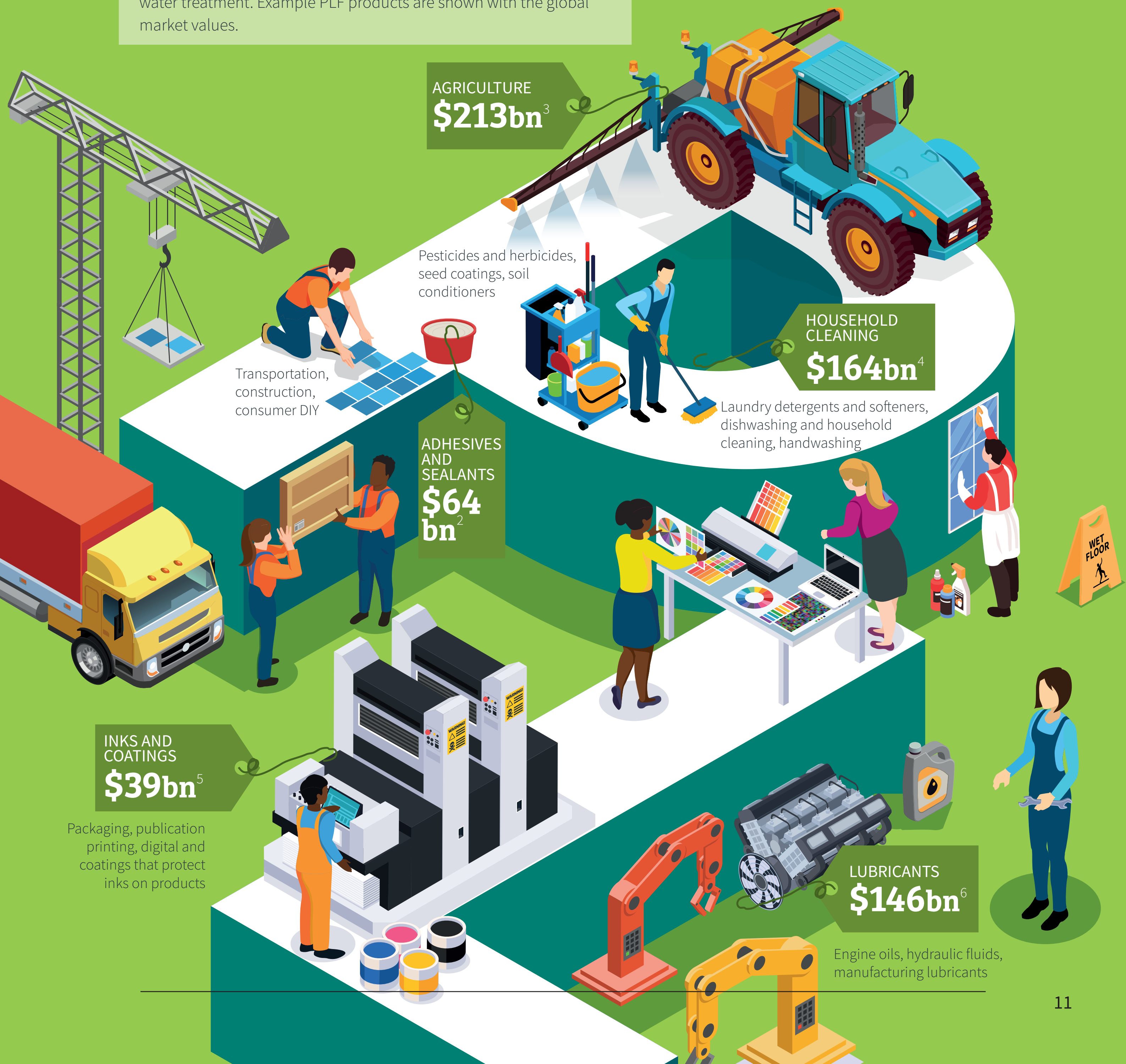
Bio-based polymer	A polymer that is produced from biological resources, including chemicals derived from plants and algae. For example, polylactide is produced from sugar, which is harvested from plants like sugar cane
Biodegradable polymer	A polymer that undergoes accelerated degradation by organisms and biomolecules such as enzymes, forming small molecules that are metabolised by natural organisms. Biodegradable polymers should break down to natural materials that can be returned to the environment without pollution or damaging effects
Carbon capture and utilisation (CCU)	A process that captures carbon dioxide emissions from sources like coal-fired power plants and reuses it so it will not enter the atmosphere
Formulation stability	A key aspect of formulation that defines the period of time over which a customer may expect the product to deliver consistent, optimised and safe performance. It sets a specification for shelf life
Feedstock	A material that is used to produce something in an industrial process
Life cycle assessment (LCA)	A method used to evaluate the environmental impact of a product through its life cycle, encompassing raw material extraction and processing, manufacturing and distribution, use, recycling and final disposal
Microplastic	Very small pieces of plastic that result from degradation of plastic in the environment or directly from certain products. Microplastics are plastic fragments of a size between one micrometre and five millimetres
Molecular weight	The mass of one mole of a substance and an important characteristic that can determine a polymer's thermo-physical and mechanical properties
Monomer	A type of small molecule that makes a larger chain of polymers
Natural/biopolymer	A naturally occurring polymer, such as cellulose or starch
Plastic	Plastics are primarily comprised of polymers, along with various additives (such as stabilisers, flame retardants, and plasticisers) that affect the physical properties of the material
Polymer	Polymers are long-chain molecules built from smaller repeating units called monomers. Some polymers contain only one type of monomer as its building block; others, known as copolymers, may contain two or more different types of monomer
Sustainability	Meeting our own needs without compromising the ability of future generations to meet their own needs. Natural, social and economic resources are the three factors that influence sustainability
Synthetic	A material made by chemical synthesis from fossil-derived feedstocks
Technology Readiness Level (TRL)	A method for estimating the maturity of technologies, from an idea to a commercial product

PLFs: a situation analysis

Market overview

Polymers in liquid formulations (PLFs) are a high value, critically important class of speciality chemicals worth $125.2 billion to the global economy. A significant proportion of the global volume of PLFs sold each year – over 31 million metric tonnes – are sold into paints and coatings, inks and coatings, and adhesives and sealants markets.

PLFs are used in eight key markets, which have a combined estimated global value of **$1.27 trillion**. These are: adhesives and sealants, agriculture, household cleaning, inks and coatings, lubricants, paints and coatings, personal care and cosmetics, and water treatment. Example PLF products are shown with the global market values.



The PLF market is technically diverse and complex, comprising hundreds of different polymer types within the categories of acrylic, epoxy resins, polyesters, polysilicones, polyurethanes, radiation curable, vinyl, water-soluble and other low volume polymers.

As the global population grows, demand for PLFs will increase, contributing to rises in material production and waste generation, which are already expected to double by 2050.[10]

Without PLFs, key industries like construction, utilities, automotive and aerospace would face enormous challenges in operating the way they do today. In order to ensure that the PLF sector is economically and environmentally sustainable in the future, new approaches to PLF production, use and end-of-life treatment are needed.

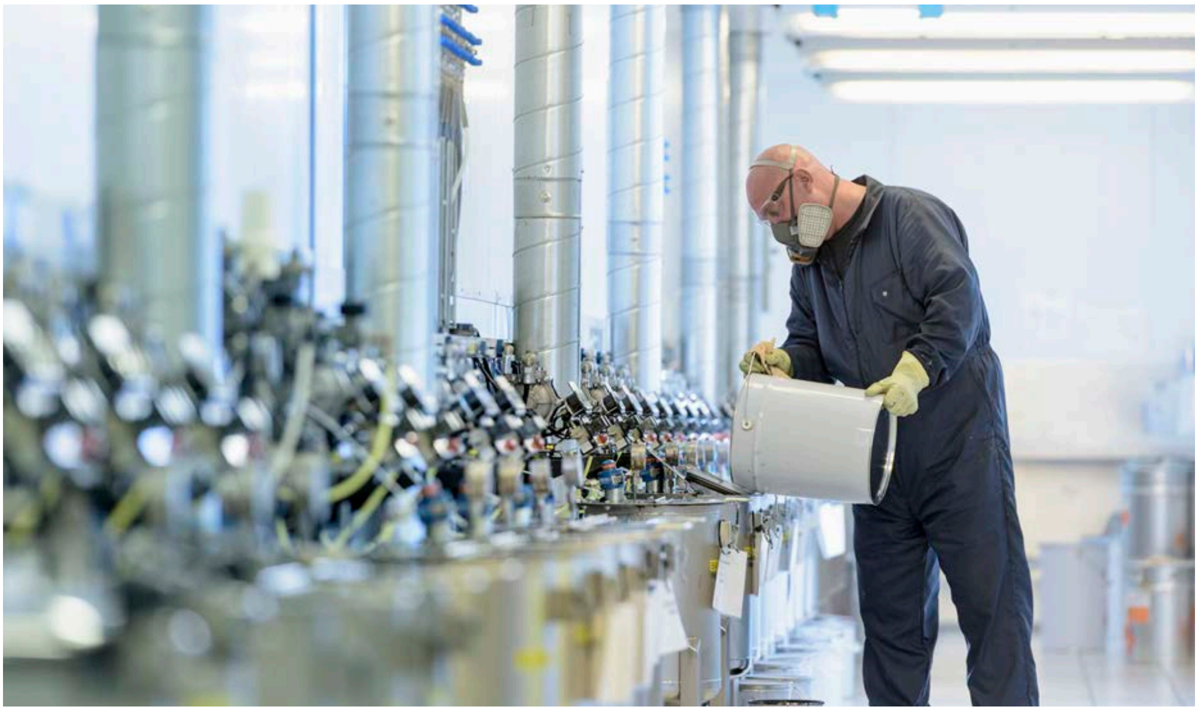
In our investigation, we identified more than 200 different PLFs across the eight market segments displayed above.

The technical report Polymers in liquid formulations: A landscape view of the global PLFs market provides an overview of the PLF landscape and offers a qualitative assessment of PLF sustainability in each market by considering their production, use and fate.

Types and production of PLFs

Manufacturers produce PLFs from a variety of raw materials including natural, bio-based and fossil-derived monomers. Synthetic PLFs are the most commercially significant because of their availability at high volumes, their competitive cost and the highly specialised properties that they deliver. However, in some markets, natural and bio-based materials are growing in use.

PLFs are used in formulations that are either liquid, which remain liquid on application and throughout use, or curable, which form solids on application and remain solid in use. These formulation systems can explain key differences in the use and fate of PLFs across different markets.



	Key markets	Use timeframe	Environmental fate
Liquid formulation	Personal care and cosmetics, household cleaning, agrochemicals, lubricants and water treatment markets	In use for short–medium timeframes generally	Likely to enter the environment as they pass through wastewater treatment plants at the end of their life
Curable formulation	Adhesives, sealants, paints, inks and coatings which protect, join and seal other materials	Form solids on application and provide durability over much longer timeframes than other markets	Chemical and mechanical resistance means that they may remain on substrate (base) materials and enter waste streams at the end of their life or enter the environment during use

Sustainability of PLFs

Society widely accepts that the take-make-dispose model of product creation is unsustainable, both in terms of resource consumption and waste production. There are three significant sustainability issues facing the world: **our reliance on fossil-derived raw materials for producing products, waste generation and pollution in the environment**. A global total of 36.3 milllion tonnes of PLFs are made and used each year, with a significant amount ultimately disposed of. PLFs currently have a linear take-make-dispose model (Figure 2), which means that they are contributing to these global sustainability issues.

Figure 2. Linear economy

Figure 3. The waste hierarchy

The United Nations established the Sustainable Development Goals (UNSDGs) as a blueprint to achieve a more sustainable future and address global challenges like these. Countries are also adopting a range of approaches, practices and concepts to move towards more sustainable practices. The waste hierarchy (Figure 3), for example, ranks waste management options according to risk to the environment.[11] Ultimately PLFs are disposed of at the end of their life, which is the least favourable outcome for the environment.

This investigation identified **eight key sustainability risks** that affect PLFs:

1. **PLF markets currently rely on synthetic PLFs for their products**. However, as demand increases for fossil-derived feedstocks, price increases, competition with other industries and increasing environmental strain creates supply risks for the PLF industry.

2. **Natural and bio-based PLFs may not always be ethically or sustainably sourced** and increased demand for these products may lead to unsustainable practices, which could include deforestation and competition for land used for food sources.

3. PLFs in liquid formulation systems entering water treatment plants at the end of their life will be diluted with a wide range of other compounds in household and industrial wastewater streams. **Biological treatment processes are unlikely to remove PLFs and therefore have a high probability of entering agricultural land as treated sludge**.

4. PLFs in liquid formulation systems, especially water-soluble polymers and any breakdown products, will be **highly mobile in soil and water, resulting in widespread environmental fates**.

5. PLFs in curable formulation systems may **produce unintentional microplastics during use** from paint flaking and partial degradation of seed coatings and active ingredient delivery mechanisms. Uncontrolled release of these materials into the environment may be contributing to wider problems with microplastic pollution in marine and land environments.

6. PLFs in curable formulation systems may be difficult to remove from substrate materials at the end of life, especially in multicomponent products. This may **prevent materials like composites, plastic packaging and traditional metal, wood and glass from being recycled**, contributing to the generation of waste in landfill.

7. Biodegradable replacements for existing PLFs must remain stable in the formulation with other ingredients and solvents/carriers. This is especially technically challenging in formulations with high aqueous contents since this catalyses degradation. **Formulators must balance the complete breakdown of PLFs into environmentally friendly products after life and formulation stability, without compromising performance**.

8. **There are significant differences in the way that consumers and industry use and dispose of PLF products across the eight markets around the world**. Factors like consumer behaviour and waste infrastructure will influence the volume of PLF products consumed and their fate.

In considering the wider global sustainability context, our analysis of the PLF landscape and our discussions with experts in industry, we have identified three major challenges that must be addressed to make PLFs more sustainable: **innovating for sustainability; creating a circular economy**; and **optimising waste management processes**. We address each of these over the next few pages, supported by a range of case studies at different Technology Readiness Levels (Figure 1).

Stage		Production		Use	End of life
Formulation system	**Market segment**	**Global production volume per year (million metric tonnes)**	**Concentration (%)**	**Time in use**	**Fate**
Curable	Paints and coatings	21.6	20 to 100	Medium to long	Landfill, incineration, environment
	Adhesives and sealants	7.8	20 to 100	Medium to long	Landfill and incineration
	Inks and coatings	1.7	2 to 100	Medium to long	Landfill and incineration
Liquid	Agrochemicals	2.1	<1	Short to medium	Environment (agricultural land)
	Water treatment	1.5	<1	Short	Environment (agricultural land via wastewater treatment)
	Personal care and cosmetics	0.8	1 to 10	Short	Environment (agricultural land via wastewater treatment)
	Household cleaning	0.4	1 to 10	Short	Environment (agricultural land via wastewater treatment)
	Lubricants	0.4	1 to 2	Medium	Incineration

Table 1. Summary of sustainability risk in each market

Challenge 1: innovating for sustainability

To ensure that the PLF sector is economically and environmentally sustainable in the future, new approaches to PLF production, use and end-of-life treatment are needed.

Our analysis of the current PLFs landscape found that a significant proportion of PLFs are synthetic and are produced from fossil-derived feedstocks, which puts strain on the environment and may cause future supply risks. In addition, we found that PLFs in liquid formulation systems are likely to have widespread environmental fate and PLFs in curable formulation systems are likely to enter landfill.

We also found that businesses are innovating for sustainability, but they face significant technical challenges in developing novel PLFs and products that make it too risky for any organisation to develop alone.

Future solutions need to be sustainable and avoid 'regrettable substitutions' that can happen when new products are developed. Using consistent life cycle assessment approaches will be important to know if new chemicals really are more sustainable than what they are replacing and to ultimately help businesses make the right decisions.

The opportunities

Innovation in the following areas could reduce the market's reliance on fossil-derived feedstocks, reduce waste generation and maximise the value of PLFs in liquid and curable formulation systems.

In the technical report Polymers in liquid formulations: a landscape view of the global PLFs market we include examples of novel solutions that require further exploration.

- The use of platform technologies and high-throughput screening methods to rapidly test novel PLFs in different applications
- The development of novel bio-based and biodegradable PLFs for liquid formulation systems
- The development of novel bio-based durable PLFs for curable formulation systems
- The development of triggered degradation mechanisms to enable easy removal during recycling processes and break down into safe products at end of life
- The improvement of PLF performance, functionality and efficiency by designing future formulations that maximise resources

TRL 9
FULL COMMERCIAL APPLICATION

Case Study

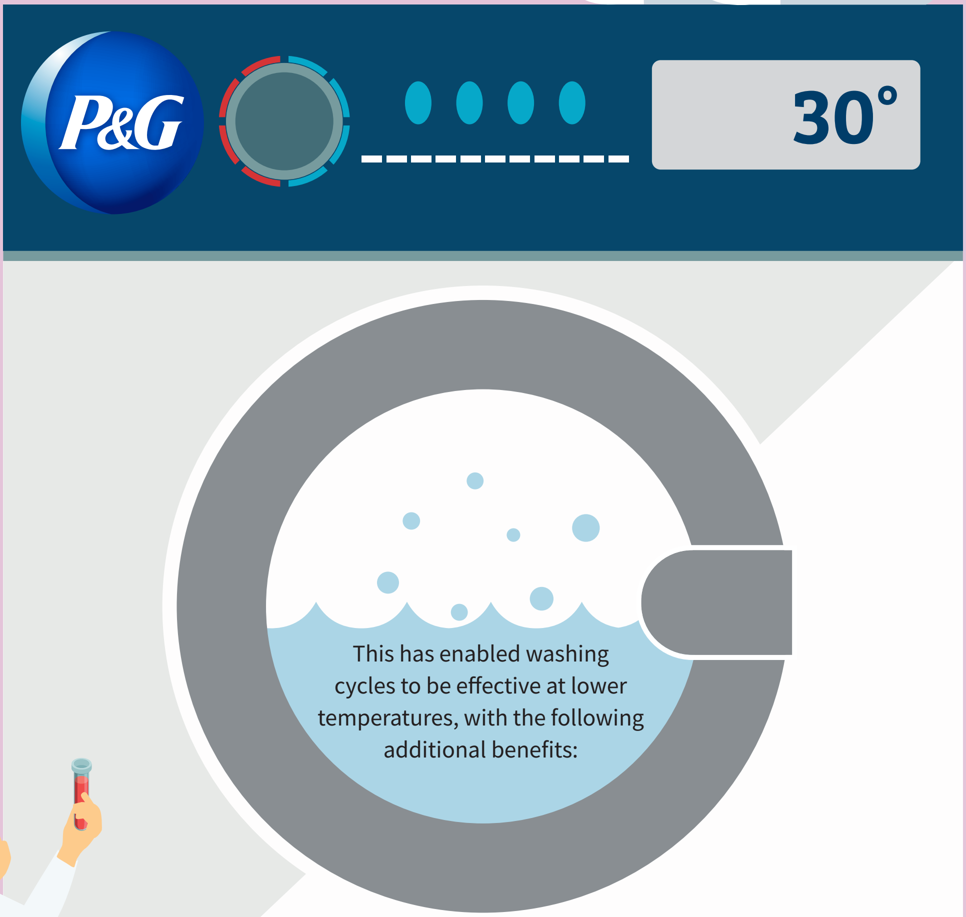
Procter & Gamble

USING PLFS FOR MORE SUSTAINABLE 30 DEGREE WASHING CYCLES

Washing detergents have contained the PLF carboxymethyl cellulose (CMC) for many years, which is used in quantities of over 100,000 tonnes per year. To maximise the potential for the industry to deliver cost savings and sustainability benefits, P&G has developed an alternative version called blocky carboxymethyl cellulose (BCMC). Many P&G laundry powder detergents around the world now contain BCMC, formulated at levels of 0.1 to 1%, including those sold in Europe, Latin America, Middle East and Africa.

The BCMC make fabric and dirt particle surface more negatively charged, so it is better able to repel soil particles from textiles once adsorbed onto cotton fabrics and soil particles. The key innovation during development was the use of regioselectivity in the carboxymethylation process to impart 'blockiness' or clustering of the negatively charged groups to free up unsubstituted regions that are able to adsorb onto textiles.

This affects the performance of the detergent in two major ways. Firstly, the increase in fabric surface and dirt particles' surface charge reduces the redeposition of dirt particles back onto the fabric surface, leading to whites and coloured items retaining their intended colour. Secondly, it modifies the fabric surface to reduce the transfer of dyes between garments during the washing process.



This has enabled washing cycles to be effective at lower temperatures, with the following additional benefits:

- produced by carboxymethyl modification of wood cellulose, it is ~75% bio-based and inherently biodegradable
- there is a fourfold improvement in the efficiency of BCMC compared to CMC, meaning it can be used in lower quantities and reduces environmental impact during transport
- improved efficiency also requires fewer natural resources for the same level of performance
- BCMC can also be used to enable replacement of other non-sustainable PLFs in detergent formulations
- the anti-redeposition and dye transfer inhibition benefits contribute to improved garment longevity by helping to keep clothes looking like new

TRL 6
PROTOTYPE SYSTEM

Case Study

Naturbeads

CELLULOSE BASED MICROPARTICLES AS A POTENTIAL SOLUTION FOR PLFS THAT RELEASE MICROPLASTICS

Naturbeads is developing a process to manufacture cellulose microparticles to replace plastic microbead exfoliants, binders, abrasives, anti-caking agents and enzyme carriers, which are used in a wide range of applications including cosmetics and paints. Naturbeads' technology could provide further insight into sustainable solutions for PLFs in paints and agrochemicals, which release microplastics into the environment throughout their lifetime.

There are current bans on using microplastics specifically as exfoliants in cosmetics, due to the potential risks that these materials may have. However, the EU has proposed further restrictions, which encompass a wider range of functions and applications including PLFs.

Naturbeads' technology provides a solution to this problem by producing microbeads from a natural biopolymer, cellulose, which is 100% biodegradable. The main advantages of its technology are:

- the ability to produce particles between 1 and 50 micrometres in size
- the customisation and modification of the mechanical, surface and optical properties to mimic the performance of polymeric microbeads
- the potential to source cellulose from waste products and recycled paper as secondary raw materials

Naturbeads is currently scaling up its process to industrial scale and customising its beads for different applications.

TRL 4 SMALL SCALE PROTOTYPE

Case Study

ViridiCO$_2$

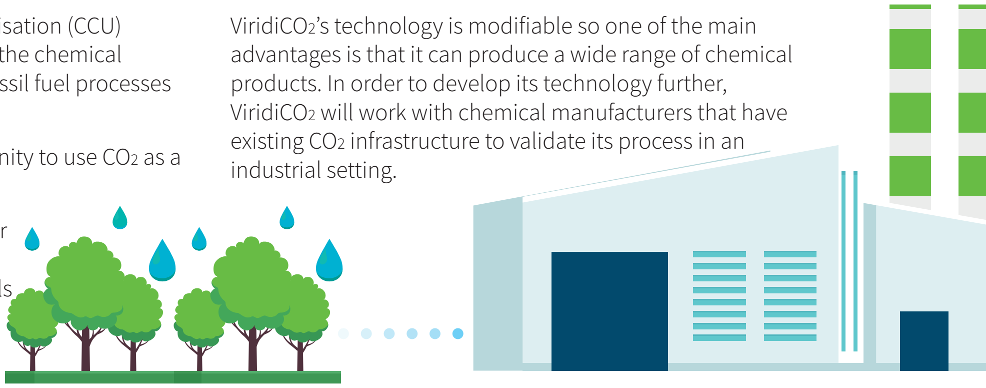
HETEROGENEOUS CATALYTIC PLATFORM AS A FUTURE METHOD FOR MANUFACTURING SUSTAINABLE PLFS

ViridiCO$_2$ has developed a heterogeneous catalytic platform to manufacture high value chemicals using CO$_2$. Using uniquely designed active sites within the catalyst, its technology rapidly activates CO$_2$ under mild conditions, which subsequently reacts with substrates to produce products like polymers. There may therefore be potential to exploit this technology to manufacture sustainable PLFs.

The company's carbon capture and utilisation (CCU) technology has the potential to reduce the chemical industry's dependence on traditional fossil fuel processes for producing chemicals, while offering:

- chemical manufacturers an opportunity to use CO$_2$ as a direct feedstock for products
- other industries a way to reduce their emissions by incorporating their waste CO$_2$ output into other materials

ViridiCO$_2$'s technology is modifiable so one of the main advantages is that it can produce a wide range of chemical products. In order to develop its technology further, ViridiCO$_2$ will work with chemical manufacturers that have existing CO$_2$ infrastructure to validate its process in an industrial setting.



TRL 8 FIRST-OF-A-KIND COMMERCIAL SYSTEM

TRL 9 FULL COMMERCIAL APPLICATION

Case Study

kaumera

United Utilities Water for the North West

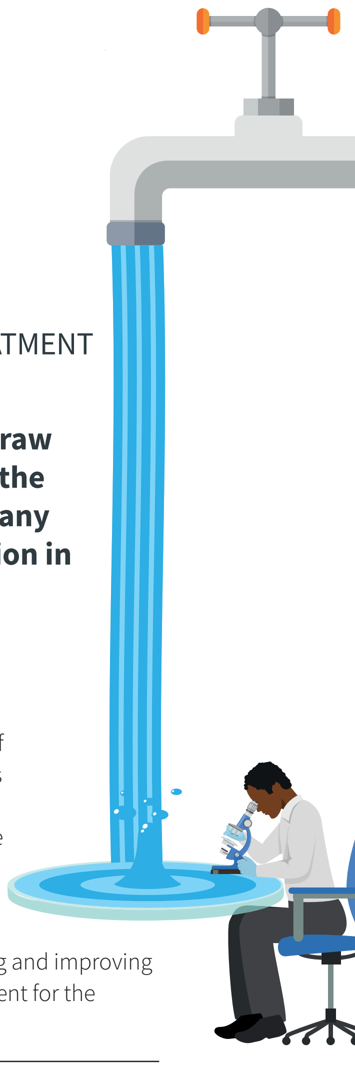
Kaumera Nereda® Gum

GENERATING BIO-BASED RAW MATERIALS FOR PLFS FROM WASTEWATER TREATMENT

Royal HaskoningDHV's Nereda biological wastewater treatment process cleans water using aerobic granular sludge technology. A new bio-based raw material, Kaumera Nereda® Gum, is extracted from this process that has the potential to be converted into a wide range of high value PLFs. The company is now working with United Utilities to develop a circular economy solution in the UK, following successful scaling up operations in the Netherlands.

Biological sludges from wastewater treatment often have a high transportation and treatment cost, which is typically partially offset from the recovery of energy as biogas, with any residual waste being recycled to land.

An opportunity to make the costs of municipal wastewater treatment net positive is by harvesting the high proportions of extracellular polymeric substances (EPS) from waste granules. EPS, a biopolymer backbone, are a complex mixture of polysaccharides, proteins, nucleic acids, (phospho) lipids, humic substances and intercellular polymers. Once harvested from the excess sludge, the gel-forming exopolysaccharides can be used as a new bio-based raw material – called Kaumera Nereda® Gum. Kaumera Nereda® Gum is extracted through a number of simple pH correction and physical separation steps and can be tailored to alter the property of the raw material. The material's properties include the ability to strengthen material, retain water and repel water. This could be used for applications such as lightweight composite material for the building or transport sector, as bio-stimulant in agriculture/horticulture (reducing leaching and improving crop uptake of fertilisers) or as a curing agent for the concrete industry.



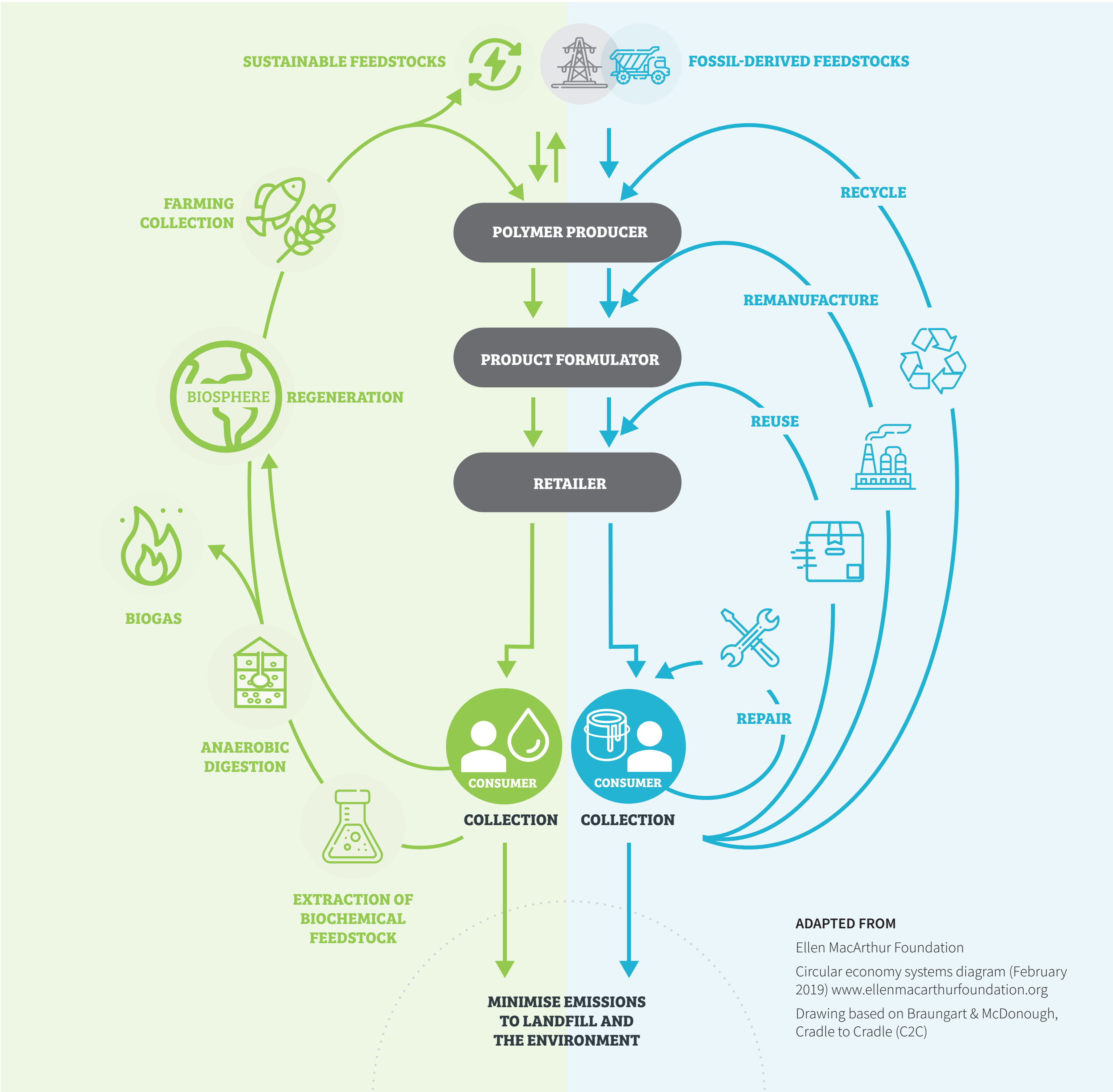
Challenge 2: creating a circular economy

Our analysis of the PLF landscape across the eight markets confirms that these materials currently follow a linear take-make-dispose model.

Formulators select PLFs in the design of formulations based on the specific properties and effects that they deliver. However, they are typically just one ingredient in a product and the value that the PLF brings is likely to go unnoticed by consumers and industrial end users. This makes these materials difficult to collect, which means that they are likely to enter landfill or the environment as waste at the end of their life.

The circular economy is an example of a transformative approach that could offer an alternative way of managing resources. This concept focuses on regenerating natural systems, designing out waste and pollution and keeping products and materials in use. Figure 4 highlights the differences between a linear and circular economy and emphasises implementation of the waste hierarchy (Figure 3) to reduce, reuse and recycle materials and products to minimise waste production at end of life.

Figure 4. The circular economy. This diagram illustrates a conceptual circular economy framework for PLFs. It highlights possible options for sustainable PLFs in liquid and curable formulation systems



The opportunities

Although our investigation found some examples of circular systems for paints, these currently operate at a small scale and are unlikely to have major impacts on waste production.

There are opportunities to grow circular economy solutions:

- Scale up existing take-back schemes and extend them for other markets by exploring new markets for secondary raw materials
- Digital track and trace for paints and coatings and specific PLFs like polyacrylamide that markets are particularly reliant on could improve industry's understanding of supply risks and help develop more sustainable practices
- Developing technology to create secondary raw materials from waste PLFs could reclaim monomers from PLFs and convert waste PLFs into energy for the chemical industry

TRL 9 FULL COMMERCIAL APPLICATION

Case Study

Cambond

PLANT-BASED RESINS AND COMPOSITES FOR PLF INDUSTRIAL ADHESIVES AND CONSTRUCTION PRODUCTS

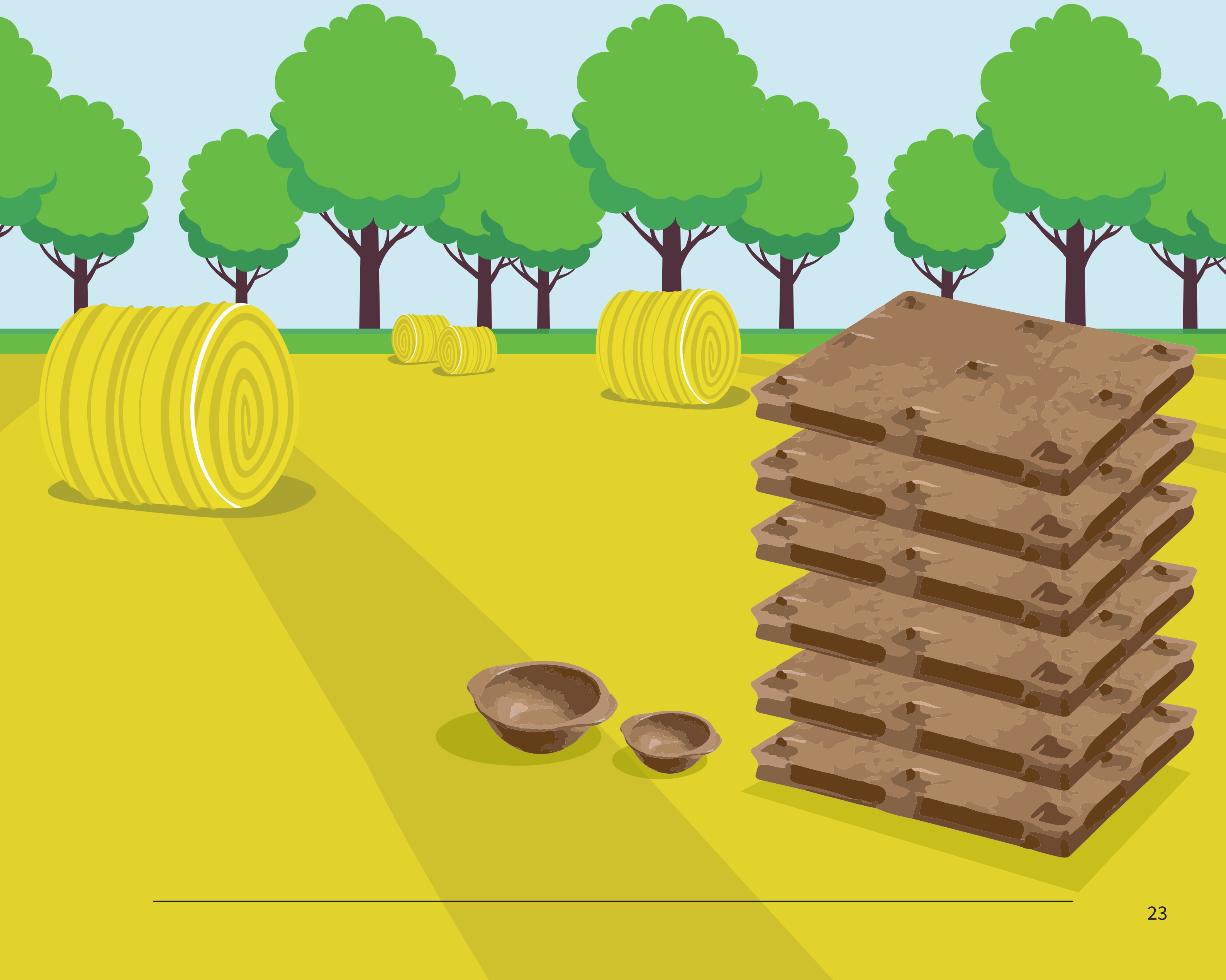
Cambond developed an innovative bio-based resin that provides an environmentally friendly industrial adhesive to replace formaldehyde-based resins in products like MDF, particleboard and plywood.

Formaldehyde-based resin is an example of a synthetic PLF that is manufactured in a highly regulated process that produces CO_2 and toxic by-products. Cambond's technology offers a direct replacement for this PLF, which is more sustainable.

It has also combined its resin with other biomass fibres or polymers to produce biocomposites, which can replace plastics in applications such as sustainable packaging, compostable materials and construction board manufacturing.

This technology is a low cost solution that can be used in existing manufacturing processes. The other advantage of this technology is that it offers a fully circular solution that turns biomass by-products from agriculture into valuable materials, which are readily available in large quantities.

Wasware, Cambond's subsidiary agricultural business, is also investigating the opportunities to exploit this technology for seed coatings and other household and homeware products such as cups and bowls.



TRL 9 FULL COMMERCIAL APPLICATION

Case Study

PaintCare

PAINTCARE – A CIRCULAR ECONOMY INITIATIVE FROM THE BRITISH COATINGS FEDERATION

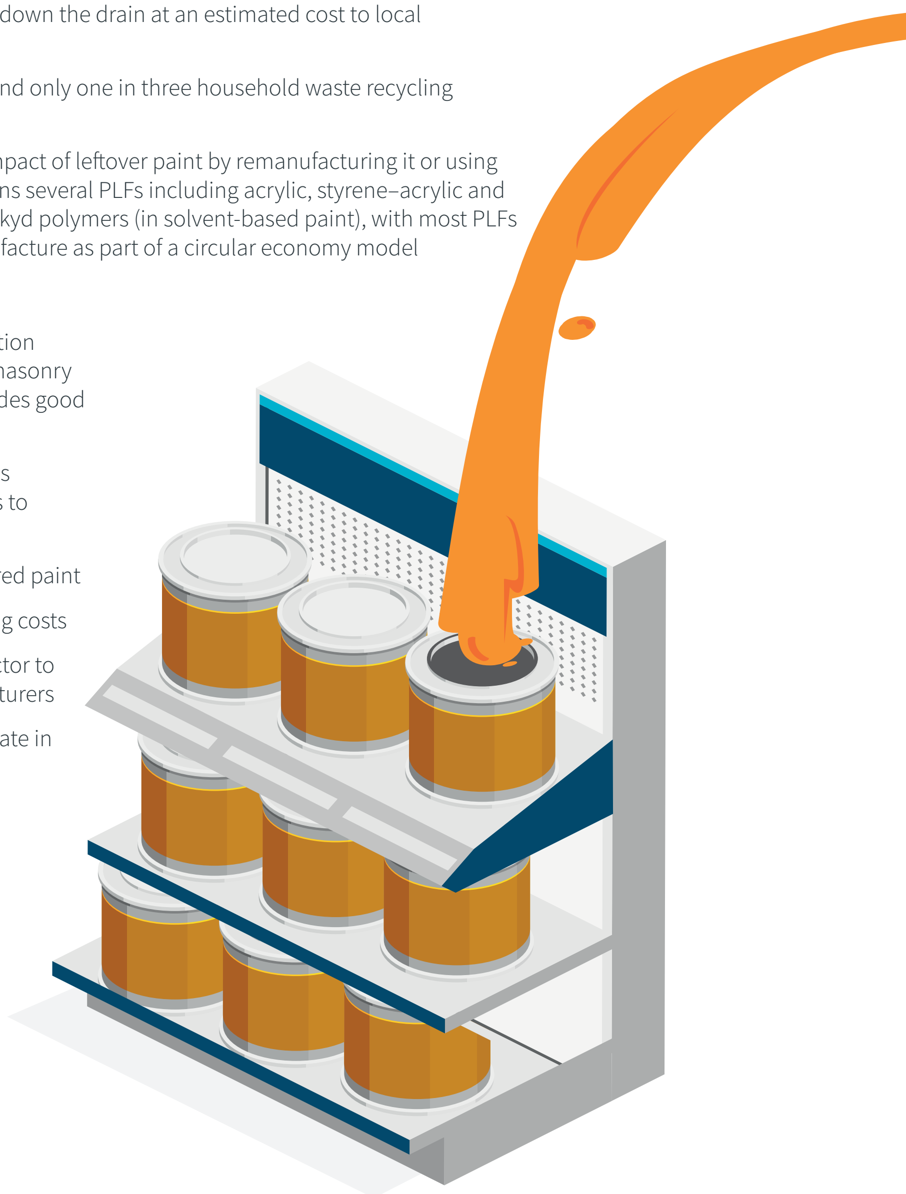
Each year in the UK:

- 55 million litres of waste paint are generated each year, with a retail value of between £165 and £220 million. Of this, an estimated 20 million litres are considered useable
- 98% of paint ends up landfilled, incinerated or down the drain at an estimated cost to local authorities of £20.6 million
- only 1% is remanufactured and 1% is reused, and only one in three household waste recycling centres currently accept leftover paint
- PaintCare aims to reduce the environmental impact of leftover paint by remanufacturing it or using it as a resource for other products. Paint contains several PLFs including acrylic, styrene–acrylic and vinyl copolymers (in water-based paint), and alkyd polymers (in solvent-based paint), with most PLFs in water-based paint being suitable for remanufacture as part of a circular economy model

Remanufacture involves collection and storage at household waste recycling centres before segregation into usable product types, eg vinyl matt, exterior masonry paint, and then by colour. Further treatment provides good quality, regulatory compliant paint for resale.

While the process itself is simple, existing initiatives only exist on a small, local scale. The main barriers to establishing a widespread circular economy are:

- stimulating consumer demand for remanufactured paint
- improving collection networks without increasing costs
- developing a business model that allows the sector to grow, to stimulate a network of paint remanufacturers
- raising awareness of how the public can participate in remanufacturing schemes



PaintCare hopes to overcome these barriers by bringing together local and national government, the waste industry, paint companies and retailers. Part of this work is to develop a national, voluntary product stewardship scheme and guide future standards for leftover paint.

There is also the opportunity for research and technological advances to play a key part, for example by removing paint from containers more efficiently, providing low cost quality analysis of the leftover paint, and by developing new ways to remanufacture paint or recycle it into other products such as concrete.

Challenge 3: optimising waste management

High value PLFs produced from predominantly fossil-derived feedstocks are lost after use and contribute to waste generation (see Table 1). Although some value may be recovered from PLFs at the end of their life through incineration for energy recovery, the waste hierarchy (Figure 3) depicts this as high risk to the environment.

There are significant differences between the production, use and end-of-life fates of PLFs in curable and liquid formulation systems, which results in different opportunities to improve their sustainability. For example, PLFs in liquid formulation systems, used in personal care and cosmetics, and cleaning and washing products, are likely to enter municipal water treatment at the end of their life via household, commercial and surface water entering sewers. PLFs in curable formulation systems, used in paints and coatings, inks and coatings, adhesives and sealants, form solids after application and are likely to remain on the substrate material at the end of their life.

This means they can enter landfill as well as water treatment facilities. These PLFs may also contribute to air emissions if recycling processes remove them from substrate materials (eg glass and metal recycling typically uses high temperature processes, which are not likely to consider PLFs).

The opportunities

Innovation and implementing circular economy principles should offer the greatest opportunity to improve sustainability in the long term. However, these solutions may not be suitable for all PLFs in all applications. Optimising existing waste management infrastructure may provide another opportunity to reduce PLF waste generation.

Improving existing processes or developing new technologies to effectively remove PLFs on substrate materials could improve the recyclability of materials such as wood and plastic. There may also be opportunities to improve biological processes in wastewater treatment processes to ensure that organic matter containing PLFs is broken down into safe products before application of sludge onto agricultural land.

TRL 6
PROTOTYPE SYSTEM

Case Study

Puraffinity

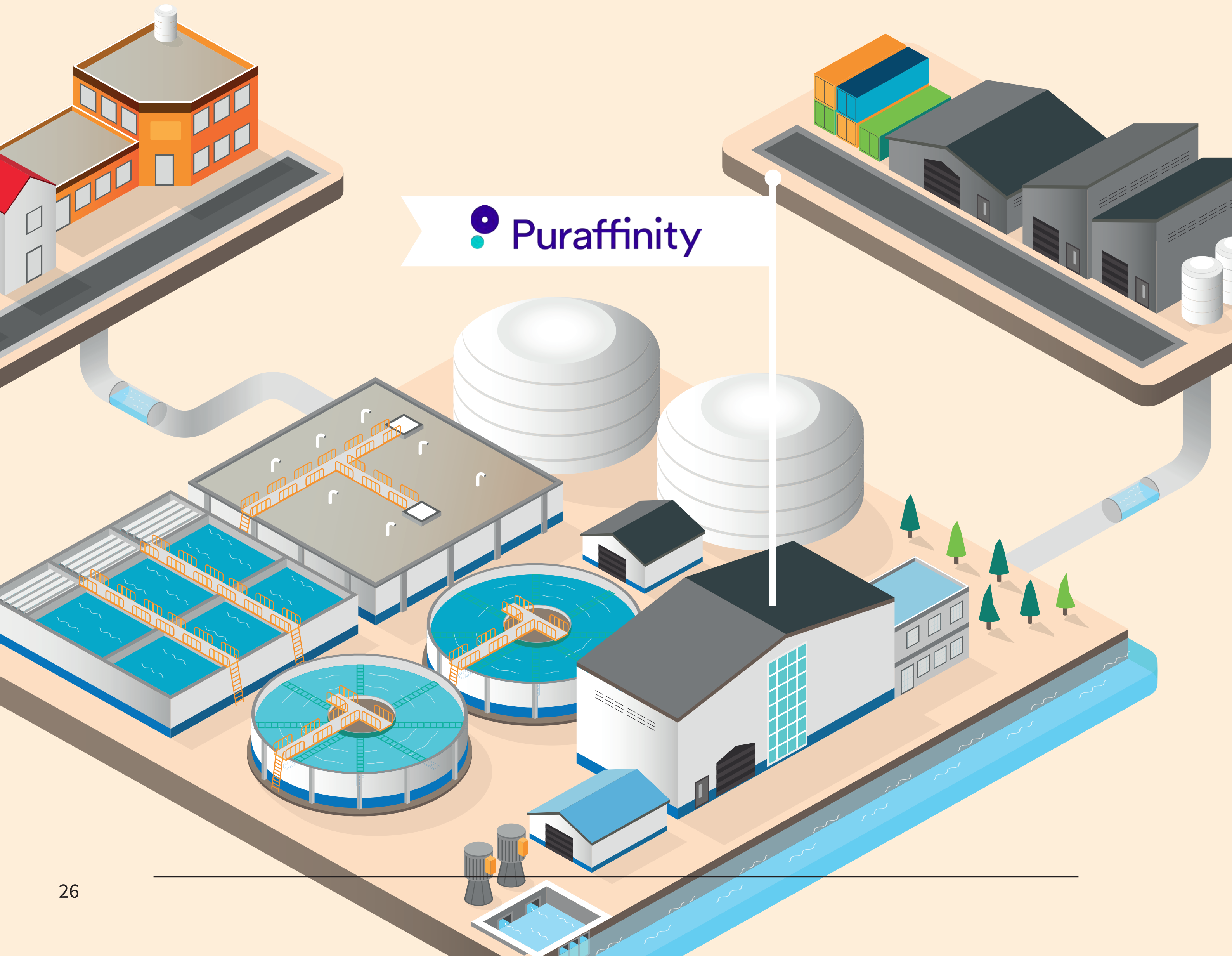
BUILDING ON WASTE MANAGEMENT OF PFAS FOR PLF REMOVAL FROM WASTEWATER

Puraffinity has developed a molecular binding technology to capture and remove target molecules from wastewater. Using molecular receptors the company's technology electrostatically binds to a target compound that would otherwise enter the environment at the end of its life. Utilising a targeted approach ultimately enables target molecules, like PLFs, to be recovered for recycling or reuse.

Currently, Puraffinity is developing solutions for perfluroalkyl substances (PFAS), highly persistent and potentially hazardous molecules used in a range of applications including flame retardants, waterproofing agents and surfactants. However, Puraffinity's platform technology has wider benefits that could make it suitable for the recovery of PLFs:

- tailored technology with the potential to capture a wide range of target molecules including inorganic and organic compounds
- a grab and unlock mechanism to enable recycling and reuse of target molecules, opening up circular economy approaches
- highly efficient and precision tools to capture specific compounds rather than broadly capturing all chemicals

The company's current focus is developing solutions for large engineering solutions in drinking and wastewater treatment plants to capture target molecules at scale.



Next steps

Improving the sustainability of PLFs is a significant challenge that no single organisation or sector can address alone.

In 2021 we will establish a PLF task force that will prioritise and progress five key opportunities to galvanise industry, academia, policymakers and funders into action.

1. Establish new innovation networks that promote collaboration between industry, academia, and policymakers

New PLF innovation networks are needed to help the PLF community address the specific technical, market and supply chain challenges (highlighted in full in the technical report Polymers in Liquid Formulations: a landscape view of the global PLFs market). Such networks would enable knowledge exchange between different markets, catalyse new collaborations and facilitate the exploitation of emerging technologies to progress sustainable solutions. These mechanisms would also facilitate a dialogue between industry, governments and funding bodies to address wider innovation challenges. This investigation identified several areas that offer a starting point for collaborative discussions. There are many examples of existing networks that align with this topic which may be helpful to explore.

2. Identify and champion key research themes and priorities that will support businesses and researchers to tackle PLF innovation challenges

Engaging with funding bodies in identifying key PLF research themes and priorities across all TRLs would lead to further support for researchers, SMEs and large businesses working in this area. This investigation identified several areas where further investment is needed in fundamental and applied research, emerging technology development and large scale research and development challenges. This represents an important starting point that could unlock and accelerate the development of sustainable PLF solutions for applications across key PLF markets.

3. Explore the emerging need for a consistent approach to PLF biodegradability and stability testing across key markets

Businesses in the key PLF markets must work with governments to establish platform technologies for biodegradability and stability testing to enable industry to develop novel polymers and formulations. Further exploration into the needs and technical requirements across multiple markets in collaboration with key stakeholders would progress the key components of this approach:

- open access testing facilities for companies of all sizes
- standards to help industry develop innovative bio-based and biodegradable materials

4. Investigate opportunities for chemistry-based innovations in developing circular economy solutions for key markets such as paints, adhesives and sealants

There is potential to scale up existing schemes that reuse, re-purpose and recycle paints at national levels to reduce PLF waste in the global paints market. There is also potential to expand them to other markets such as adhesives and sealants. Further exploration into the following areas would help overcome current challenges:

- chemical science technology and innovation that can support the scale up of existing circular economy initiatives
- the integration of digital track and trace across the supply chain to inform future technology and innovation needs
- the creation of new markets for secondary raw materials from waste paint

We also identified a role for chemical scientists to support discussions between trade associations, industry and governments to develop consistent take-back schemes, collection facilities and infrastructure at a national level. In addition, there is a role for experts to help the wider public understand recycling options through consistent product labelling and engagement.

5. Engage with key stakeholders to ensure that a science- and evidence-based approach is used to develop future policy for PLFs

Policy is a significant enabler of innovation and developing sustainable PLF solutions. The following examples represent key focus areas that will be important for governments to consider in developing future policy for PLFs:

- consistent life cycle assessment (LCA) approaches
- communications to the public on the benefits, hazards and risks of chemicals in our lives, so consumer demand drives sustainable product innovation through informed choice
- transparent risk–benefit frameworks to inform whether exposure to a given chemical is acceptable or unacceptable to citizens and wildlife
- open, transparent evidence-based risk assessment to authorise and restrict the use of chemicals of concern in products and processes
- incentives to promote collaboration between academia, SMEs, corporates and citizens to develop sustainable solutions

In 2021, we will establish a PLF task force to convene key industry partners to prioritise and progress these five opportunities.

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