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The Sustainable Plastics Policy Commission

KEY FINDINGS FOR THE UK GOVERNMENT

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Chair's Foreword

When the University of Birmingham approached me to discuss their ambitions to create a sustainable future for plastic, I was immediately interested. Plastics are ubiquitous across the economy, from the obvious uses, such as packaging, to the lesser known, such as insulation, car tyres, and synthetic textiles. Over the last 50 years, plastic's low cost, lightweight nature, and durability has provided convenient solutions to many problems. Plastics are particularly vital to the healthcare sector, from enabling widespread home testing kits to the delivery of essential vaccinations. However, for all its benefits, plastic presents a wide range of environmental challenges, and there are significant uncertainties around their long-term impacts on human health. For these reasons, I am passionate about supporting the development of evidence-based policies which minimise the negative impacts of plastic, while retaining its societal benefits.

Over the last few years, we have seen a necessary emergence of global plastics policies. In 2019, the Basel Convention adopted two decisions to deal with plastic waste, making it the only global legally binding instrument to specifically address plastic waste. Subsequently, in 2022, the UN Environment Assembly convened an Intergovernmental Negotiating Committee (INC) to develop the first international legally binding instrument on plastic pollution, a process which is now at a midway point, with an ambition for a binding treaty by the end of 2024.

Against this backdrop, the University of Birmingham Policy Commission on Sustainable Plastics was activated. I, alongside a group of expert Commissioners, endeavoured to develop well-informed, evidence-based, policy recommendations. To achieve this, we consulted with key stakeholders from across the plastics value chain, including those from the packaging, healthcare, and construction sectors, to name but a few. This report outlines these recommendations, as well as the data we gathered to inform their development.

In order to achieve the systemic change required to resolve the plastic waste problem, we cannot work alone. We must work collectively and collaboratively, using the recommendations and information set out in this report, to initiate a journey towards a sustainable future for plastic in the UK. We must implement solutions which enhance our economy, protect our people and our environment, and place the UK as a leader in this area. We must act now. I am passionate about connecting people to drive forward this change, and I encourage all those who are interested to engage with this report and join us in our efforts to create a sustainable future for plastics.

Baroness Meacher

Introduction from the Academic Co-Chairs

In January 2023, we launched a Call to Action Report, which outlined a forward strategy to move beyond fragmented solutions to the plastics problem and presented a clear interest in creating solutions that are interdisciplinary, inclusive, and holistic. One of the key conclusions of this report was that whilst academia, business, policymakers and publics can all provide parts of the solution, there is an urgent need for a systemic approach which encompasses the whole plastics lifecycle.

Since then, the vision has developed into a large-scale Policy Commission, which we have had the privilege to lead on this last year. For perhaps the first time, this Commission has enabled us to engage with the plastics waste problem, considering economic, environmental, and social impacts and developing comprehensive and evidence-based recommendations to tackle an issue that has seen the same challenges and piecemeal solutions presented for decades.

This area of inquiry presented a unique challenge due to the sheer breadth and depth of the issue. Throughout our evidence sessions, we have addressed a vast range of sectors across the entire plastics lifecycle, with each sector and lifecycle stage presenting enough information for a Policy Commission in its own right. It was essential that we had expert insights from a range of stakeholders, so we are grateful for the time and energy that all of our Commissioners and Witnesses have contributed to this project. The information presented to us throughout these sessions has been invaluable in seeking well-rounded, evidence-based solutions to the plastic problem, from production through to end of life.

We know that the plastic waste problem is not static and that the challenges it presents to society will continue to change as more is learned about the unique impact, challenges, and opportunities that these materials present. The recommendations outlined in this report should be seen as a way to improve our relationship with plastics now, with further considerations for longer-term action referenced in the report body. Overall, we wish to highlight the significant need for collaboration and cooperation in this area to continue to create meaningful change and to build a sustainable future for plastic across its entire value chain.

Professor Andrew Dove and **Professor Fern Elsdon-Baker**

About the Birmingham Plastics Network Policy Commission

The Birmingham Plastics Network is an interdisciplinary network of over 60 researchers at the University of Birmingham. The unique team brings together chemists, environmental scientists, philosophers, linguists, economists, artists, writers, lawyers, and experts in many other fields, to address the global plastic waste problem in its entirety. The Birmingham Plastics Network is committed to prioritising collaborative working methods, such as this Policy Commission.

A Policy Commission is a tried and tested method for achieving systemic change within and beyond Government, and the University of Birmingham has a track record of delivering these successfully. Utilising the knowledge and input of a range of stakeholders from different backgrounds, we possess the information required to influence plastics policy through a systemic lens, creating impact for a range of beneficiaries and not just one cluster of society.

Our Policy Commission has brought together voices from across the plastics landscape to develop a set of well-informed and evidence-based policy recommendations which promote a sustainable future for plastics in the UK, enhancing the positive contributions that plastics make to our lives whilst minimising the negative impacts across their life cycle. We have engaged with a range of stakeholders across a range of themes including Sourcing and Manufacture, Recycling and End of Life, Behaviour and Business Models, and Additives and Human Health. These sessions ran over a period of three months and were followed by a period of extensive consolidation with the Commissioners, which ultimately led to the development and refinement of our recommendations.

The University of Birmingham would like to express its gratitude to those who contributed to the work of the Policy Commission both as Commissioners, who gave their time and expertise so generously, and those who otherwise contributed to the work of the Commission by giving evidence, offering advice, and participating in discussions. In particular, we would like to thank Baroness Meacher, Crossbench Peer for the House of Lords, for agreeing to Chair this Commission and for her expert insight into Government policy making. For his continued support, we would also like to extend thanks to Adrian Whyle.

We would like to thank the Professional Services staff at the University of Birmingham who supported the delivery of the Policy Commission, including Dr David Boardman, Rachael Egglestone, Kim Ekste, Amil Khan, Alasdair MacLachlan, Nathan Miller and Kate Stewart. We would like to express significant thanks to Robyn Macpherson, Project Manager for the Birmingham Plastics Network, and Kathryn Miles, Research Strategy and Development Partner, without whom this project would not have been possible. The work of Zendo Pen Ltd and Think Creative has been essential to the development of this report, and we would like to thank them for their hard work in its development.

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The views expressed in this report reflect the discussions of the Policy Commission and the research that informed them. They do not necessarily reflect the personal opinions of the individuals involved or the companies they represent.

Our Commissioners

Professor Sally Beken, Founder and Lead of the UK Circular Plastics Network at Innovate UK Business Connect.

Professor Andrew Dove, Professor of Sustainable Polymer Chemistry at the University of Birmingham.

Simon Ellin, Independent, Previous CEO of the Recycling Association.

Professor Fern Elsdon-Baker, Professor of Science, Knowledge and Belief in Society and Director of Research Institute for STEMM in Culture and Society (ISTEMMiCS) at the University of Birmingham.

Judit Guerra-Falcon, Technical Affairs and Circular Economy Manager, Plastics Europe.

Keith James, Head of Policy and Insights, WRAP.

Professor Stefan Krause, Professor of Ecohydrology and Biogeochemistry at the University of Birmingham.

Professor Richard Lampitt, Professor at the National Oceanography Centre.

Brian Lodge, Director of Packaging, British Plastics Federation.

Professor John McGeehan, Independent Consultant, Recycling, Upcycling and Redesign.

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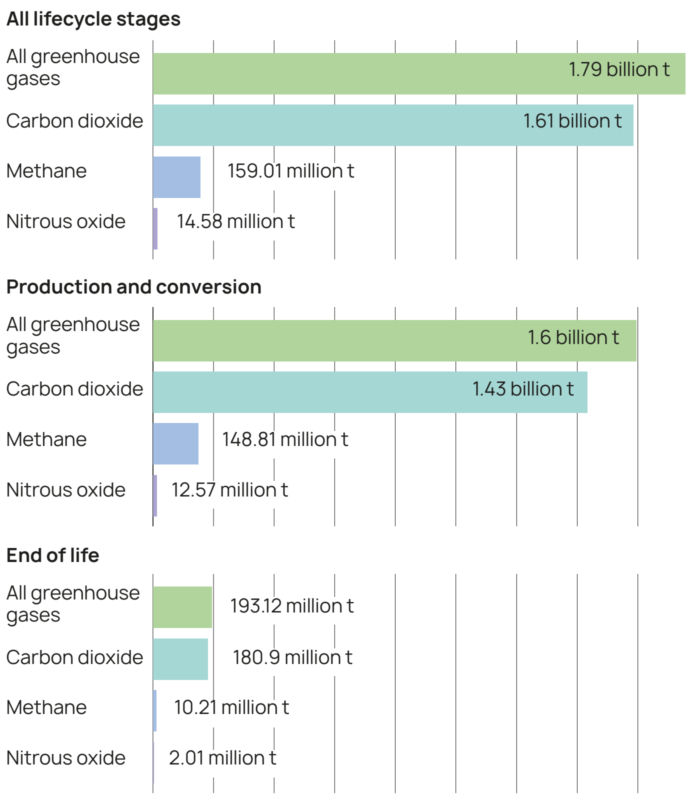
Plastics: Our past, our future

As the world grapples with the net zero challenge, the plastic waste crisis has emerged as a key transitional issue. On the one hand, plastic is an essential commodity found everywhere in society, from life-saving medical equipment to daily conveniences, often contributing to better sustainability outcomes thanks to its versatility, strength, light weight, and affordability. On the other, the growing quantities of plastic waste and pollution have led to its vilification as a material. Plastic remains an essential material to society with over nine billion tonnes produced since the 1950s[1] and annual production growing from two million tonnes to over 450 million tonnes[2].

During this time, plastic has made an immeasurable contribution to human well-being, but it is also entangled with a fossil fuel-based energy system and a linear economic model that are incompatible with a sustainable future. From production through to disposal via incineration or landfill, plastics are responsible for 3.3% of global greenhouse gas (GHG) emissions, with 90% of that coming from the energy used during production and conversion[3]. Furthermore, plastic waste is despoiling marine environments and ecological systems. An estimated 6.9 billion tonnes of plastic has so far been discarded as waste and 12 billion tonnes are forecast to be in landfill by 2050[4,5,6]. Inadequate collection and recycling in turn drives an insatiable demand for virgin production.

Figure 1: **Greenhouse gas emissions from plastics, 2019.**

Emissions are measured in tonnes of carbon dioxide-equivalents.



Source: Our World in Data[1]

Unlike fossil fuels, which simply must be phased out, plastic cannot be dispensed with. It is used in life-saving medical items such as syringes, blood bags, and surgical instruments. Food supply chains rely on packaging to preserve perishable goods in transit[7]. It cannot easily be replaced without performance, cost, or safety trade-offs with some touted alternatives having a potentially higher overall environmental impact, such as (single use) glass, which can weigh 20 times more than a plastic bottle, increasing transport emissions[8].

Plastic also cannot easily be separated from global value chains. The primary plastics sector contributes $600 to $700 billion a year to the world economy, from transport to textiles[9,10]. Millions work in the industry throughout the value chain[11], and the UK alone directly employs 155,000 people in the plastics sector. For every direct job the sector creates, 2.74 are created in the broader economy[12]. In India, plastic manufacturers, waste pickers, and civil society have developed complex interdependencies that make it challenging to address plastic in isolation[13].

An evidence-based policy response

Achieving a sustainable future for the plastics industry is a daunting challenge, but not without reward. Globally, transitioning to a circular plastics economy could produce 700,000 additional jobs by 2040, save the private sector $1.3 trillion, and governments $70 billion, as well as reduce the costs of social and environmental externalities by at least $3 trillion[14]. This calls for an ambitious reinvention of the life cycle, from more environmentally sustainable feedstock production to design innovation and effective regulation, as well as incentives and investment on everything from labelling to life cycle analysis.

The public clearly cares about the plastic waste crisis. An influential BBC documentary in 2017, Blue Planet II, showed the impact of plastics on our environment, sparking the so-called 'Blue Planet Effect' with consumers choosing to consume less plastic, such as opting for reusable water bottles instead of single-use[15]. In a 2021 survey of adults in the UK, 92% of respondents expressed concern about plastic pollution and a majority wanted action from governments and brands[16].

Countries cannot reach their net zero targets without a radical change to the making and management of plastics.

While there is broad agreement on the issue, stakeholders are at odds over the remedy. Governments have differing and, at times, conflicting positions. Small island developing states (SIDS) suffer the most from plastic pollution due to the waste that washes onto their beaches, heavy reliance on imports, and lack of recycling centres and treatment facilities[17]. However, voices in some large developing countries oppose overly stringent restrictions on a commodity which proves so essential to value creation and contributes to tackling other pressing priorities such as food waste[18].

In 2019, the Basel Convention adopted two landmark decisions for plastic waste, making it the first legally binding instrument addressing plastic waste globally. It includes actions for preventing and minimising plastic waste generation; improving its environmentally sound management and controlling transboundary movement; reducing risk from hazardous constituents in plastic waste; and public awareness, education and information exchange[19].

In 2022, the UN Environment Assembly convened an Intergovernmental Negotiating Committee (INC) to develop a ground-breaking, legally binding international instrument focused on plastic pollution[20,21]. The mandate states that the treaty must address 'the full life cycle of plastic', which has sparked debate over the scope of the concept[22]. The goal is a sustainable plastics roadmap covering all dimensions, from litter, to carbon emissions, to human health. The process is at its midway point, aiming for a binding treaty by the end of 2024.

Some measures discussed at the INC include reducing emissions from plastic production, implementing design standards for plastic focused on reuse, and downstream efforts to eliminate waste. Delegates at INC-3, the most recent meeting in Nairobi, disagreed as to whether the priority should be to encourage the production of reusable and recycled plastics or to reduce plastics production at the source[23]. These debates will continue throughout INC-4 and INC-5 as member states grapple with the text of the final treaty.

Just as national policy efforts proceed alongside, and are motivated by, the UN Conference of the Parties (COP), plastic also falls subject to national sustainability policies and regulations. These include tax incentives for increasing recycling, bans on single-use plastics, circularity schemes, infrastructure investments, and extended producer responsibility frameworks.

The devil is in the detail on such measures, though. Taxes levied on products without a minimum threshold of recycled material, for instance, can put smaller producers at a disadvantage, especially if there is limited access to recycled plastics to draw from. Restrictions on certain chemicals used as additives can lead to 'regrettable substitution', in which alternatives are introduced with the same or worse environmental or health profiles. Lastly, plastics are a global commodity, meaning any country-level change must contend with differing systems elsewhere.

Against this backdrop, the Birmingham Plastics Network Policy Commission was launched to bring together informed and evidence-based insights from across the plastics value chain to develop policy recommendations for building a sustainable future for plastics in the UK. The Commission, comprising 12 experts from industry, academia, non-governmental organisations and scientific institutions, has set itself the task of evaluating the current challenges and policy landscape, and attempting to synthesise diverse views on building a sustainable plastics ecosystem.

Through a comprehensive approach considering economic, environmental, social, and ecological impacts, our Commission aims to clarify this complex issue and promote high-impact solutions and innovative changes with a workable framework for reducing, reusing, and recycling plastics.

Policy Recommendations

Harness the tax system to promote sustainable decisions.

- Tax is a powerful instrument to ensure end of life impacts are priced into materials. The UK's 2022 Plastic Packaging Tax, applied to products that do not contain at least 30% recycled plastic, was a welcome step in encouraging circular economy practices. The Government could now introduce a sliding scale to reward companies that surpass the 30% threshold, with appropriate measures to mitigate the risk of fraud. To support the packaging industry to adjust, the Government should consider corresponding investments in plastic and waste management infrastructure to ensure sufficient availability of recycled plastics. The Government could raise the threshold in the medium term and use additional tax instruments to target the most difficult-to-recycle plastics, for example, or the most environmentally problematic.

Broaden the scope of Extended Producer Responsibility (EPR) beyond packaging and create a 'demand pull' for sustainable alternatives across sectors.

- EPR incentivises sustainable product design and the prevention or minimisation of plastic waste by making producers financially responsible for their products at the end of life. The UK's EPR scheme, set to begin in 2025, targets 62% of packaging waste by 2030, with a collection scheme for films and flexibles to begin in 2027[24]. While welcome, these targets are lower than EU packaging targets, which are 65% by the end of 2025 and 70% by 2030[25]. EPR should also go beyond packaging; textiles and construction are two potential sectors of application.

Incineration remains a dominant waste management method and produces greenhouse gas emissions (GHGs) and toxic pollutants, including acid gases and heavy metals; the Government should set ambitious but achievable targets to reduce incineration and landfilling[26].

- Due to heavy reliance on landfilling and incineration, the UK's plastic consumption results in 26 million metric tons of carbon dioxide equivalent emissions over the entire lifecycle. This indicates how plastics management performance directly impacts the UK's progress towards net zero[27]. The Government should urgently set ambitious targets to reduce incineration and review current incentive frameworks to keep polymeric carbon in the economy for longer.

Strengthen regulation and oversight on compostable and biodegradable plastics.

- Biodegradable and compostable plastics production is rising, but while these are primarily composed of non-fossil-based carbon feedstocks, they require appropriate recovery systems to ensure they are disposed of correctly. Otherwise, they may contaminate existing recycling streams or end up in natural environments where they may not biodegrade, rather than in industrial composting environments. Stronger oversight of marketing claims, enforced by the Competition and Markets Authority (CMA), can improve consumer awareness as part of a broader push to tackle greenwashing. There is a lack of public understanding of the term 'biodegradable,' which can be used in misleading ways.

Build the evidence base on plastic pollution's human and environmental harms.

- There is mounting evidence that plastic pollution harms environmental systems and human health, especially as plastics break down, allowing additives to enter ecological and biological systems. These effects increase risks of future governmental expenditures to treat, mitigate or remediate externalised costs. Plastic incineration is also associated with health impacts in nearby areas. Given that data and evidence is fragmented and often based on laboratory studies that do not approximate actual levels of exposure, the Government should invest in building the evidence base further. It should continue to lead global coordinated efforts in this area, supporting the development of the UN science-policy panel to contribute to the sustainable management of chemicals and waste to prevent the harm caused by pollution[28]. The Government should propose that plastic additives are a priority for this panel and lead in developing an international consensus on action. The UK science base also has the opportunity to spearhead and become a world leader in research methodologies to tackle issues like 'regrettable substitution'[29]. These methodologies could include precision toxicology approaches that leverage genetics, genomics, metabolomics, and related fields to enable toxicological review of chemicals by groupings, rather than individually. The Government could also consider setting environmental migration limits for companies to prove additives do not migrate out of plastics under certain conditions.

Drive innovation in sustainable plastics through a national centre of excellence.

- Due to an uncertain policy landscape, an unclear strategy and unpredictable reform timelines, the UK currently limits investment in plastics recycling and innovation. The Government is uniquely placed to unite diverse actors through a world-leading national sustainable plastics innovation research centre that can pool skills and investment to encourage co-creation across academic disciplines and industries. Such an institute, which extends the work of centres in other nations, including the Netherlands and Germany, can encourage long-term ambitious thinking and signal to the private sector that sustainable plastics are part of the UK's low-carbon future. Building on the success of the UKRI Plastics Research and Innovation Fund and the Smart Sustainable Plastics Packaging Challenge, the UK should further incentivise researchers and companies to become world leaders in circular polymer systems, from materials design to next-generation recycling. These incentives could include blended finance, investor partnerships, competitions, and challenge funding, access to subsidised land, and scaling up pilot and full-scale facilities in key areas like chemical recycling, which have already delivered benefits, such as those within the Teeside Freeport area, which hosts the largest chemical recycling facility in the country. The Government should also support private sector innovation by sticking to timelines on reforms like the Deposit Return Scheme (DRS), thereby demonstrating a long-term commitment to the circular economy and giving confidence to investors.

Utilise procurement to raise sustainability data and standards in plastics.

- The Government should use procurement to spark innovation and encourage best practices through protocols on holistic life cycle assessments and sustainability metrics. This could be achieved through a dedicated task force, harnessing insights from research, non-governmental bodies, and academic, certification, and standardisation bodies, as part of the broader effort to improve ESG reporting. The UK Government can encourage best practices and evidence-based decision-making by using the most robust methodologies in public sector procurement for all materials, such as creating data quality scoring systems and promoting open data sharing.

Reform 'end of life' licensing to support green growth and incentivise the emergence of next-generation production and recycling technologies.

- The current waste permitting system needs to be re-defined to accelerate circular economy models and support green growth by allowing plastic waste to be revalorised to benefit the environment and the economy. The UK Government should instruct the relevant bodies (Environment Agency in England, SEPA in Scotland, Natural Resources Wales in Wales, and NIEA in Northern Ireland) to agree to end-of-waste criteria that incentivise recirculation of polymeric carbon. Current UK waste licensing directives determine that an item can be waste if there is no certainty that it will be used. To decide if the materials' use is certain, the applicant must consider if there is a market or demand for all the materials. Awarding more opportunities to companies seeking to use materials innovatively may foster the market for materials.

Chapter 1: Reckoning with the 'Plasticene'

Plastics are heterogeneous synthetic chemical materials composed of a backbone produced from natural or synthetically created carbon resources. They can also include a number of chemical additives which add specific properties such as flexibility, stability and flame retardation[30].

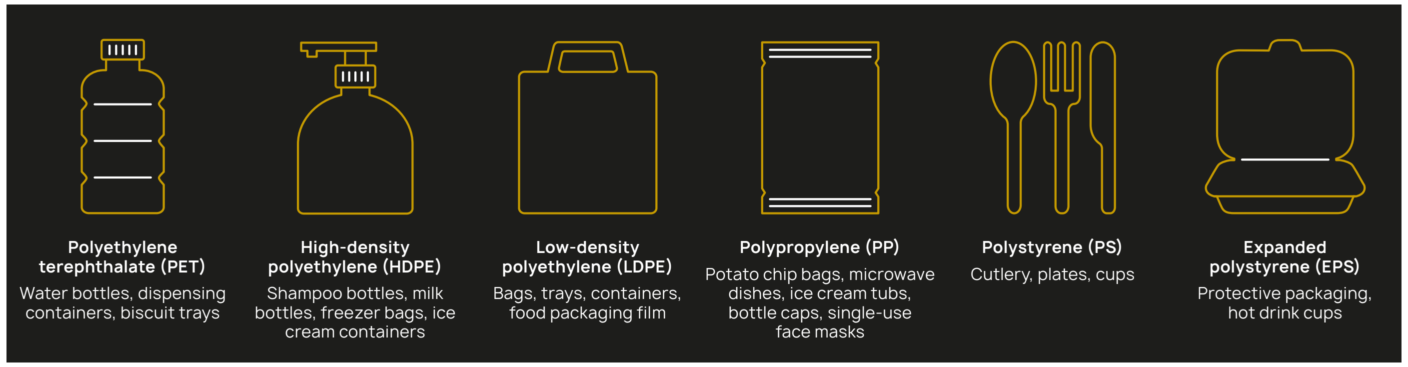
Thanks to their excellent properties, plastics are useful almost everywhere: consumer products, foams, coatings, adhesives and sealants, packaging, textiles, building and construction, electronics, automotive and medical[31]. Even paint particles and road markings are imbued with different amounts of metals and additives and, once dry, can be considered a plastic material. Some have characterised plastics to be the defining material footprint marking the start of the Anthropocene[32].

Thanks to this versatility and utility, large volumes of plastic are produced and eventually become waste, estimated at 114 kg per person annually in European OECD countries[33], which, coupled with inefficient disposal and collection, has created a mounting environmental crisis[34].

Plastic waste is now widely distributed across ecosystems[35], recently discovered at the deepest point on earth, the Mariana Trench, and a few hundred metres from Mount Everest's 8,850-metre summit[36]. This pollution results from the inadequate collection and disposal of larger products or macroplastics, and from microplastics, particles of a size less than 5mm, that originate from products like synthetic textiles and tyres[37].

Some are known as primary microplastics and were engineered to be micro-sized; these are found in products such as facial cleansers, toothpaste, and exfoliating creams; while these have been banned in recent years, they are still a form of legacy pollution to be contended with[38]. Microplastics are difficult to degrade in the environment and may attract other materials that stick to them and further prevent degradation[39]. As they accumulate, the proportion of microplastic pollutants in the weight of global plastic pollutants is expected to reach 13.2% by 2060[40].

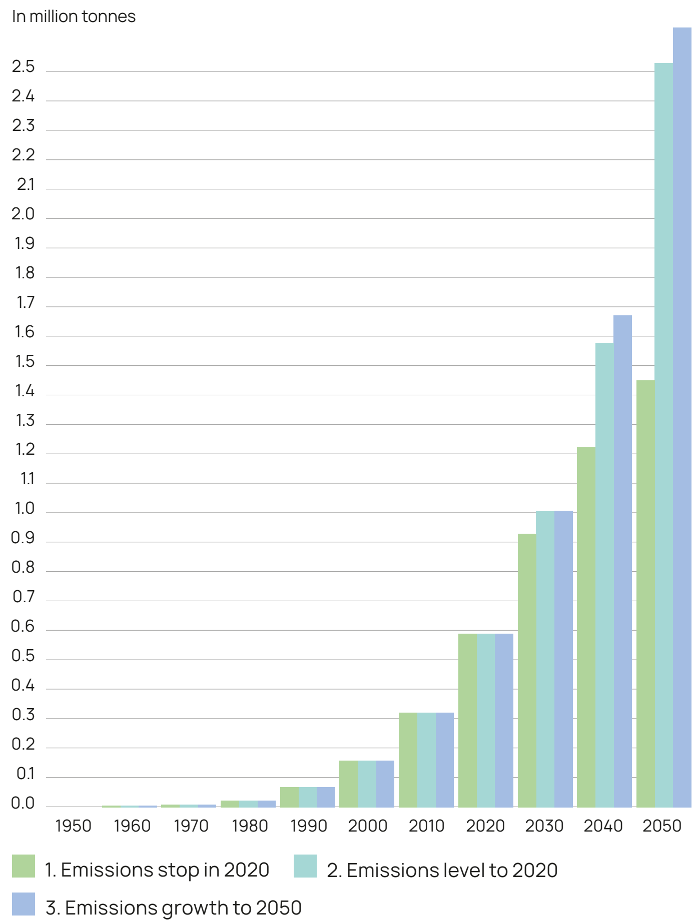
Figure 2: **Plastics in everyday life.**



Source: UNEP[2]

Figure 3: **Buoyant microplastics in the surface ocean.**

Microplastics are plastic materials smaller than 0.5 centimeters in diameter. Future global accumulation in the surface ocean is shown under three plastic emissions scenarios: (1) emissions to the oceans stop in 2020; (2) stagnate at 2020 rates; or (3) continue to grow until 2050 in line with historical plastic production rates.



Source: Our World in Data[3]

Plastic and microplastic waste have been linked to harmful impacts on animal growth, intestinal tissues, and intestinal flora[41]. These are found in animals all across the world: a recently discovered species of amphipod, *Eurythenes plasticus*, is found at a depth of 6,900m and is named after the plastic found to contaminate its gut[42]. Microplastics could pose an additional risk when their surface area absorbs toxic substances such as antibiotics like ciprofloxacin and amoxicillin[43], heavy metals like copper and zinc[44], and persistent organic pollutants that include polycyclic aromatic hydrocarbons (PAHs)[45]. The absorbed substances affect the ecosystem as microplastic particles may act as a sink or vector for absorbed compounds.

Unfortunately, given the complexity of different exposure mechanisms, evidence on ecological and human health impacts is still fragmented and incomplete. More systematic research is needed for fully conclusive assessments of the conditions under which microplastics and their additives pose critical dangers to the environment and human health. However, current evidence is clear that allowing plastics to end up in the environment can have harmful effects.

Additives are also a key toxicity consideration in evaluating environmental and human risk. Some plastics, such as polyvinyl chloride (PVC), contain up to 50% additives by mass; these additives have the potential to leach out after disposal. Substances such as flame retardants, UV stabilisers, dyes, and plasticisers are all present in plastics, sometimes at very high concentrations. Additives are added for clear purposes, including safety and performance, but they can become harmful when they leach out of plastics in natural environments as a result of either diffusion or the breakdown of plastics due to weathering effects, like UV radiation[46,47]. Some additives can also have physiological effects on some organisms; for example, lipophilic, or fat-loving, additives, which can penetrate the cell membranes of aquatic organisms[48]. Chemical additives from within plastics may also be directly released into the guts of these creatures[49].

A recent review has linked exposure to phthalates, one of the additives used in plastics, to several adverse health outcomes including reduced semen quality[50], impaired child motor development and intelligence[51], increased childhood asthma risk[52], and more. Research also shows the potential for sublethal pollution effects that do not cause particular diseases but can harm healthy growth, development, fertility and functioning[53,54]. In addition, studies have demonstrated endocrine disruption effects from human exposure to certain chemicals[55].

If they co-occur, environmental pollutants can also interact, having an unknown impact on human health that can differ from individual pollutant exposures. Additionally, the replacement of chemicals or additives with alternatives, that are similarly poorly-understood, bears the risk of causing similar or worse impacts. An example of this is in the banning of bisphenol A (BPA) from baby bottles in Europe: bottles are now labelled as BPA-free, but the chemicals being substituted are similarly concerning in their effects on human health[56]. This problem is known as 'regrettable substitution,' and rigorous data and research are essential to understand the mechanisms behind chemicals' impact on health and environmental systems. Evidence-based regulations and risk awareness are paramount to ensure appropriate regulations that harness the properties of plastics and the chemicals sector responsibly.

Plastic production also poses environmental and health threats in regions close to manufacturing and disposal[57]. Studies from the US reveal that communities near petrochemical, plastic production and incineration facilities face higher exposures and risks driven by proximity to sources and a higher baseline susceptibility[58].

Thanks to advances in data science, toxicology and life cycle assessment, there is an opportunity to build a more definitive evidence base on the health and environmental profile of plastics to inform a balanced approach that harnesses the manifold benefits of plastics to the benefit of people and the planet while mitigating potential negative impacts of current plastic products.

While there is broad agreement on the need to tackle pollution, there is no viable or reasonable case for phasing out plastic. Instead, the goal is to vastly improve the circular economy system to keep plastics in use for as long as possible and manage the risks of disposal. A holistic policy response, therefore, should focus on the lifecycle management of plastics and keeping polymeric carbon in use for as long as possible.

Chapter 2: Achieving a Circular Economy

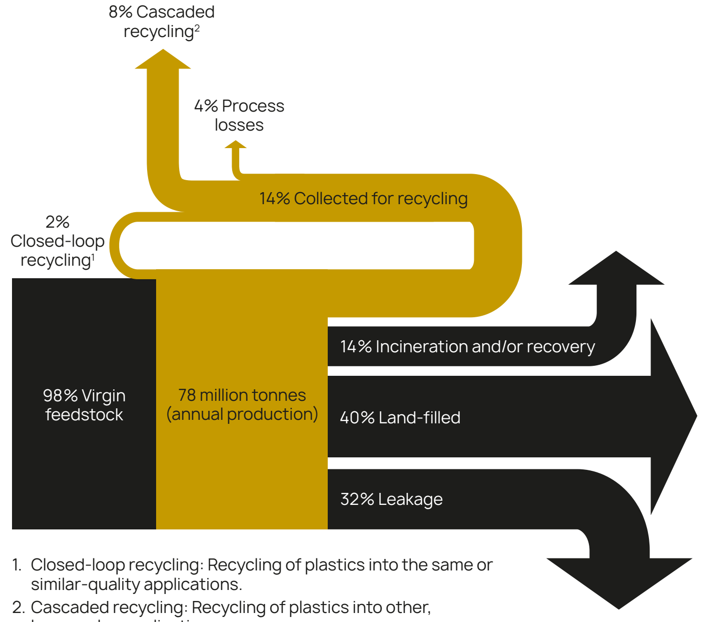
Currently, nearly two-thirds of plastic waste comes from plastics with lifetimes of under five years, 40% from packaging, 12% from consumer goods, and 11% from clothing and textiles, which have increasingly short lifespans[59]. After a short, single-use, life cycle, 95% of the value of plastic packaging material is lost to the economy, resulting in losses of $80–120 billion annually[60]. Retaining the value of products through optimal recycling and reuse is critical to reducing these economic losses.

Figure 4: **Waste hierarchy.**

Source: Department for Environment, Food and Rural Affairs[4]

The circular economy model can maintain the value of products, materials, and resources by re-introducing them into the product cycle at the end of their use and minimising the generation of emissions and waste. Instead of the predominant 'linear' economy model, it emphasises intelligent product design and sustainable production. In the plastics sector, this means more efficient use of virgin material by incorporating recycled content, increasing recycling and reuse, and minimising waste. The preferred plastic waste hierarchy is prevention, reuse, recycling, recovery, then disposal (although the preferability of recovery, which turns waste into energy but releases carbon dioxide (CO_2) and other harmful gases, over landfilling, is under review)[61]. Prevention and reuse are useful for reducing waste, but many crucial plastic applications rely on single usage, with medical-grade plastics among the most important. All plastics eventually reach the end of life stage and need careful management and circular economy options to either keep them in use as long as possible, or return them to use with minimal environmental impact.

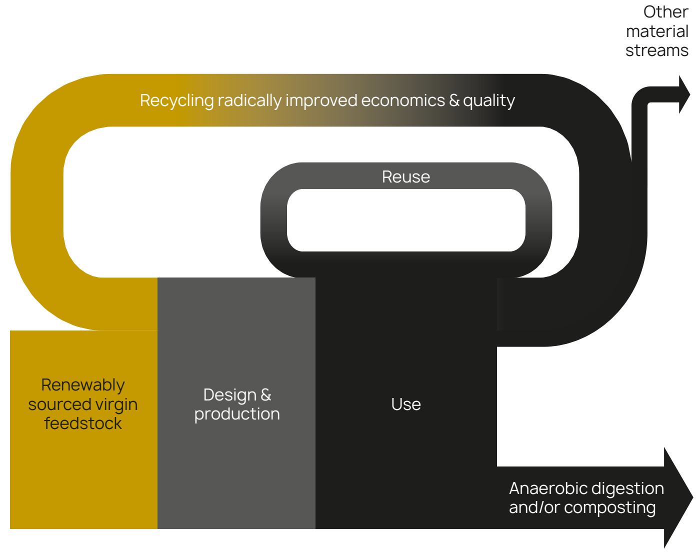
Figure 5: **Today, plastic packaging material flows are largely linear.**



1. Closed-loop recycling: Recycling of plastics into the same or similar-quality applications.
2. Cascaded recycling: Recycling of plastics into other, lower-value applications.

Source: Ellen MacArthur Foundation[5]

Figure 6: **A circular economy for plastic.**



Source: Ellen MacArthur Foundation[6]

Closing the recycling gap

Recycling is key to circularity. Although recycling systems exist worldwide, only 9% of plastic waste is recycled. Another 50% is landfilled, 19% is incinerated, and 22% is mismanaged, resulting in uncontrolled dumpsites, burning in open pits, or polluting terrestrial or aquatic environments, especially in low-income countries[62]. All of this represents lost material value. Achieving a circular economy will require closing this gap through recycling capacity and efficiency.

The vast majority of recycling is classified as mechanical recycling, or the processing of plastic waste into new materials without significantly changing their chemical structure. Plastics are collected, sorted, cleaned, and transformed into raw materials to be used to manufacture new products.

Polyethylene terephthalate (PET)[63] is a common material for bottles, which are the most recycled form of plastic packaging; plastic bottle recycling rates in the UK are as high as 74%[64]. It is the easiest polymer to recycle and can be transformed into new bottles multiple times while retaining its functionality[65].

Recycling is more difficult for other plastics, including some with important properties like their light weight and food safety compliance. One example is non-woven fabrics, which are commonly used for medical gowns and masks[66]. These contain several different polymers fused together which are very difficult to separate[67]. Due to the lack of infrastructure for recycling multilayer plastics, these often get shipped overseas with no guarantee of being recycled[68].

Polyvinyl chloride (PVC) is another commonly used plastic that is problematic to recycle. Because of its high chemical resistance, it is commonly used in the construction and medical fields and for food preservation. However, it often has additives, such as thermal stabilisers, which complicate mechanical recycling, and the removal of these additives requires specialised technologies[69]. Recycling PVC is, therefore, rarely profitable without subsidies or accounting for externalities and can use almost as much energy as virgin material production[70].

The complexity of packaging design is one of the biggest hurdles to achieving high volumes and quality of recycled plastics[71]. Combinations of materials are difficult to sort, but automated detection can be improved by tagging an item with a unique code using methods such as chemical tracers and digital watermarks. A chemical tracer is a molecule embedded in a label detected by its spectroscopic properties such as fluorescing under UV light. It acts as a binary code - the molecule is either present or not present[72].

Fluorescent markers are one example. Plastic Packaging Recycling using Intelligent Separation technologies for Materials (PRISM) applies luminescent materials as labels on plastic packaging, creating an invisible barcode for plastic recycling. Mixed plastic waste on the conveyor belt is positioned in the appropriate recycling stream when an ultraviolet (UV) light source triggers the high-speed sorting system that identifies and reads the coded PRISM label. PRISM has been researched extensively and is now well-proven in Materials Recovery Facility (MRF) setups[73].

A digital watermark is an optical code applied within the artwork of the product or directly on the surface of the plastic, removing the need for added materials. Digital watermarks have proven to be a promising innovation. These are imperceptible and are normally the size of a postage stamp. They are presently the subject of a European initiative, Digital Watermarks Initiative Holy Grail 2.0, which aims to determine if digital watermarks can deliver higher rates of quality recycling in the EU and drive the circular economy[74].

To ensure a truly circular economy, manufacturers must be incentivised to determine the traceability of their products. For the value of the product to be maintained, it must be clear throughout the lifecycle of the product where it is, that those who collect and separate it are clear about what it is, and that those who process it or transform it into raw material again do not mix it with materials that make the product lose value[75]. To prevent fraud, there must also be checks to verify the authenticity and provenance of recycled materials at each stage of the cycle. Suppliers should be vetted and audits conducted to ensure transparency and accountability, and this information must be made visible to stakeholders in the supply chain.

A digital passport makes this possible. In Europe, work is ongoing on an initiative called "R-Cycle", which gives recycled plastic products this digital passport. The passport consists of three things: an ID number to identify the product, data that is recorded for the product, and a marking that assigns the ID number to the product. This can be done through different methods, for example, a barcode, a QR code or a digital watermark[76]. Technological solutions like blockchain can also help validate transactions and preserve transaction history to make sure that digital passports cannot be tampered with.

Various technologies are being deployed to improve recycling processes. One example is a robotic-based sorting system, using AI, which seeks to reduce losses from incorrect sorting of plastics by removing human error and improving quality control[77]. Artificial intelligence and blockchain technologies can play an important role. For example, high levels of purity can be achieved using deep learning to sort plastic waste, where a machine is trained to recognise different types of plastic[78].

One research group has used blockchain smart contracts powered by multi-sensor data-fusion algorithms using artificial intelligence to show how different data-fusion modes can be employed to retrieve various physiochemical parameters of plastic waste for accurate segregation[79]. Other companies are looking at improving the recyclability of plastics through additives such as antioxidants and polymer chain extenders, which can help stabilise recycled products to enhance their performance[80]. While these innovations contribute to closing the recycling gap, large-scale changes will be necessary to ensure that more plastics are reintegrated into the circular economy, as these innovations could complicate subsequent recycling viability.

Recyclability depends on the purity levels and post-use contamination of the various polymers. The wide variety of polymers used is a challenge for polymer separation, leading to significant yield losses in mechanical recycling. Ramping up recycling capacity will therefore require plastics to be designed for recycling, and made with polymer combinations that will not impede recyclability now or in the future[81]. One potential solution for contamination is supercritical CO_2 extraction. This is an innovation used to decontaminate plastics from organic solvents before recycling, in which a form of CO_2 is put under enough pressure and heat to give it both liquid and gas properties[82]. Typically, contamination hinders the reuse of plastic, particularly in applications such as the food and beverage industry. Chemicals such as polycyclic aromatic hydrocarbons (PAHs) can be found in plastics through contamination of raw materials; these chemicals are toxic, do not degrade, and are hard to clean from plastic materials.

Heterogeneity is also a challenge for consumers, as people often need help distinguishing plastics and how they should dispose of them based on which polymers they contain. The difficulty of distinguishing between different types of plastic can create confusion and make consumers more vulnerable to greenwashing. A switch from larger, easier to recycle packaging to smaller, difficult to recycle packaging may be marketed as a reduction of plastic, even though it will ultimately lead to more plastic waste. This highlights the importance of building public understanding around recycling as well as challenging the assumption that less plastic is inherently better.

While reducing the number of polymer types used in plastic products could allow more efficient recycling[83], this may cause unintended consequences such as product spoilage or reduced shelf life of produce as the barrier properties of available materials may not be sufficient.

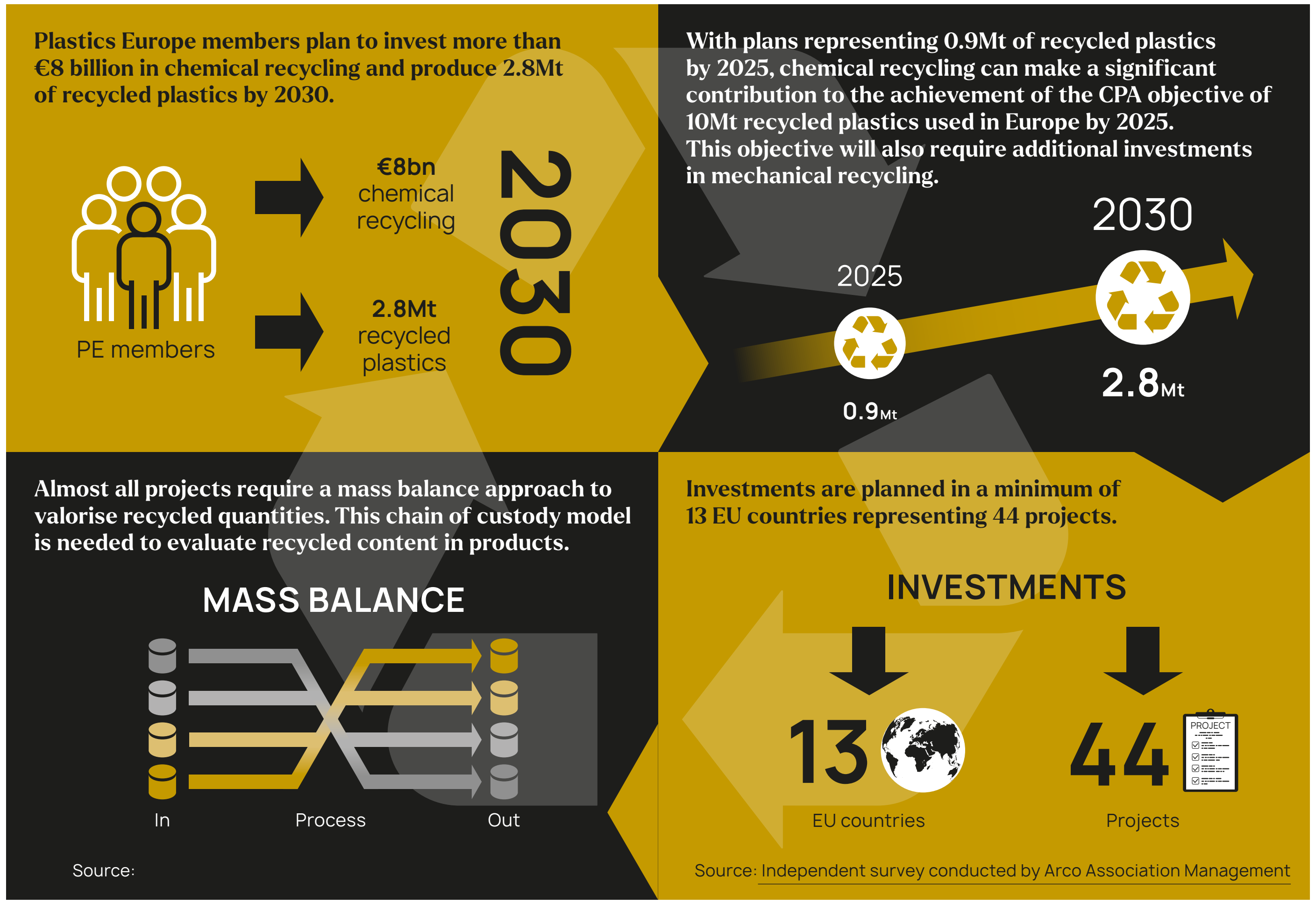
Wales leads the way

Wales is the leading nation in the UK for recycling. Since devolution, the Welsh Government has invested £1 billion in municipal recycling, which has catapulted rates from just 4.8% in 1998-1999 to more than 65% today[84]. Wales has set statutory recycling targets for local authorities since 2010 and extended those to cover non-domestic premises, requiring them to separate food waste from dry recyclables to reduce the risk of contamination. The Welsh Government has also made education and information on recycling readily available by investing millions in an awareness and advertising campaign. This campaign has helped achieve high recycling rates, including in remote and deprived areas.

Chemical recycling

Mechanical recycling is a cost-effective strategy for high-quality, clean, and sorted waste, but the difficulty of separating complex plastics, and the risks of contamination, results in high yield losses[85]. The process of mechanical recycling consists of sorting waste plastics and employing methods such as extrusion, which uses heat and rotating screws to soften the plastic and make granulated material that can be used to make new plastics. The extrusion process degrades the original plastic polymer and reduces its mechanical properties, such as tensile strength[86]. The degradation of recycled plastic is countered by mixing specific amounts of virgin or new plastic with recycled plastic (recyclate)[87]. This means that even in a perfectly circular economy, plastic quality would constantly be degraded and eventually need to be converted into its original molecular structure. Chemical recycling offers a promising means of doing this.

Figure 7: **Plastics Europe chemical recycling.**



All quantities of recycled plastics are based on mass balance with credit method and fuel-use exempt attribution rule.

Source: Plastics Europe[7]

Chemical recycling changes the chemical structure of polymeric waste, turning it back into substances that can be used as raw materials for manufacturing new plastic products. It produces recyclate with virgin plastic properties, which can be used in critical applications such as food contact. These technologies include pyrolysis, gasification, hydro-cracking, and depolymerisation.

Chemical recycling complements other plastic recycling options because it can recycle a wider variety of plastic and provide food-grade recycled content[88]. It can also deal with complex plastic waste streams, like films or laminates, which would otherwise be incinerated or landfilled[89]. Scaling up chemical recycling can help close many of the gaps in current recycling infrastructure, including by facilitating the recycling of PVC and other mixed plastics[90].

Chemical recycling aims to use feedstock that cannot be reduced, substituted, or mechanically recycled, ensuring that chemical conversion does not divert resources from higher-priority solutions. Therefore, while it can be used to process both flexible and rigid plastics, using it for flexible plastics is preferred because mechanical recycling is a more sustainable option for most rigid plastics, as long as they are not highly contaminated[91].

Compared to mechanical recycling, chemical recycling has the potential for higher-quality output, higher tolerance for contaminated feedstock, and increased versatility. The products of chemical recycling can be turned into high-quality, single-use packaging, potentially making up 100 per cent of a package's plastic requirements with the same quality as virgin plastic[92]. This includes food-grade quality, which typically is not the case for mechanical recycling due to potential contaminants.

Chemical conversion has more tolerance for different materials and feedstock, with lower yield losses than mechanical recycling[93]. This is most important for multi-material packaging and plastics contaminated by food residue, two of the most common obstacles to mechanical recycling. Chemical recycling also facilitates many more recycling loops than most mechanical recycling processes. For these reasons, European plastic producers are expected to invest as much as €7.2 billion in chemical recycling by 2030[94].

Several areas of chemical recycling require more research for industries to understand the process and its results better[95]. There are uncertainties around energy requirements, yields, and economic costs. There are also concerns about the potential presence of impurities in recyclates; it is not fully clear whether substances of concern present in the input waste could be reintroduced into the output recyclate. Consumers may also be afraid of health risks from unknown chemicals. The Natural Resources Defense Council found that the majority of chemical recycling plants in the United States release dangerous amounts of hazardous pollutants[96]. More research is needed to make chemical recycling cleaner, more energy efficient, and able to produce the building blocks for high-quality recycled material.

The circular economy policy toolbox

To accelerate the circular economy transition, government policies are vital. They provide the carrots and sticks to guide better choices by producers and consumers and influence the materials economy by, for instance, raising standards in areas like labelling and life cycle assessment. This section outlines the key circular economy policy instruments currently in adoption elsewhere in the world.

Taxing virgin plastics

Taxes on non-recycled single-use plastics are among the most frequently used national instruments. The EU has implemented an "own resources plastics contribution" policy to incentivise states to pursue plastic tax legislation. Rather than applying a tax across the region, the EU requires a national contribution from each member state based on the amount of non-recycled plastic packaging waste. It leaves member states to determine their policies for decreasing plastic waste. A rate of €0.80/kg is applied to the weight of non-recycled plastic packaging waste, with an adjustment mechanism that applies an annual lump sum reduction to less wealthy member states. This contribution is estimated to provide the EU with €7 billion in additional yearly revenue[97]. Contributions are calculated based on Eurostat data, as member states are already required by European Commission directives to provide data on plastic packaging waste and recycling.

EU countries can pay this contribution directly from their national budget regardless of whether they collect tax on plastic waste domestically (like France and Sweden) or they can design their own plastics tax legislation to fund their contribution to the EU (like Spain and Italy)[98]. Each country can define which products will be taxed and what tax collection mechanism will be used[99].

The **Spanish** non-reusable plastic packaging tax entered into effect as of 1 January 2023[100]. It taxes the amount of non-recycled plastic used in non-reusable plastic packaging, expressed in kilograms, when the packaging is delivered through its sale by the manufacturer, an intra-EU acquisition, or importation. The tax rate is €0.45 per kilogram of non-recycled plastic. Its exemptions include packaging used for medicines, sanitary products, meals for special medical uses and hazardous health waste, products that cannot be used or are to be destroyed, and intra-EU acquisitions and imports of less than five kilograms of non-reusable plastic packaging per month (low-volume operators)[101].

Mechanically or chemically recycled plastic is not taxable as long as it is certified by entities accredited by the National Entity of Accreditation ("ENAC" in Spanish) or by the national accreditation body of any other EU Member State. In third countries, the taxpayer must obtain certification from any entity accredited by a National Accreditation Body and internationally recognised by ENAC. Taxpayers must know how much non-recycled plastic is in the non-reusable plastic packaging contained in the shipments they receive, which must be furnished by the suppliers.

Italy has proposed a plastic tax similar to the Spanish model[102]. It taxes manufactured single-use items that contain, protect, handle, or deliver goods or food products, and it applies when the product is delivered into the country. The taxable persons are the manufacturer, the seller, the purchaser (if the items are bought from other EU countries and sold for business activity within Italy), the EU supplier (if the items are purchased from other EU countries and sold to a private consumer in Italy), and the importer. It also includes exemptions for pre-defined medical devices, recycled plastic material in single-use products[103], and compostable plastics as defined by the European EN 13432 standard[104]. As in Spain, the tax rate is €0.45 per kilogram of non-recycled plastic.

The **UK** has had a plastic packaging tax since 1 April 2022[105]. It aims to encourage using recycled plastic rather than new plastic, targeting all plastic packaging manufactured in, or imported into, the UK with less than 30% recycled plastic by weight. The current rate is £210.82 per tonne of plastic packaging, or approximately EUR 0.24 per kg, with a scheduled increase on 1 April 2024. Its scope is wider than that of the UK's previous Packaging Waste Regulations, including biodegradable, compostable, and oxo-degradable plastics[106].

Bans and restrictions

Many countries have pursued additional policies to limit the use of single-use plastics. Single-use plastic bans are among the most popular. **Luxembourg's** Waste Law requires restaurants serving on-site meals and drinks to use reusable containers and with reusable cutlery as of 2025[107]. **Kenya** has one of the world's toughest single-use plastic bag bans, including a ban on the

'usage, manufacturing and importation' of plastic bags in the country[108]. **Hungary** has banned specific single-use beverage cups from being placed on the market and requires companies to charge consumers for single-use plastic fast food containers[109]. **Canada** proposed a national ban on single-use plastics that a federal court ultimately struck down; the law gave plastic items a blanket toxicity label, which the judge deemed unconstitutional as not every plastic has the potential to create a reasonable apprehension of harm[110]. The Canadian Government is therefore considering alternative approaches, such as a national plastics registry requiring companies to track and recover their plastic products[111].

The **EU** adopted a European strategy for plastics, which aims to transform the design, production, use and recycling of plastic products as a part of the EU's circular economy action plan[112]. The strategy also aims to protect the environment and reduce marine litter, greenhouse gas emissions and dependence on fossil fuels while supporting more sustainable and safer consumption and production patterns for plastics.

To achieve these aims, the EU introduced new rules on packaging to improve recyclability, increase demand for recycled plastics, improve separate collection, and launch a campaign targeting industry and public authorities across the EU. A directive on single-use plastic products was introduced to curb plastic waste, along with restricting the use of microplastics in products and other measures to ensure that plastics are more bio-based, biodegradable and compostable.

Mandatory funding and responsibility requirements

Other policies require producers and vendors of plastics to fund anti-waste initiatives. The **Netherlands** passed a Packaging Management Decree requiring single-use plastics manufacturers and importers to cover the costs of raising consumer awareness around the environmental impact of single-use packaging[113]. Similarly, **Greece** requires that single-use plastics producers participate in, or organise, a Collective Alternative Management System for packaging waste[114]. **Turkey** implemented a Zero Waste Management System that increased the recyclable recovery rate from 13% to 19% in 2020 and plans to increase the recycling rate for packaging to 65% by 2026[115].

As consumers often lack the information, ability, and funds needed to manage their plastic waste properly, the role and responsibility of the industry is increasingly important. Extended Producer Responsibility (EPR) is an environmental policy approach that addresses this.

The Organization for Economic Cooperation and Development (OECD) defines EPR as an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle[116]. It is characterised by shifting responsibility to the producer, away from municipalities, and creating incentives for manufacturers to consider environmental considerations in product design.

Under EPR, producers must ensure the collection, sorting, and recycling of their products, which can be done either through funding municipal programmes or operating the programmes themselves[117]. An EPR system is operated by a Product Responsibility Organisation (PRO), which manages the fees and issues contracts with waste management operators and municipalities. This organisation can be run by producers, a third party, a government, or a combined system[118]. Instruments implemented in an EPR system include product take-back requirements, deposit return schemes, or advance disposal fees.

EPR regulations vary across the EU. The European Packaging and Packaging Waste Directive aims to harmonise them by requiring member states to set up systems for the return and/or collection and reuse or recovery of used packaging in line with the EU's recycling targets by 2024. By 31 December 2025, at least 65% of all packaging waste by weight must be recycled, which will be 50% of all plastic. By 2030, this must rise to 70% or 55% of all plastic[119].

The European Commission believes a harmonised EPR scheme will have far-reaching benefits, enabling consistency of product design and more effective waste flows and infrastructure investment, reducing the costs of circulation of materials, scaling up waste collection, and helping to establish traceability and transparency[120].

Research shows that EPR policies have accelerated the collection and recycling of target material to over 75% in **British Columbia, Belgium, The Netherlands, Spain,** and **South Korea**[121]. **Belgium's** EPR scheme has been in place since 1996, leading to one of the highest recycling rates in Europe and encouraging waste prevention programmes across the country[122]. The system is divided between a PRO for household packaging and another for industrial and commercial packaging. It was extended to cover various single-use plastic packaging and items in January 2023[123].

Deposit Return Schemes (DRS) are a policy requiring consumers to pay a small deposit when purchasing drinks in single-use containers, which they then redeem by returning to a "reverse vending machine" collection point. Producers administer and fund collection points, making it an important policy instrument for EPR. Retailers like Tesco, Aldi, and Morrisons have already piloted digital DRS programmes, which provided a mobile phone app through which people could claim their 10p reward for recycling drinks containers[124].

Germany, Finland, and **Denmark** have had DRS in place for over two decades and have achieved 90% recycling rates for PET plastics[125]. There has been a wave of other European countries adopting DRS in recent years, with one of the most successful being Lithuania in 2016, which recovered 70% of drinks containers in the scheme's first year and over 90% in its second year[126].

DRS follows either a return-to-retail or a return-to-depot model. The return-to-retail model holds drinks retailers responsible for recovering empty containers. In contrast, the return-to-depot model requires consumers to return containers to a collection centre. The return-to-depot model is implemented in parts of the US and Canada, but the only example in Europe is **Iceland**, which achieved an 85% collection rate in 2016 despite the additional responsibility placed on consumers[127].

Informed consumers

Consumers consistently show high levels of interest in sustainable plastics and more circular models. In Trivium's 2023 Buying Green report, 79% of consumers stated that they look for products in sustainable packaging. Young people are particularly enthusiastic, with 88% of consumers younger than 45 willing to pay more for sustainable packaging[128].

However, survey results also indicate insufficient supply to meet the demand. More than half of the respondents say that most of the products they buy do not have sustainable packaging. 46% said that unclear labelling is a barrier they face when thinking about purchasing products with sustainable features. The findings illustrated a lack of understanding about recycling and the diversity of plastics and their properties, suggesting a need for simplification of available plastic products, collection processes, and better public communication initiatives regarding plastics.

While policy improvements to expand recycling infrastructure will help address public knowledge gaps, innovation in plastic materials and technology will also play a key role. As recycling literacy improves, the public will gain more exposure to recycling-friendly product design. Plastics are diverse and complex materials, and many consumers are unaware of the need to properly sort and separate their plastic waste to enable recycling[129]. Changing consumer perception is also essential for incentivising reuse. People are accustomed to single-use packaging and often perceive reusable packaging as unsanitary or contaminated; overcoming this perception barrier by proving that reusable packaging is safe and viable will be essential.

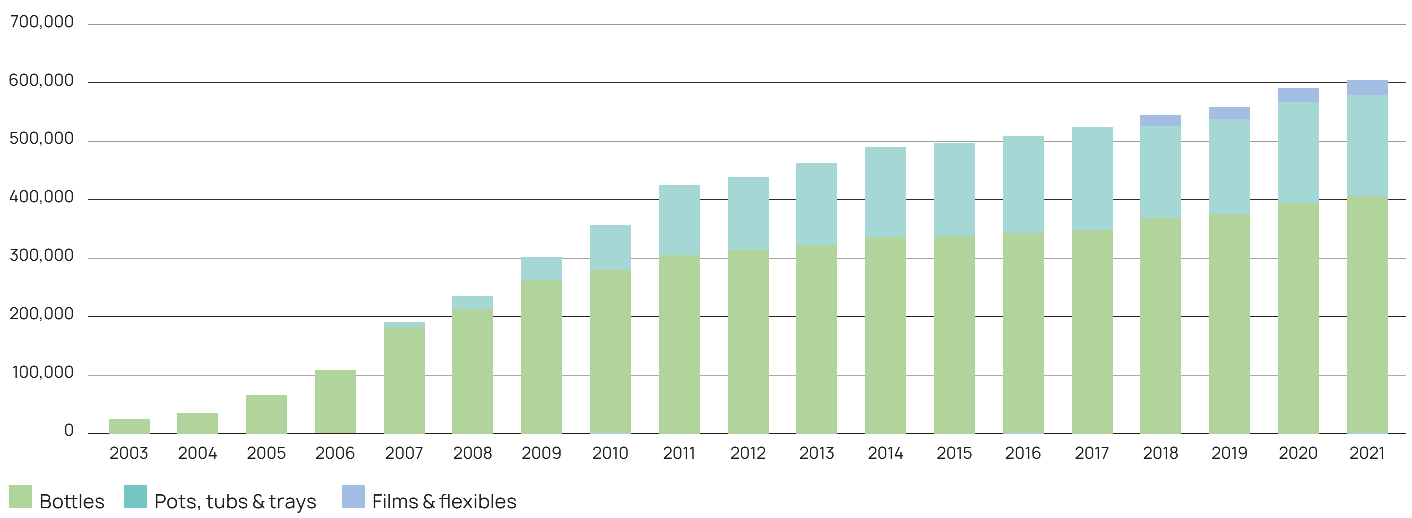
Snapshot: Taking the UK circular

Recycling has been implemented in the UK since the 1980s, initially as a voluntary measure by industry. In 1997, the Government's Producer Responsibility Obligations Regulations implemented more thorough household collection schemes[130]. During this time, recycling has grown to 400,000 tonnes of household plastic per year[131].

However, significant amounts of plastic go unrecycled, and their value is lost to incineration or landfilling. In 2018-19, 43.8% of municipal waste collected in England was incinerated, the largest single waste management method, with 16.8% of waste across all of the UK landfilled in 2017[132, 133]. The global warming potential generated by landfilling or incineration is double that of recycling, which means the UK's plastic consumption results in 26 million metric tons of carbon dioxide equivalent emissions over the entire lifecycle. Recycling saves a significant amount of GHG emissions by reducing the need for new fossil fuel feedstocks[134].

Figure 8: **UK plastics collected.**

IN TONNES



Source: RECOUP[8]

Landfilling has decreased as local authorities have improved efforts to separate and recycle plastics, leading to a five-fold drop in standard waste sent to landfills between 1996 and 2015. Still, only 12% of plastic waste, 0.4 million metric tonnes, gets recycled domestically. Another 0.7 million metric tonnes gets shipped abroad, where it is impossible for UK authorities to verify whether or not it is recycled or repurposed, and where its value as a material or a feedstock will be lost to the UK economy. Currently, only 1% of the UK's plastic demand is met by recycled plastic[135].

For this number to increase, the UK must significantly ramp up recycling capacity; mechanical recycling levels must double to reach future targets by 2030. While the technology exists to recycle all common plastics, the UK does not have the capacity to do so, and the amount of recyclable plastic exported abroad will need to be retained in the UK to supply the demand for recycled plastic in a circular model. The volume of plastics going to recycling could increase fivefold by 2030, to 220 million metric tonnes per year, if the plastic currently sent to landfill and incineration is redirected and recycling capture improves[136]. Increasing recycling capacity in the UK could reduce 20% of UK plastics emissions by 2050[137].

Figure 9: **Plastics recycling statistics.**

361 local authorities in the UK in 2023
100% collect plastic bottles
88% collect plastic PTT
12% collect plastic film

1,154,000 tonnes of plastic packaging declared as recycled from all sectors in 2022
52% recycling rate

Advice to citizens
35% lids on bottles
49% flatten & squash
74% empty & rinse

1,025 HWRCs in the UK at which
120,000 tonnes of plastic packaging and non-packaging is disposed of annually

>13 billion plastic bottles are used each year in the UK
8.5 billion collected for recycling
4.8 billion NOT collected for recycling

80% of local authorities ran a recycling communication campaign in the last 12 months

Key policy areas
- Extended Producer Responsibility (EPR)
- Deposit Return Scheme(DRS) in England, Wales and Northern Ireland
- Deposit Return Scheme(DRS) in Scotland
- The Plastic Packaging Tax
- Single-Use Plastics (SUP)
- Simpler Recycling

578 kt of household plastic packaging collected for recycling in 2022
29% plastic PTT
66% plastic bottles
4% plastic film

~46% of UK waste plastic packaging declared as recycled is exported
Main export destination Turkey

Residual waste treatment
34% reported they recover recyclables from residual waste streams
82% energy recovery
16% landfill

Household collection rates
63% plastic bottles
39% plastic PTT
7% plastic film

21 kg of plastic packaging collected per household
14 kg plastic bottles
6 kg plastic PTT
1 kg plastic film

At kerbside local authorities collect recycling materials:
75% use wheelie bins to collect plastic for recycling at kerbside
57% source-separated
43% co-mingled

42% overall collection rate of all consumer plastic packaging in 2022
53% overall collection rate of all rigid plastic packaging (bottles and PTT) in 2022

60% of local authorities reported fly-tipping to be a greater concern in their area than litter
Of those who shared an opinion 51% felt their area was predominantly free of litter and refuse apart from small items.

Drinks bottle collection rates
76% PET bottles
78% natural HDPE bottles
45% non-drinks bottles

Source: RECOUP[9]

The UK Government has taken steps to improve recycling, including simplifying household collections, increasing oversight of waste operators, and committing £20 million to new recycling technologies, including chemical recycling[138]. Most chemical conversion plants are still in the pilot stage. UK-based petrochemical company Mura Technology opened one of the first commercial-scale hydro-cracking plants in Teesside in 2023, with an initial capacity of 20,000 tonnes a year and the potential to triple capacity. It hopes to deliver the first recycled hydrocarbon products in early 2024 and to provide 80% carbon emissions savings by avoiding incineration, saving up to five barrels of oil per tonne of plastic waste[139].

One way of boosting chemical recycling in the UK is implementing a mass balance approach. Mass balance is a set of rules for using recycled content in a final product that uses recycled and virgin feedstock, which aims to balance total inputs and outputs[140]. With chemical recycling capacity still low, it is not yet feasible to make products entirely out of chemically recycled materials, so it is important to be able to blend recycled and virgin feedstock to use chemically recycled feedstock.

The UK is in the process of a consultation on the adoption of the mass balance approach for calculating recycled content, which the British Plastics Federation called 'the only chain of custody method that will enable the chemical recycling industry to grow, which will in turn maximise the amount of plastic the UK can recycle'[141]. A mass balance approach with oversight and traceability will incentivise using recycled feedstock and help scale up chemical recycling to meet the demand for circular products.

Quantifying the UK's circular economy opportunity

Achieving a circular economy is not just good for the environment, but also a promising growth opportunity for the UK economy. Currently, 500,000 people are directly or indirectly employed by the plastics industry[142]. On the country's current development path, the circular economy has the potential to create over 200,000 jobs and reduce unemployment by about 54,000 by 2030. A more expansive circular economy development path could create half a million new jobs and reduce unemployment by 102,000[143].

Moving towards a circular economy can address labour challenges in the UK. Infrastructure and facilities can be built across the country, addressing regional unemployment disparities. It can benefit existing manufacturing sites, where unemployment tends to be higher, as these sites can be repurposed for circular economy activities which will help unemployed former workers in these areas[144].

Additionally, waste disposal leads to significant economic losses, and reuse in a circular economy enables retaining the value of products made in the UK. Adopting a circular economy model could contribute £75 billion to the economy by 2030[145]. Though a linear plastic consumption model is still economically compelling for businesses, this can be addressed through legislation that limits the use of difficult-to-recycle materials. This will allow reuse models to compete on a more level playing field as the actual costs of waste disposal are accounted for.

Table 1: **Potential for a circular economy.**
A more detailed report of this work is available, providing full information on the analysis, calculations and data sources[1].

	Scenario 1 No new initiatives	**Scenario 2** Current development rate	**Scenario 3** Transformation
Gross jobs growth[2]	31,000	205,000	517,000
Net job creation[3]	10,000	54,000	102,000
Unemployment rate fall	0.02%	0.15%	0.28%
% offset of predicted decline in skilled employment over the next decade[4]	1.3%	6.8%	17.7%

Note: Jobs figures are rounded to the nearest 1,000

1. J Morgan and P Mitchell, 2015, Opportunities to tackle Britain's labour market challenges through growth in the circular economy, Green Alliance/WRAP.
2. Estimated increase in labour demand from the growth in the circular economy (total jobs created directly less any jobs lost in displaced activities). No indirect or induced employment is included.
3. Estimated change in the number of people unemployed as a result of the gross job creation, after taking into account labour market interactions. No indirect or induced employment is included. These figures are the average of the net job creation estimates under the regional and occupational mismatch approaches.
4. Projections taken from: UKCES, March 2014, Working futures, evidence report 83, UK Commission for Employment and Skills.

Source: WRAP[1]

Extended Producer Responsibility in the UK

The UK is set to implement its own EPR scheme in 2025, targeting 62% of packaging waste by 2030. This includes a collection scheme for films and flexibles that will begin in 2027 through separate regulations across the devolved nations[146].

This scheme will include mandatory labelling with the "Recycle Now" mark and funding for national and local communication campaigns around recycling. Under the scheme, local authorities will get close to 100% cost recovery. It can provide a funding mechanism to enable development in the recycling industry, serving as a fiscal incentive to drive up recycling rates and as a source of revenue for recycling innovation.

In conjunction with other EPR policies, deposit return schemes can also enhance the quality and quantity of recycling, promote reuse systems, and encourage eco-design[147]. They are more successful than kerbside collection at collecting higher quality plastic material, thus creating greater resource efficiency. The UK's DRS is set to be implemented in 2025 and aims to reduce the 14 billion plastic drink bottles consumed yearly, hoping to reduce 85% of drink container litter within three years[148].

Deposits of plastic and metal cans will be made across England, Wales, and Northern Ireland, though Scotland's DRS system will remain functionally separate unless interoperability agreements are made. The timeline for implementing DRS changed several times, which made it difficult for businesses to plan accordingly. In the future, having a clear, consistent timeline for policy implementation is vital so that companies can invest confidently in the necessary changes.

Product design innovation is a critical aim for EPR, as designers target reducing the environmental impact of products at the end of life. EPR measures across the UK have not yet sufficiently motivated eco and circular design among packaging producers. This is due to low compliance costs for producers and a lack of differentiation of producer fees for circular design. New incentives are therefore needed to favour circular products and incentivise sustainable product design. One example is introducing limits on the use of additives or substances that are problematic for waste management[149].

Bright ideas to boost recycling performance

- Designing for closed-loop recycling from the start.
- Extracting more recyclables from general waste streams.
- Advancing sorting to enable more targeted material separations.
- Resolving policy hurdles around food-grade recycled content.
- Developing technologies to reprocess collected materials like films.
- Expanding recycling systems beyond packaging to major products like tyres.

Private sector recycling push

Retailers and manufacturers are taking significant steps to improve recycling and reuse in their supply chain. Tesco, for instance, has a traffic light characterisation code for packaging materials based on end of life recyclability and recycled content, which incentivises their suppliers to increase recyclability. Tesco also worked with Plastic Energy, SABIC, Sealed Air and Bradbury's Cheese to create the company's first food-grade recycled flexible packaging, addressing a significant gap in recycling capacity for flexible plastics[150]. In the construction sector, flooring manufacturers Altro and Polyflor launched a vinyl flooring take-back scheme to collect and recycle waste from vinyl flooring[151].

Irish building materials company Kingspan launched its Planet Passionate initiative to implement circularity in its insulation business, minimising waste through planning and recovering products for reuse and recycling across its 200 global facilities. The company has set ambitious targets for energy, carbon, circularity and water management. In 2022, they recycled over 803 million PET bottles for use as insulation, with a goal of recycling over 1 billion plastic bottles annually by 2025. They also achieved a 42% reduction of waste sent to landfills, with a target of zero company waste sent to landfills by 2030. Through Kingspan's partnership with the ECOALF Foundation, which seeks to remove waste from the oceans, Kingspan Group member Synesthesia Technology uses recycled PET from the oceans to produce polyol, a key ingredient in insulation. Additionally, they are partnered with the World Green Building Council on the Net Zero Carbon Buildings Commitment to achieve net zero by 2030[152].

Amazon is working to make recycling its products more accessible to customers through their Recycle with Amazon and Amazon Second Chance programmes, which allow customers to send products back for recycling and provide information on how to recycle products and packaging at home[153]. Their Climate Pledge Friendly programme also makes sustainable products more visible to consumers with a green tag awarded based on sustainability certifications; the company assesses the product's sustainability to simplify selection for the customer.

Chapter 3: The Future of Plastics

Whilst it is critical to strive for a circular economy, some material loss is inevitable. With its associated environmental toll and consequent demand for new virgin production, this will require innovations in feedstocks and material design to improve the sustainability profile of new plastics.

The petrochemical industry has been developing plastic products for over a century, and the high performance of plastics reflects that time, funding, and effort. The world has relied on polyolefins, polyesters and polyamides over the last 60 years, and while there are still applications where currently fossil-based plastics are irreplaceable, such as insulation, electronics and wire coatings, there are now efforts to develop alternatives.

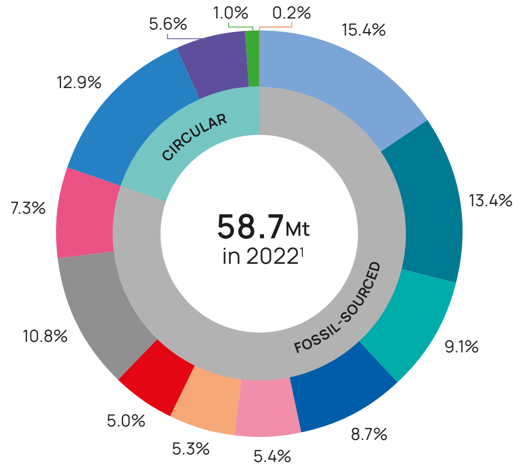


Figure 10: **European plastic production by polymer.**

- Chemically Recycled **0.2%**
- PP **15.4%**
- PE-LD, -LLD **13.4%**
- PVC **9.1%**
- PE-HD, -MD **8.7%**
- PS, PS-E **5.4%**
- PUR **5.3%**
- PET **5.0%**
- Other Thermoplastics **10.8%**
- Other Thermosets **7.3%**
- Mechanically Recycled (Post-Consumer) **12.9%**
- Mechanically Recycled (Pre-Consumer) **5.6%**
- Bio-Based & Bio-Attributed **1.0%**

1. Scope including fossil-sourced, recycled (mechanically and chemically), bio-based and bio-attributed plastics.

Source: Plastics Europe[10]

One approach is developing bio-based plastics, which are expected to help achieve some of the UN's Sustainable Development Goals like diverting fossil resources, introducing new recycling and degradation pathways, and being less toxic[154]. They can reduce GHGs, since the plants from which bio-based plastics are made temporarily remove carbon dioxide from the atmosphere[155].

Bio-based plastics are made from renewable resources such as sugars in plants and then polymerised to make either a direct replacement for an existing plastic, or a novel polymer[156]. This approach cannot yet make the same wide range of polymer types as fossil feedstocks, at appropriate scale. However, while production volumes are still small in comparison to fossil-based plastics, the market is expected to grow by 40% over the coming five years[157].

Two examples of bio-based plastics are polylactic acid (PLA), which is made using the starch from food items such as corn, cassava and sugar cane, and polyhydroxyalkanoates (PHAs), which are obtained from micro-organisms fed a high-carbon diet of sugars. These plastics are carbon-neutral[158]. PLA finds applications in industries such as healthcare, textiles and electronics, but its major use is in the packaging industry, where it is gaining popularity as green food packaging[159]. PHA appears to be a good replacement for medical devices such as inhaler casings[160]. For other applications, such as in the automotive sector, research is ongoing to replace carbon fibre-reinforced resins with flax fibres with bio-derived resins[161].

Consumer-driven companies are more concerned about plastic use and are likely to be the quickest to adopt bio-based alternatives. Coca-Cola is one early adopter in this area, having designed the world's first recyclable PET plastic bottle in 2011 based on 30% plant-based material, reaching 100% a decade later[162]. Another large consumer company, L'Oréal, is reducing their use of plastics with 26% of their packaging coming from either recycled or bio-based sources[163]. They have also developed a world-first alternative to plastic packaging, the paper bottle for packaging their cosmetics[164].

Despite their virtues, bio-based plastics do have shortfalls and trade-offs. The desire to move from fossil-based plastics to renewable feedstocks has been fraught with limitations. The use of bio-based stocks is expensive, and current supplies are far from able to satisfy overall demand for plastics[165]. Scaling can cost billions, and the resulting product is more expensive. There is no certainty around the long-term price evolution of fossil-based plastics, although there is hope that the cost of bioplastics will come down as supply increases.

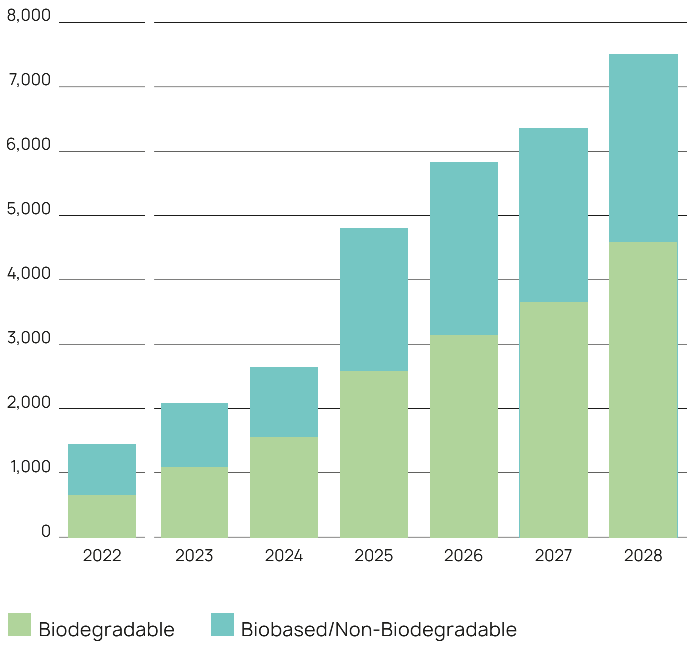
Another challenge is that bio-based plastics' benefits over conventional plastics depend on factors such as the manufacturing process[166]. A recent study found that some bio-based plastics contain toxic additives and are similarly harmful compared to conventional plastics, with cellulose and starch-based products showing the strongest in vitro toxicity[167]. Toxicity was less prevalent and potent in raw materials than in final products. Many toxic chemical additives in conventional plastics are required to keep plant-based plastics waterproof, flexible, durable and colourfast[168]. Their additives can be as toxic, or even more toxic, than conventional plastics, making them harder to recycle and less of an eco-friendly, non-toxic alternative to plastics.

A second challenge is the conflation of the terms bio-based plastics and biodegradable plastics. Bio-based plastics are not necessarily biodegradable: bio-based plastics are derived from non-petroleum sources, while biodegradable plastics break down on exposure to naturally occurring microbes[169].

Because the term biodegradable is poorly understood by consumers, it may create an assumption that it disappears in the environment[170]. Labelling standards should ensure that the terminology used to describe plastics accurately represents its impacts. While leakage of plastics in the environment should be avoided, it will inevitably occur in some cases, and efforts should be taken to make sure that harm is reduced if they do degrade in nature. Biodegradable plastics may still have a part to play in helping tackle plastic pollution, as they play a helpful role in reducing waste in short-term and single-use applications. These include organic waste collection and diversion, mulch-films, food packaging and disposable tableware[171].

Research has shown that soils containing mulches of PLA change how nutrients are cycled due to a carbon-priming effect on the microbial community. There is a need to understand whether biodegradable plastics change the function or diversity of the microbial population. Still, the presence of additives means that these could be released into the environment.

Figure 11: **Global production capacities of bioplastics.**



Source: European Bioplastics[11]

Prices and economic dynamics are in flux, and could influence the evolution of bio-based approaches. Bioplastics were originally introduced due to concerns about running out of oil; plastics were growing exponentially, and thoughts turned to alternative feedstocks. There is now less urgency, and it has been difficult for bio-based polymers to compete with petro-polymers on a price basis. Oil and gas logistics are more centralised and efficient compared to agricultural or forestry feedstocks, which are more distributed and fragmented. However, this preference for oil and gas may be changing, as geopolitical uncertainties have led to increasing price volatility and traditional petrochemical companies are looking for other sources of revenue, driving interest and investment in bio-based materials[172]. Another factor impacting cost is that oil and gas are often imported, while agricultural and forestry feedstocks are easier to source locally, thereby driving down costs and having a greater impact on local income and employment[173].

The variable costs of renewable feedstocks influence the cost of bioplastics, and alternative, less expensive feedstocks are currently the focus of research to develop new products. Engineered strains of bacteria are able to produce PHAs at a reduced operational cost[174] and research on synthetic biology to produce intermediates directly from agricultural waste via engineered microbes is promising to avoid the challenges of traditional biotech.

Advocacy groups have tabled policies to improve the economics of bioplastics. European Bioplastics, for example, released its Policy Manifesto, which calls on the EU to accelerate the growth of the bioplastics industry while prioritising six key points that include incentivising access to sustainable biomass, enhancing financial support for innovation and increasing market uptake[175].

Other feedstocks could also enter the fray, such as carbon dioxide extracted from energy-intensive plants together with renewable hydrogen to produce intermediates. The £5.4 million Flue2Chem project is a two-year programme spearheaded by Unilever and SCI and aims to take waste gas from industries such as metal, glass, paper and chemicals and generate an alternative source of carbon for UK consumer products[176]. Carbon Clean, the company spearheading the research, is also working on a carbon capture project where captured carbon dioxide will be combined with green hydrogen to produce synthetic hydrocarbons for use in other industries[177].

The OECD has used patent counts to determine innovation in environmentally relevant plastics technologies. These were placed into three broad categories: innovations for plastic circularity (preventing and recycling), innovations for converting or disposing of waste and removing plastic leakages from the environment, and innovations in bio-based feedstock. Innovation in plastics circularity has grown the most from 1990 to 2017[178].

One innovation is in redesigning thermoset polymers to ensure they have dynamic covalent bonds, which allows them to be reshaped, reprocessed and recycled. Thermoset polymers are sought after for their high strength and stability, but their existing structure limits their potential for recycling. When made with dynamic covalent bonds, the polymers are known as 'recyclable by design' and promote the circular economy[179].

Chemical safety regulation: Beyond REACH?

Another key trend shaping the future of plastics, and opportunity for innovation, is regulation. The European Union Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) legislation is an influential broader regulatory framework for plastics. REACH establishes procedures for collecting and assessing information on the properties and hazards of substances[180].

Under these procedures, all companies must register their substances with The European Chemicals Agency (ECHA). The ECHA receives and evaluates individual registrations for compliance, and the EU Member States then evaluate selected substances to clarify any initial concerns for human health or the environment. REACH applies to manufacturers, importers, and downstream users who handle chemicals in an industrial or professional capacity.

The legislation aims to register and restrict the use of substances of very high concern[181]. These are substances that are carcinogenic, mutagenic, and reprotoxic (CMR); those that are endocrine disruptors; those that are persistent, bioaccumulative and toxic (PBT); those that are very persistent and very bioaccumulative (vPvB); immunotoxicants, neurotoxicants, and substances toxic to specific organs; and respiratory sensitisers. The dangerous substances prioritised under the chemicals restriction roadmap (a roadmap for REACH reform aiming to address entire groups of chemicals across broad uses) include PFAS, bisphenols, and flame retardants. However, this roadmap has been slow to come into effect.

REACH restricts bisphenol A (BPA) as of 2018 and specifically restricts its use in thermal paper as of 2020[182]. However, the roadmap aims to go further and restrict bisphenols as a category, as some uses of BPA have currently been replaced with the potentially equally harmful bisphenol S (BPS), which was also restricted as of late 2023. In 2023, new rules were added under EU REACH to restrict microplastics intentionally added to products, covering all synthetic polymer particles below five millimetres that are organic, insoluble and resist degradation[183].

After 16 years of operation, studies suggest a need for REACH reform to fix the shortcomings, such as preventing the harmful impacts cosmetic ingredients can have on the environment or ensuring that sufficient evidence is generated to enable effective identification of endocrine disruptors[184].

Other shortcomings include:

- A lack of hazard data that prevents the identification of hazardous substances and their proper risk management, coupled with a lack of regard to the fact that our exposure is to a mixture of chemicals, not single chemicals;
- Slow and ineffective regulatory measures to limit the use of substances of high concern in products and industrial processes;
- A lack of information and regulation of hazardous polymers;
- A lack of data on the uses of chemicals, hampering (targeted) risk assessment, (regulatory) risk management and risk communication[185].

Since exiting the European Union, the UK has departed from REACH, initiating a process to install its own version. With the shortcomings of EU REACH comes the opportunity for the UK to improve its own regulatory framework. However, the implementation of UK REACH has faced multiple hurdles that have led to repeated delays in the restriction and registration of chemicals[186].

The UK seems to be falling behind in adding hazardous chemicals to its list of substances of very high concern. The EU has reportedly added 24 to its list since the UK left the EU, but the UK have added none, although Defra is considering four of those added by the EU in 2021[187]. One of the substances added by EU REACH in 2023 was bis(2-ethylhexyl) tetrabromophthalate, used as an additive for flexible PVC[188], a commonly used plastic.

There have been debates about how the UK could improve on their approach to REACH legislation. UK NGO Chem Trust has suggested the UK follow Switzerland's example, which does not require companies to register chemicals but adopts EU chemicals standards while reserving the right to take a different stance when needed; this will require independent oversight[189].

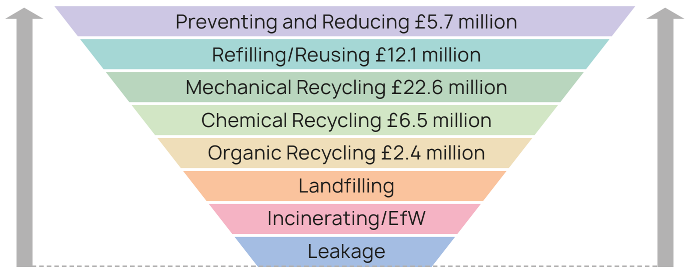
Another solution would be a new data agreement that grants the UK access to ECHA's database, but few consider this a realistic option. NGOs are wary of changes that would make UK REACH

diverge from its EU counterpart, which is unanimously seen as the most protective law on chemicals in the world[190]. The Government remains positive that UK REACH provides freedom to make regulatory decisions based on risk and exposure patterns to human health and the environment in Great Britain. For example, some parts of the EU have significantly more heavy industry than the UK[191].

The bulk of the UK's chemicals legislation was enacted in compliance with REACH when the UK was part of the EU. Under the European Union (Withdrawal) Act 2018, REACH was brought into UK law on 1 January 2021 and is known as UK REACH[192]. It replicates EU REACH alongside the changes needed to make it operable in a domestic context. The UK REACH and the EU REACH regulations operate independently from each other. Companies must ensure they comply with both regulations, which has increased costs for industry. Companies need to register with the UK Health and Safety Executive (HSE) as well as ECHA.

The 2022-2023 work programme on UK REACH prioritises PFAS[193], intentionally added microplastics, formaldehyde and formaldehyde releasers, bisphenols in thermal paper, and flame retardants, keeping it aligned with the current priorities of EU REACH revision. While provisions remain aligned currently, UK REACH could diverge from EU regulations long term, particularly if the UK does not work to replicate the chemicals restriction roadmap on the same timeline as the EU.

Figure 12: **UKRI Smart Sustainable Plastic Packaging grants.**



Source: Smart Sustainable Plastic Packaging (ukri.org)[12]

Towards a Sustainable Plastics Centre of Excellence for the UK

Thanks to its academic and industrial prowess, the UK should contribute to the future of sustainable plastics innovation, but in recent years, it has punched below its weight. Many companies are operating old equipment, and the workforce shows a widening skills gap. The UK could benefit from a centre of excellence that could pool skills and resources and coordinate cross-sector collaboration.

Germany has demonstrated the value of institutional coordination through the Fraunhofer Institute which catalysed progress in applied sciences. In The Netherlands, the Dutch Polymer Institute also demonstrated excellence in bringing together industry, academia and government around key research topics relating to polymers.

The demise of Imperial Chemical Industries (ICI), which powered UK innovation in chemistry in the post-war period, had a major impact on polymer research and education. General polymer research has retreated to niche applications like biomaterials rather than core manufacturing technologies. However, lately, two UK government-backed industry-focused innovation programmes - the Plastics Research and Innovation Fund and the Smart Sustainable Plastics Packaging challenge - have both supported industry innovation, predominantly in the packaging sector[194].

Part of the problem for innovation, say experts, is a short-term policy cycle. Innovation requires significant capital investment; for example, SABIC invested £850 million in its hydrocarbon cracker to run on hydrogen in a refinery in Wilton Teesside[195]. Encouraging such large outlays requires a shift from politically-driven short-term policies to predictable, strategic frameworks that businesses can rely on across economic and political cycles.

Government innovation funding has cultivated private sector innovation, notably the UK Research and Innovation's Smart Sustainable Plastic Packaging Challenge which is deploying £60 million of public funding alongside £149 million of private funding to sustainable plastic projects through 2025. Projects include early research, collaborative Research and Development (R&D), and large-scale demonstrations of new technologies, including the UK's first commercial-scale chemical recycling plant and the world's first mechanical recycling plant creating food-grade recycled polypropylene. So far, the initiative has spent and committed over £55 million, with 30 completed, and 55 active, projects.

Chapter 4: Data Deep Dive

Sustainability data and metrics are critical for quantifying the social and environmental impact of different plastic products, providing evidence to improve material decision-making, and tracking progress. Only by collecting data on life cycle factors like recyclability rates, product lifespan, and carbon emissions, can companies and governments make informed decisions.

By regularly quantifying sustainability performance through scientifically validated metrics, the plastics industry can transition from traditional plastics reliant on fossil fuels for production and conversion towards more sustainable alternatives. Consistent, comprehensive, transparent, and understandable reporting that accurately represents sustainability performance, will improve decision-making and accountability and provide a benchmark for progress.

With increasing consumer demand for environmentally friendly goods, the accuracy of product sustainability labels is paramount, as terms such as 'green', 'recycled', and 'biodegradable' are often the main signal to consumers of a product's environmental impact. But nearly half of consumers state that unclear labelling is an obstacle to purchasing sustainable products[196]. Accurate assessment of plastic products and effective labelling are both key components of a sustainable plastics strategy, but 53% of green claims in Europe give vague, misleading, or unfounded information, while 40% of green claims in Europe have no supporting evidence at all, making it very difficult for consumers to make informed decisions[197].

Standardisation of labelling that effectively communicates environmental impact is an important step to facilitate sustainable consumption. The UK is taking a step towards standardising recycling labels with its planned EPR initiative, which will apply a single, UK-wide approach to plastic packaging labels. The current non-mandatory labels of "widely recycled", "check local recycling", and "not currently recycled" will be replaced with mandatory "recycle" and "do not recycle" labels from 2026[198]. Defra also conducted a consultation on the incoming DRS in England, Wales, and Northern Ireland that showed 95% support for mandatory labelling of products with a DRS logo[199].

Commonly made green claims, such as "biodegradable" and "compostable", need to be monitored to ensure accurate usage. There is potential for the term "biodegradable", in particular, to be misused or misunderstood, as many products can be labelled biodegradable but take decades to break down in nature. There are technical industrial standards defining these terms, but they are often not understood by wider audiences.

Towards holistic life cycle assessment and sustainability data

Life cycle assessment is a method designed to evaluate a product's social and environmental impact from extraction and processing of raw materials, manufacture, transport and distribution, use and retail, repair and maintenance, and end of life disposal or recycling[200]. A comprehensive assessment considers environmental impacts ranging from carbon emissions to resource depletion and soil acidification. They are typically conducted by a company in consultation with outside experts, although they are also undertaken by government agencies or researchers who have created publicly available databases for use by others.

LCA Stages

Defining the goal and scope: the reasons for carrying out the assessment, the intended audience and end-use, and how much of the product's life cycle will be addressed.

Inventory analysis: understanding the material and energy flows involved in the product and their interactions with the environment.

Impact assessment: defining the impacts of the elements of the inventory analysis and their importance.

Interpretation: critical review of the findings and data.

Source: Plastics Europe[201]

Governments and international standards bodies support and shape LCA and sustainability reporting. Policy frameworks such as the European Strategy for Plastic in a Circular Economy[202] require that innovative feedstocks and alternatives to plastic "are developed and used where evidence clearly shows that they are more sustainable than non-renewable alternatives". Such frameworks highlight the importance of metrics and tools for assessing sustainability[203].

As countries pursue net zero and set goals for plastics, it is increasingly important for companies to accurately manage and report on their environmental responsibilities as they work to meet mandatory industry standards. This will enable better corporate sustainability reporting, provide evidence to back up companies' sustainability claims, and connect to a broader increase in sustainability reporting in the commercial sector[204].

Currently used LCAs, however, suffer from certain deficits. When it comes to plastics, they can be insufficiently holistic, such as not including littering potential or lacking a definition of a full life cycle. They depend heavily on the quality of the available data and of the skill of the LCA practitioners, and are therefore very difficult to standardise across industries and regions[205].

Companies decide on the consultants they select and the lifecycle scope of the assessment which can lead to biased LCAs geared to obtain a result that justifies the status quo. Traceability in supply chains is also nascent; for individuals in the packaging value chain, it is difficult to trust existing sustainability data. These issues are not unique to plastics, but they do become more pertinent given the length and complexity of the supply chain. Peer reviewing results from an LCA study is one way of giving stakeholders more confidence in the results.

Data is also insufficiently granular. Decisions must be made based on localised data that reflects a specific supply chain model, and comparisons between LCAs must be within that shared local context. While collecting sufficient data to compare LCAs accurately is a complex and time-consuming process, truly granular quantitative analysis is critical for determining the optimal logistics, especially in packaging, where environmental impact is highly dependent on the nature of the product.

An LCA on reusable glass milk bottles compared to single-use plastic bottles offers one example of the importance of context. The critical factor in this case was distance from the dairy. Within 25 miles, reusable glass washed locally was the more sustainable option; beyond 25 miles, single-use recyclable plastic was more sustainable, as the lighter weight reduced emissions from transport. In a comparative LCA of plastic and paper bags, the paper bags were shown to have a higher global warming potential as a result of the fertiliser used in tree farming and plantation, the water usage in cardboard production, and the ecosystem damage caused by the land use required for wood production[206].

Comparative LCA studies show that plastic can be a better option for human and marine health when compared to aluminium cans, which showed disproportionately higher toxicity rates due to high emissions of toxic hydrocarbons and hydrogen fluoride[207]. However, care needs to be taken when using any LCA and assuming it represents a product or material's sustainability. Very few LCAs claim to measure the objective sustainability of the object of enquiry but rather offer a partial analysis with reference to an external standard or regulation.

When conducting a comparative LCA of chemical recycling and mechanical recycling, mechanical recycling appears to be the more sustainable option. However, chemical recycling uses material that cannot be mechanically recycled; therefore, there is the possibility that the application of a conventional LCA of these two processes with incompatible feedstocks will not yield a valid comparison due to problems with the selected boundary of this LCA. Instead, chemical recycling should be benchmarked against landfilling, the alternative end of life solution for materials that would otherwise be chemically recycled. In this case, it is more likely that the results of these comparative LCAs would favour chemical recycling over landfilling in cases where mechanical recycling is impossible. However, there are likely to be additional dimensions of sustainability that are not included in this evaluation exercise, e.g. air pollution, human health impacts or future affordability.

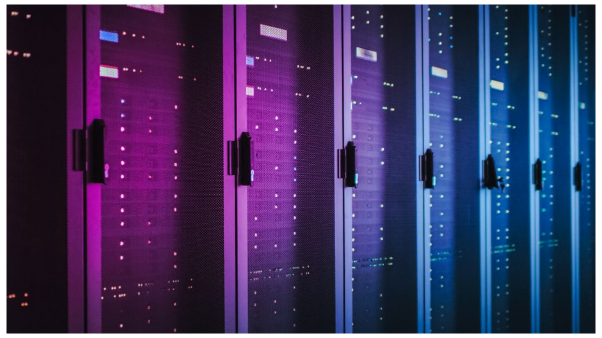
LCAs and sustainability assessments, which aim to inform a decision about the sustainability of materials, must be based on robust, relevant, and contextually appropriate data, while ensuring they include critical differentiating criteria. It is difficult to numerically quantify the impacts of potential future improper waste disposal without making assumptions based on expected or probabilistic behaviour. These assumptions can include the availability of land for landfill sites, the quantity and type of energy used in recycling the product, models of the leaching of chemicals into the environment, and other processes that are similarly difficult to accurately track and measure at end of life[208]. Improving data quality and availability will help, but more research and standardised methodologies are still needed to better account for end of life impacts in LCAs.

One difficulty is in accessing useful datasets on waste outputs and their environmental impact. Many LCAs are undertaken at the expense of companies and thus considered private or commercially confidential. This means companies may be spending money on LCA and data that others already have.

Greater data sharing and even public subsidies for LCA open access data could avoid duplication.

Methodologies also need to improve. Sustainable solutions depend on the capacity of an evaluation protocol to differentiate the sustainability impacts of different proposals. Accordingly, any protocol must be informed by a complete mapping of the whole lifecycle of plastic, from feedstock to end of life, and account for multiple time frames, stakeholder perspectives, and future scenarios, as well as measuring positive and negative impacts relative to frameworks such as the UN Sustainable Development Goals.

Given the complexity, ubiquity and multi-functionality of plastics, there is no universally applicable method of evaluating sustainability. The absence of a universal standard creates problems in meaningfully comparing or combining findings from different sustainability assessment methods. This prompts a need to establish a sustainable evaluation protocol that reflects the realities of how plastic positively and negatively impacts people's lives and natural systems. Developing such a protocol will provide a framework for identifying what is, and perhaps more importantly, what is not included in any specific LCA. Understanding the underlying scope of any sustainability assessment is critical to appropriating any findings into different decision use cases.



Database power

The collection of granular data required for an accurate LCA is greatly facilitated by third-party LCA databases. They house data on the material and energy flows into and out of systems and the associated environmental impacts, including greenhouse gas emissions, land use, and toxic chemical releases, and are expressed per functional unit of the product or process. Their sources include industry reports, national statistics, inventory datasets, and scientific literature[209].

Large LCA databases can host data on thousands of products, materials, and processes; even those focused on a particular country or sector can be extensive. Various free and open LCA databases are available, like IMPACT World+ and the US Life Cycle Inventory Database. However, as data quality and reliability of sources are crucial, some companies choose to pay for the services of commercial databases, like ecoinvent and GaBi.

LCA databases are contingent on the quality and relevance of available data and must change rapidly alongside new developments in research. For example, researchers in 2020 found that methane emissions from fossil fuels are 25-40% higher than earlier estimates[210]. These findings indicated that fossil fuel extraction and combustion were responsible for an even larger proportion of climate change than previously known. This required a shift in LCA database data, counting naphtha as contributing up to 40% more methane. Incomplete data remains an issue for LCA databases, so consistent data quality review should be a priority[211].

While there are various methods of creating an LCA, the European Union is working to improve consistency across its member states by encouraging use of the Product Environmental Footprint (PEF) and Organisation Environmental Footprint (OEF) methods, which were outlined in an EU Commission Recommendation in December 2021[212]. The European Commission recommends that European companies produce LCAs per these methods to ensure consistent and comparable LCAs. The European Commission also developed the International Life Cycle Data (ILCD) system to create a common basis for data, incorporating several existing LCA databases. It includes data from the Italian National LCI Database, the Plastics Europe database, and the Environmental Footprint (EF) database, among others[213].

The PEF and OEF methodology is not yet mandatory, but it is in a pilot phase expected to be completed by the end of 2024. However, it has already influenced the LCA process in the European construction sector by initiating new product declaration requirements under the EN15804 standards that align companies with the PEF methodology, including calculations for the end of life benefits of recycling and six additional environmental impact categories[214].

Creating national and international LCA databases can help ensure that data is accessible, up-to-date, and locally relevant, as well as encouraging standardisation and consistency across LCA studies as practitioners have access to the same data standard. The UNEP has recommended the creation of national databases, providing a roadmap for countries. As well as the European Union, government agencies in Brazil, Malaysia, Switzerland, Thailand and the U.S. host their own LCA databases. The European Commission's influence has extended beyond Europe, as national databases in Brazil, Malaysia, and Thailand use the ILCD system. Databases using the ILCD system have consistent nomenclature and formatting and enable data interoperability.

The development and expansion of national LCA databases also encourages the increased use of LCA for policy making. For example, LCA analysis of greenhouse gas emissions provided support for the establishment of sustainability requirements for biofuels under Europe's Renewable Energy Directive. It also impacted the standards for environmental labelling under the European Single Market for Green Products.

Various non-profit organisations and commercial LCA databases offer support to countries seeking to develop a national LCA database. India is developing a national database[215] based on a roadmap produced in partnership with Life Cycle Initiative's Development of National LCA Database Roadmaps project[216]. Coordinated by the ecoinvent Association, this project represents a public-private, multi-stakeholder partnership aiming to improve national LCA landscapes. India's goal is to match global best practice but adapt it to the local context with a combination of new and existing data and LCA software. They have set up a national database working group (NDWG) to guide the roadmap alongside government research institute CSIR-NEERI to ensure they can access government resources and authorisations.

Sustainability data in the UK

LCA in the UK is covered by the standards of the International Organisation for Standardisation (ISO)[217]. Two standards impact LCA: ISO 14040:2006 and ISO 14044:2006. These standards define the goal and scope of an LCA, including its four phases, limitations of the LCA, and conditions for the use of value choices and optional elements. It does not require any particular techniques or methodologies. While the definition of the goal and scope considers the intended application, the application itself is outside the scope of the standards.

The British Standards Institution also developed Publicly Available Specification (PAS) 2050 as a standard for greenhouse gas-specific LCAs. Developed in 2008 and revised in 2011, this standard defines requirements for recording GHG impacts[218]. It is complemented by the GHG Protocol Product Standard, which includes requirements for public reporting. The two standards are broadly consistent in their approach to sector and product-specific rules and recognise the importance of consistent application of standards. UK LCA practitioners must consult both documents when assessing GHG emissions to ensure they comply with both standards.

The UK Green Claims Code requires that businesses offer clear explanations of any LCA they have done to back up green claims and be forthcoming about the limitations of a given LCA[219]. It also requires that LCAs remain up to date if they are used to back up green claims.

UK companies still have a great deal of freedom in choosing how to conduct an LCA. So far, no mandatory LCA regulations apply internationally beyond the ISO standards. However, as Europe moves forward with the standardisation of PEF and OEF methods, UK companies may increasingly be incentivised to comply with these standards to remain competitive in European markets. The ILCD system has already influenced LCA databases in Asia and South America, suggesting a trend towards standardisation and shared data across borders. The UK should, therefore, begin to move towards developing a more robust methodology that is consistent with international standards, building on the ISO and GHG Protocol requirements. The British Plastics Federation envisions an agreed methodology for LCA by 2030, forming part of all product design.

Procurement power

One way in which governments can positively influence LCA practices and standards is to require best-in-class ESG and LCA standards in public procurement. Among countries implementing sustainable public procurement, the number of those that monitor and evaluate its implementation increased from 66% in 2017 to 73% in 2022, indicating growth in sustainability data collection[220].

The UK has already demonstrated positive progress in utilising procurement to drive ESG performance more broadly. NHS England published a roadmap to implement sustainable procurement policies through 2030. From April 2024, all new NHS suppliers must publish a carbon reduction plan for their Scope 1 and 2 emissions, with guidelines on how these plans must be implemented[221]. From April 2027, all suppliers must publicly report targets and emissions and align them with the NHS net zero by 2040 target for Scope 1, 2, and 3 emissions. They will also implement requirements for measuring the carbon footprint of individual products from 2028[222]. The NHS is a significant player in the UK economy, with healthcare spending representing 11.3% of GDP[223] and the healthcare system being one of the biggest users of single-use plastics[224].

As a public body, the NHS can provide a model for other public-sector organisations in implementing sustainable procurement standards. The UK government is already aiming to drive innovation through procurement, as laid out in the 2023 Procurement Act[225]. Innovate UK's Small Business Research Initiative (SBRI) is one initiative that has been used to drive sustainability in procurement and encourage the development of sustainable products. SBRI has already awarded millions to projects looking to drive sustainability in healthcare, including a project by Revolution-ZERO to produce circular surgical textiles to replace single-use gowns and drapes[226]. The Welsh public sector is looking to implement sustainable procurement more broadly, aiming for net zero emissions in the public sector by 2030 and actively seeking SBRI projects that will reduce waste and retain the value of materials to progress the circular economy[227]. Similar sustainable economy procurement strategies can be implemented across public bodies in England, Scotland, and Northern Ireland, as the NHS roadmap has shown.

Conclusion

A clean future for plastics

The coming decade has rightly been described as 'make or break' for humanity to bring consumption into alignment with our planetary boundaries. The challenge of changing the engine of the world economy is not insignificant, however the opportunities presented by this change cannot be understated.

The sun must set on polluting resources, but plastics, an industry that emerged out of the fossil fuel sector, cannot be dispensed with. A circular economy model and innovations across the life cycle will allow us to preserve this essential material in a means compatible with sustainable consumption. To support policy makers to draw up effective reforms at both the national and global level, this Commission has put forward a series of ambitious but practical measures, informed by expert evidence and the latest science. None of the steps are easy, or without risk. But failing to act would be a graver gamble.

Appendix: Witnesses

alphabetically by surname, witnesses include:

Dr Margaret Bates, Managing Director, On Pack Recycling Label (OPRL)

Dr Esther van den Beuken, Market Manager Circularity, TNO

Christine Bradley, Sales Manager - Plastic Additives, BASF

Dr Geoff Brighty, Head of Sustainability, Mura Technology Ltd

James Bull, Head of Packaging and Food Waste Strategies, Tesco

Rowan Byrne, Marine Plastics Lead, Mott MacDonald

Ian Chisnall, Product Manager - Polyolefins, Plastribution

Hannah Clifford, Strategic Development Manager, Biffa

Dr Matthew Cole, Senior Marine Ecologist and Ecotoxicologist, Plymouth Marine Laboratory

Catherine Conway, Director and Reuse Lead, GoUnpackaged

Dr Paul Davidson, Challenge Director - Smart Sustainable Plastic Packaging, UKRI

Ben Dixon, Partner, SYSTEMIQ Ltd

David Dyce, Senior Waste Management Consultant, Vegware

Dr Jacqualyn Eales, Senior Research Fellow - Evidence Synthesis, University of Exeter

Paul East, Head of Packaging Recycling and Design, RECOUP

Paul Garner, Director, Urthona Consulting, previously Senior Commercial Manager - Sustainable Business at Asda Stores Ltd

Stuart Hayward-Higham, Chief Technical Development and Innovation Officer, SUEZ Recycling & Recovery UK

Dr Alice Horton, Anthropogenic Contaminants Scientist, National Oceanography Centre

Dr Chris Howick, Product Regulation Manager, INOVYN

Dr Richard Hixson, Consultant in Critical Care Medicine and Co-founder of Healthcare Ocean

Daniel Hummelberger, Account Executive, Salesforce

Professor Edward Kosior, Managing Director, Nextek Ltd

Sarah Lightowler, Business Development Manager - Circular Plastics, Cargill

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References

1 Drewniok, P. Michal, Gao, Y., Cullen, M. Johnathan, & Serrenho, C. Andre'. (2023). What to do about plastics? Lessons from a study of United Kingdom plastics flows. Environ. Sci. Technol., 57, (11), 4513–4521 https://pubs.acs.org/doi/10.1021/acs.est.3c00263

2 Ritchie, H., Samborska, V, and Roser, M. (2023). Plastic pollution. https://ourworldindata.org/plastic-pollution

3 Ritchie, H. (2023). How much of global greenhouse gas emissions come from plastics? https://ourworldindata.org/ghg-emissions-plastics

4 Drewniok, P. Michal, Gao, Y., Cullen, M. Johnathan, & Serrenho, C. Andre'. (2023). What to do about plastics? Lessons from a study of United Kingdom plastics flows. Environ. Sci. Technol., 57, (11), 4513–4521 https://pubs.acs.org/doi/10.1021/acs.est.3c00263

5 Nature. (2021). Chemistry can help make plastics sustainable-but it isn't the whole solution. https://www.nature.com/articles/d41586-021-00391-7#:~:text=By%202050%2C%20an%20estimated%2012%20billion%20tonnes%20of,incinerators%2C%20which%20are%20a%20source%20of%20carbon%20emissions.

6 OECD. (2022). Plastic pollution is growing relentlessly as waste management and recycling fall short, says OECD. https://www.oecd.org/environment/plastic-pollution-is-growing-relentlessly-as-waste-management-and-recycling-fall-short.htm

7 United Nations Environment Programme (UNEP). (2022). Single-use supermarket food packaging and its alternatives: Recommendations from life cycle assessments. https://www.lifecycleinitiative.org/wp-content/uploads/2022/10/UNEP-D010-Food-Packaging-Report_Final-Version-1-1.pdf/UNEP-D010-Food-Packaging-Report-2-1.pdf

8 Oakes, K. (2022).Plastic has seeped into every aspect of our existence. Can we live without it? BBC. https://www.bbc.com/future/article/20220526-what-would-happen-if-we-stopped-using-plastic

9 UNEP. (2023). Turning off the Tap: How the world can end plastic pollution and create a circular economy. https://www.unep.org/resources/turning-off-tap-end-plastic-pollution-create-circular-economy

10 Our World in Data. (N.d). Global primary plastic production by industrial sector, 1990 to 2019. https://ourworldindata.org/grapher/plastic-production-by-sector

11 International Labour Organization. (2022).The International Labour Office welcomes the outcomes of the UN Environment Assembly. https://www.ilo.org/global/topics/green-jobs/news/WCMS_840345/lang--en/index.htm

12 British Plastics Federation. (2024). About the British Plastics Industry. https://www.bpf.co.uk/industry/Default.aspx

13 Greene, R. and Mirsha, N. (2023). How India is creating collaborative solutions to tackle waste. World Economic Forum. https://www.weforum.org/agenda/2023/08/how-india-is-coming-up-with-innovative-solutions-to-tackle-waste/

14 UNEP. (2023). Turning off the Tap: How the world can end plastic pollution and create a circular economy. https://www.unep.org/resources/turning-off-tap-end-plastic-pollution-create-circular-economy

15 Dunning, H. (2020). 'Blue Planet II' may not have caused a change in plastic preference. Imperial Collage London News. https://www.imperial.ac.uk/news/205253/blue-planet-ii-have-caused-change/

16 Tiseo, I. (2023). Opinions and concerns about plastic waste pollution in the United Kingdom in 2021. https://www.statista.com/statistics/1269433/plastic-waste-pollution-opinions-uk/

17 Samson, E. (2023). Plastic Pollution affecting Small Island Developing States (SIDS). https://www.oecd-forum.org/posts/plastic-pollution-affecting-small-island-developing-states-sids

18 Back to Blue. (2019). Plastic treaty negotiations produce new debates but few results. https://backtoblueinitiative.com/plastic-treaty-negotiations-produce-new-debates-but-few-results/

19 Basel Convention. (N.d). Plastic Waste. https://www.basel.int/Implementation/Plasticwaste/Overview/tabid/8347/Default.aspx

20 UNEP. (2024). Intergovernmental negotiating committee on plastic pollution https://www.unep.org/inc-plastic-pollution

21 United Nations Environment Assembly. (2022). End plastic pollution: Towards an international legally binding instrument - resolution adopted by the United Nations Environment Assembly on 2 March 2022 (UNEP/EA.5/Res.14) https://wedocs.unep.org/handle/20.500.11822/40597

22 IISD Earth Negotiation Bulletin. (2023). Summary report, 11–19 November 2023 https://enb.iisd.org/plastic-pollution-marine-environment-negotiating-committee-inc3-summary

23 Miriri, D. (2023). U.N. plastic treaty talks grapple with re-use, recycle, reduce debate. Reuters. https://www.reuters.com/business/environment/un-plastic-treaty-talks-grapple-with-re-use-recycle-reduce-debate-2023-11-19/

24 GOV.UK. (2024). Extended producer responsibility for packaging: Who is affected and what to do. https://www.gov.uk/guidance/extended-producer-responsibility-for-packaging-who-is-affected-and-what-to-do

25 Salini, M., & Burkhardt, D. (2023). BRIEFING EU Legislation in Progress. https://www.europarl.europa.eu/RegData/etudes/BRIE/2023/745707/EPRS_BRI(2023)745707_EN.pdf

26 Jia, C. (2021). Converting Plastic Waste into Fuel - Science in the News (harvard.edu). https://sitn.hms.harvard.edu/flash/2021/converting-plastic-waste-into-fuel/

27 Cullen, J. Drewniok, M., and Serrenho, A. (2020). Plastics in the UK: Practical and pervasive…but problematic. https://www.refficiency.org/wp-content/uploads/2020/10/ThePWord2.pdf

28 UNEP. (2024). Ad hoc open-ended working group on a science-policy panel on chemicals, waste and pollution prevention. https://www.unep.org/oewg-spp-chemicals-waste-pollution

29 MacIntyre, E. (2020). Plastic labelled 'BPA free' might not be safe, studies suggest. CBC News. https://www.cbc.ca/news/science/bpa-free-1.5404149

30 Landrigan, P. J., Raps, H., Cropper, M., Bald, C., Brunner, M., Canonizado, E. M., … Dunlop, S. (2023). The Minderoo-Monaco Commission on plastics and human health. Annals of Global Health, 89(1), 23. https://annalsofglobalhealth.org/articles/10.5334/aogh.4056

31 Hahladakis, J.N., Velis, C.A., Webber, R., Iacovidou, E. and Purnell, P. (2018). An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling. Journal of Hazardous Materials, 344: 179–199. http://ccc.chem.pitt.edu/wipf/Web/Plastics.pdf

32 Porta, R. (2021), Anthropocene, the plastic age and future perspectives. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8016130/

33 OECD. (2022). Plastic pollution is growing relentlessly as waste management and recycling fall short, says OECD. https://www.oecd.org/environment/plastic-pollution-is-growing-relentlessly-as-waste-management-and-recycling-fall-short.htm

34 Landrigan, P. J., Raps, H., Cropper, M., Bald, C., Brunner, M., Canonizado, E. M., … Dunlop, S. (2023). The Minderoo-Monaco Commission on plastics and human health. Annals of Global Health, 89(1), 23. https://annalsofglobalhealth.org/articles/10.5334/aogh.4056.

35 Amobenye, A., Bhagwat, P., Raveendran, S., Singh, S., and Pillai, S. (2021). Environmental impacts of microplastics and nanoplastics: A current overview. Sec. Microbiotechnology, 12. https://www.frontiersin.org/articles/10.3389/fmicb.2021.768297/full

36 Carrington, D. (2020). Microplastic pollution found near summit of Mount Everest. The Guardian. https://www.theguardian.com/environment/2020/nov/20/microplastic-pollution-found-near-summit-of-mount-everest

37 National Oceanic and Atmospheric Administration. (2023).What are microplastics? https://oceanservice.noaa.gov/facts/microplastics.html

38 Brzuska, K. Graaf, J. D., and Schlatter, H. (2015).Use of Micro-Plastic Beads in Cosmetic Products in Europe and Their Estimated Emissions to the North Sea Environment. https://www.semanticscholar.org/paper/Use-of-Micro-Plastic-Beads-in-Cosmetic-Products-in-Brzuska-Graaf/e12837d4697ba17996076e0240b2c8ce57601f68

39 Liu, L., Xu, M. Ye Y., and Zhang, B. (2022). On the degradation of (micro) plastics: Degradation methods, influencing factors, environmental impacts. Science of the Total Environment, 806(3). https://www.sciencedirect.com/science/article/abs/pii/S0048969721063907

40 Sharma, S., et al. (2021). Microplastics in the environment: Occurrence, perils, and eradication. Chemical Engineering Journal, 408. https://www.sciencedirect.com/science/article/abs/pii/S1385894720334410

41 Liu, L., Xu, M. Ye Y., and Zhang, B. (2022). On the degradation of (micro) plastics: Degradation methods, influencing factors, environmental impacts. Science of the Total Environment, 806(3). https://www.sciencedirect.com/science/article/abs/pii/S0048969721063907

42 Da Costa, P. J., Rocha-Santo, T., and Duarte, A. C. (2020). The environmental impacts of plastics and micro-plastics use, waste and pollution: EU and national measures. https://www.europarl.europa.eu/RegData/etudes/STUD/2020/658279/IPOL_STU(2020)658279_EN.pdf

43 Stapleton, M.J., Ansari, A.J., and Hai, F.I. (2023). Antibiotic sorption onto microplastics in water: A critical review of the factors, mechanisms and implications. Water Research, 233. https://www.sciencedirect.com/science/article/pii/S0043135423002257

44 Liu, S. et al. (2022). Microplastics as a vehicle of heavy metals in aquatic environments: A review of adsorption factors, mechanisms, and biological effects. Journal of Environmental Management,302, Part A. https://www.sciencedirect.com/science/article/pii/S0301479721020570

45 Wang, T. et al. (2020).Interactions between microplastics and organic pollutants: Effects on toxicity, bioaccumulation, degradation, and transport. Science of The Total Environment, 748. https://www.sciencedirect.com/science/article/pii/S0048969720359568

46 Wang, X. (2020).Photodegradation Elevated the Toxicity of Polystyrene Microplastics to Grouper (Epinephelus moara) through Disrupting Hepatic Lipid Homeostasis. Environ. Sci. Technol., 54,(10), 6202–6212 https://pubs.acs.org/doi/10.1021/acs.est.9b07016

47 Lambert, S., Sinclair, C., and Boxall, A. (2014). Occurrence, degradation, and effect of polymer-based materials in the environment. In: Whitacre, D. (eds). Reviews of Environmental Contamination and Toxicology, 227. Springer, Cham. https://link.springer.com/chapter/10.1007/978-3-319-01327-5_1

48 Maddela, N. R. et al. (2023). Additives of plastics: Entry into the environment and potential risks to human and ecological health. Journal of Environmental Management, 348 https://www.sciencedirect.com/science/article/pii/S0301479723021527

49 Gallo, F. et al. (2018). Marine litter plastics and microplastics and their toxic chemicals components: the need for urgent preventive measures. Environmental Sciences Europe, 30(13) https://enveurope.springeropen.com/articles/10.1186/s12302-018-0139-z

50 Radke, E. G. et al. (2018). Phthalate exposure and male reproductive outcomes: A systematic review of the human epidemiological evidence. Environment International, 121, Part 1,764-793. https://www.sciencedirect.com/science/article/pii/S0160412018303404

51 Balalain, A. A., et al. (2019). Prenatal and childhood exposure to phthalates and motor skills at age 11 years. Environ Res., 171: 416–427. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6814270/

52 Navaranjan, G. et al. (2021). Early life exposure to phthalates and the development of childhood asthma among Canadian children. Environ Res. https://pubmed.ncbi.nlm.nih.gov/33691158/

53 Yuan, Z., Nag, R. and Cummins, E. (2022). Human health concerns regarding microplastics in the aquatic environment - From marine to food systems. Science of The Total Environment, 823. https://www.sciencedirect.com/science/article/pii/S0048969722008221

54 Morrison, M. et al. (2022). A growing crisis for One Health: Impacts of plastic pollution across layers of biological function. Front. Mar. Sci., 9. https://www.frontiersin.org/articles/10.3389/fmars.2022.980705/full

55 Merrill, A. K. et al. (2023). Exposure to endocrine disrupting chemicals impacts immunological and metabolic status of women during pregnancy. Molecular and Cellular Endocrinology, 577. https://doi.org/10.1016/j.mce.2023.112031

56 MacIntyre, E. (2020). Plastic labelled 'BPA free' might not be safe, studies suggest. CBC News. https://www.cbc.ca/news/science/bpa-free-1.5404149

57 United Nations Environment Programme (2021), NEGLECTED: Environmental Justice Impacts of Marine Litter and Plastic Pollution, https://www.unep.org/news-and-stories/press-release/plastic-pollution-environmental-injustice-vulnerable-communities-new#:~:text=Nairobi%2C%2030%20March%202021%20%E2%80%94%20Plastic,Programme%20(UNEP)%20and%20environmental%20justice

58 UCLA Luskin Centre of Innovation. (2022). The perils of plastic. https://innovation.luskin.ucla.edu/wp-content/uploads/2022/04/The-Perils-of-Plastics.pdf

59 OECD. (2022). Plastic pollution is growing relentlessly as waste management and recycling fall short, says OECD. https://www.oecd.org/environment/plastic-pollution-is-growing-relentlessly-as-waste-management-and-recycling-fall-short.htm

60 World Economic Forum, Ellen MacArthur Foundation, and McKinsey & Company. (2016). The new plastics economy — Rethinking the future of plastic. https://www.mckinsey.com/~/media/mckinsey/business%20functions/sustainability/our%20insights/rethinking%20future%20of%20plastics/the%20new%20plastics%20economy.pdf

61 Cullen, J. Drewniok, M., and Serrenho, A. (2020). Plastics in the UK: Practical and pervasive…but problematic. https://www.refficiency.org/wp-content/uploads/2020/10/ThePWord2.pdf

62 OECD. (2022). Plastic pollution is growing relentlessly as waste management and recycling fall short, says OECD. https://www.oecd.org/environment/plastic-pollution-is-growing-relentlessly-as-waste-management-and-recycling-fall-short.htm

63 British Plastics Federation. (2024). Polyesters (Thermoplastic) PETP, PBT, PET. https://www.bpf.co.uk/Plastipedia/Polymers/Polyesters.aspx

64 Cullen, J. Drewniok, M., and Serrenho, A. (2020). Plastics in the UK: Practical and pervasive…but problematic. https://www.refficiency.org/wp-content/uploads/2020/10/ThePWord2.pdf

65 Brivio, L., and Tollini, F. (2022). Chapter Six - PET recycling: Review of the current available technologies and industrial perspectives. Advances in Chemical Engineering, 60(1): 215-267. https://www.sciencedirect.com/science/article/abs/pii/S0065237722000217

66 Olivio, T (Ed.). (2023). Medical Nonwovens move forward: Advancements in technology are helping nonwovens replace other materials around the globe. Nonwovens Industry News. https://www.nonwovens-industry.com/issues/2023-08-01/view_features/medical-nonwovens-move-forward/

67 Malhotra, M. (2020).Multilayered plastics: A persisting problem in plastic pollution. Age of Awareness Publishers. https://medium.com/age-of-awareness/multilayered-plastics-a-persisting-problem-in-plastic-pollution-4015d95230

68 Cullen, J. Drewniok, M., and Serrenho, A. (2020). Plastics in the UK: Practical and pervasive…but problematic. https://www.refficiency.org/wp-content/uploads/2020/10/ThePWord2.pdf

69 Lewandowski, K. and Skorczewska, K. (2022). A brief review of Poly(Vinyl Chloride) (PVC) recycling. Polymers (Basel), 14(15): 3035. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9332854/

70 Cullen, J. Drewniok, M., and Serrenho, A. (2020). Plastics in the UK: Practical and pervasive…but problematic. https://www.refficiency.org/wp-content/uploads/2020/10/ThePWord2.pdf

71 Holy Grail: Tagging packaging for accurate sorting and high-quality recycling. http://go.pardot.com/l/110942/2019-05-28/lhts3n

72 Holy Grail: Tagging packaging for accurate sorting and high-quality recycling. http://go.pardot.com/l/110942/2019-05-28/lhts3n

73 Kosior, E. (2020). Fluorescent markers could transform plastic recycling. Sustainability Times. https://www.sustainability-times.com/green-consumerism/innovative-fluorescent-markers-could-transform-plastic-recycling/

74 Digital Watermarks Initiative Holy Grail 2.0. (N.d). Pioneering digital watermarks for smart packaging recycling in the EU. https://www.digitalwatermarks.eu/

75 Florez, L. I. (2022). Digital passport makes recycling transparent. https://www.plastico.com/es/noticias/digital-passport-makes-recycling-transparent

76 Tarun, K., Sreelakshmi, K., and Peeyush, K. P. (2019).Segregation of plastic and non-plastic waste using convolutional neural network. IOP Conf. Series: Materials Science and Engineering, 561: 012113. https://iopscience.iop.org/article/10.1088/1757-899X/561/1/012113/pdf

77 Edwards, G. (2024). AI revolution shaping the waste industry in 2024 and beyond: Part two. Waste 360. AI Revolution Shaping the Waste Industry in 2024 and Beyond: Part Two (waste360.com). https://www.waste360.com/industry-insights/ai-revolution-shaping-the-waste-industry-in-2024-and-beyond-part-two

78 Tarun, K., Sreelakshmi, K., and Peeyush, K. P. (2019).Segregation of plastic and non-plastic waste using convolutional neural network. IOP Conf. Series: Materials Science and Engineering, 561: 012113. https://iopscience.iop.org/article/10.1088/1757-899X/561/1/012113/pdf

79 Chidepatil, A. et al. (2020). From trash to cash: How blockchain and multi-sensor-driven artificial intelligence can transform circular economy of plastic waste? Adm. Sci., 11(3), 67. https://www.mdpi.com/2076-3387/10/2/23

80 Royal Society of Chemistry. (N.d). Mechanical recycling. 2 Mechanical Recycling v8 (rsc.org). https://www.rsc.org/globalassets/22-new-perspectives/sustainability/progressive-plastics/explainers/rsc-explainer-5---mechanical-recycling.pdf

81 Drewniok, P. Michal, Gao, Y., Cullen, M. Johnathan, & Serrenho, C. Andre'. (2023). What to do about plastics? Lessons from a study of United Kingdom plastics flows. Environ. Sci. Technol., 57, (11), 4513–4521 https://pubs.acs.org/doi/10.1021/acs.est.3c00263

82 Paben, J. (2021). How 'supercritical' CO_2 can lead to cleaner recycled resin. A Resource Recycling Inc. Publication. https://resource-recycling.com/plastics/2021/09/15/how-supercritical-co2-can-lead-to-cleaner-recycled-resin/

83 Cullen, J. Drewniok, M., and Serrenho, A. (2020). Plastics in the UK: Practical and pervasive…but problematic. https://www.refficiency.org/wp-content/uploads/2020/10/ThePWord2.pdf

84 Welsh Government (2021). New stats sow Wales upholds world class recycling rates despite pandemic. Press Release. www.gov.wales. https://www.gov.wales/new-stats-show-wales-upholds-world-class-recycling-rates-despite-pandemic

85 Peng, Z. Simons, T. J., Wallach, J., and Youngman, A. (2022). Advanced recycling: Opportunities for growth. McKinsey and Company. https://www.mckinsey.com/industries/chemicals/our-insights/advanced-recycling-opportunities-for-growth

86 Schyns, O. G. Z., and Shaver, M. P. (2020). Mechanical recycling of packaging plastics: A review. https://onlinelibrary.wiley.com/doi/full/10.1002/marc.202000415

87 British Plastics Federation (BPF). (2024). Plastic recycling. https://www.bpf.co.uk/Sustainability/Plastics_Recycling.aspx

88 UNEP. (2023). Chemical recycling: Plastics-to-plastics chemical recycling offers a promising solution in complement to mechanical recycling. https://wedocs.unep.org/bitstream/handle/20.500.11822/42232/chemical_recycling_sheet.pdf?sequence=3

89 Plastics Europe. (2024). Chemical recycling. https://plasticseurope.org/sustainability/circularity/recycling/chemical-recycling/

90 Peng, Z. Simons, T. J., Wallach, J., and Youngman, A. (2022). Advanced recycling: Opportunities for growth. McKinsey and Company. https://www.mckinsey.com/industries/chemicals/our-insights/advanced-recycling-opportunities-for-growth

91 UNEP. (2023). Chemical recycling: Plastics-to-plastics chemical recycling offers a promising solution in complement to mechanical recycling. https://wedocs.unep.org/bitstream/handle/20.500.11822/42232/chemical_recycling_sheet.pdf?sequence=3

92 Ibid.

93 Ibid.

94 Financial Times. (2024). Surge into plastic recycling by chemicals and oil groups meets pushback. Financial Times. https://www.ft.com/content/901c78e6-b4d0-467c-ab87-6fc44c8a004c

95 UNEP. (2023). Chemical recycling: Plastics-to-plastics chemical recycling offers a promising solution in complement to mechanical recycling. https://wedocs.unep.org/bitstream/handle/20.500.11822/42232/chemical_recycling_sheet.pdf?sequence=3

96 Financial Times. (2024). Surge into plastic recycling by chemicals and oil groups meets pushback. Financial Times. https://www.ft.com/content/901c78e6-b4d0-467c-ab87-6fc44c8a004c

97 KPMG. (2024) Plastic taxes: A European perspective. https://kpmg.com/xx/en/home/insights/2022/11/plastic-taxes-a-european-perspective.html

98 Zurawska, W. (2023). Plastic taxation in Europe: Update 2023. WTS Global. https://wts.com/global/publishing-article/20230522-plastic-taxation-europe-update-2023~publishing-article

99 KPMG. (2024) Plastic taxes: A European perspective. https://kpmg.com/xx/en/home/insights/2022/11/plastic-taxes-a-european-perspective.html

100 WTS Global. (2023). Plastic taxation in Europe: Update 2023. https://wts.com/wts.com/publications/climate-protection-green-tax-energy/2023/wtsglobal-plastic-taxation-in-europe-2023.pdf#page=22

101 Ibid.

102 Ibid.

103 EY Global. (2022). Italy's plastic tax will enter into force on 1 January 2023. https://www.ey.com/en_gl/tax-alerts/italy-s-plastic-tax-will-enter-into-force-on-1-january-2023

104 TUV SUD. (N.d). Consumers are demanding for environmentally friendly products and many authorities across the world have banned the use of conventional single-use plastic products. https://www.tuvsud.com/en-us/industries/consumer-products-and-retail/biodegradable-packaging-certification

105 European Recycling Platform. (N.d). Plastic packaging tax summary: ERP UK has produced this briefing for companies wanting to understand the new tax. https://erp-recycling.org/uk/what-we-cover/services/plastic-packaging-tax/plastic-packaging-tax-summary/

106 European Recycling Platform. (N.d). Plastic packaging tax summary: ERP UK has produced this briefing for companies wanting to understand the new tax. https://erp-recycling.org/uk/what-we-cover/services/plastic-packaging-tax/plastic-packaging-tax-summary/

107 C.M.S.Law-Now. (2022). New legal framework for waste management in Luxembourg. https://cms-lawnow.com/en/ealerts/2022/06/new-legal-framework-for-waste-management-in-luxembourg

108 Ngei, D. and, Karmali, A. (2020). Reflecting on Kenya's single-use plastic bag ban three years on. https://www.weforum.org/agenda/2020/11/q-a-reflecting-on-kenyas-single-use-plastic-bag-ban-three-years-on/

109 C.M.C. Law-Now. (2021). Hungary adopts additional rules on single-use plastic products. https://cms-lawnow.com/en/ealerts/2021/07/hungary-adopts-additional-rules-on-single-use-plastic-products

110 Major, D. (2023). Judge says Ottawa listing plastic items as toxic was 'unreasonable and unconstitutional': Adding plastics to list of toxic substances a key step that allowed Ottawa to ban single-use plastics. CBC News. https://www.cbc.ca/news/politics/court-rules-against-listing-plastics-as-toxic-1.7030716

111 Thurton, D. (2024). Here's how a Canada-wide plastics registry could save you money: Critics call plan impractical, government overreach. CBC News. https://www.cbc.ca/news/politics/canada-national-plastics-registry-1.7075740

112 European Commission. (N.d). Plastic strategy: The EU's plastics strategy aims to transform the way plastic products are designed, produced, used and recycled in the EU. https://environment.ec.europa.eu/strategy/plastics-strategy_en

113 C.M.S.: Tax-Law-Future. (N.d). Plastics and packaging laws in The Netherlands. https://cms.law/en/int/expert-guides/plastics-and-packaging-laws/the-netherlands

114 Packaging Europe. (2023). 2023 and packaging: What have we seen so far? https://packagingeurope.com/features/2023-and-packaging-what-have-we-seen-so-far/9331.article

115 UNDP. (2021). The Zero Waste Project receives UNDP Turkey's first Global Goals Action Award. https://www.undp.org/turkiye/press-releases/zero-waste-project-receives-undp-turkeys-first-global-goals-action-award

116 OECD. (2016). Extended producer responsibility. https://www.oecd.org/environment/extended-producer-responsibility.htm

117 OECD. (2016). https://www.oecd.org/environment/waste/Extended-producer-responsibility-Policy-Highlights-2016-web.pdf

118 WWF.org. (N.d). Extended producer responsibility (EPR) fact sheet. https://wwfeu.awsassets.panda.org/downloads/epr__briefing_for__governments__and_businesses_updates.pdf

119 Davis, P. (2023). European Plastic Pact. https://europeanplasticspact.org/wp-content/uploads/2023/07/eurpp-guidance-on-epr-july-2023-final-draft-1.pdf

120 Ibid.

121 Waste Dive. (2023). Study of extended producer responsibility policy across 7 jurisdictions worldwide shows it dramatically increases recycling rates. https://www.wastedive.com/press-release/20230206-study-of-extended-producer-responsibility-policy-across-7-jurisdictions-wor/

122 WWF Thailand. (2020). Scaling up circular strategies to achieve zero plastic waste in Thailand. https://wwfint.awsassets.panda.org/downloads/zero_plastic_waste_in_thailand_en.pdf

123 LOVAT. (2023). Belgium: Extended producer responsibility for packaging in Belgium. https://vatcompliance.co/epr-guides/belgium/

124 International Food Industry News. (2024). Tesco, Aldi and Morrisons back 'biggest trial yet' of digital deposit return scheme. https://foodindustrynetwork.com/tesco-aldi-and-morrisons-back-biggest-trial-yet-of-digital-deposit-return-scheme-news/

125 DWF Group. (2023). Don't bottle it: European Commission calls for mandatory deposit and return systems in member states. https://dwfgroup.com/en/news-and-insights/insights/2023/2/european-commission-calls-for-mandatory-deposit-and-return-systems-in-member-states

126 Ballerini, T. (2021). Making empties count: Deposit return schemes across the world. https://renewablematter.eu/articles/article/making-empties-count-deposit-return-schemes-across-the-world

127 Sensoneo. (2023). Detailed overview and results of the current deposit return scheme implementations in Europe: Overview and results of the deposit return schemes in Europe (sensoneo.com). https://sensoneo.com/waste-library/deposit-return-schemes-overview-europe/

128 Trivium Communications. (2023).Trivium Packaging I 2023 Buying Green Report. https://www.triviumpackaging.com/news-media/reports/2023-buying-green-report/

129 Jacobsen, F. L., Pendersen, S., and Thogersen, J. (2022). Drivers of and barriers to consumers' plastic packaging waste avoidance and recycling – A systematic literature review. Waste Management, 141: 3-78. https://www.sciencedirect.com/science/article/pii/S0956053X22000228#b0220

130 Legislation.gov.uk The Producer Responsibility Obligations (Packaging Waste) Regulations 1997. https://www.legislation.gov.uk/uksi/1997/648/contents/made

131 Cullen, J. Drewniok, M., and Serrenho, A. (2020). Plastics in the UK: Practical and pervasive…but problematic. https://www.refficiency.org/wp-content/uploads/2020/10/ThePWord2.pdf

132 Smith, L., and Sutherland, N. (2020). Waste incineration facilities. Debate Pack: House of Commons. https://researchbriefings.files.parliament.uk/documents/CDP-2020-0029/CDP-2020-0029.pdf

133 Europa.eu. (2019).Municipal waste landfill rates in Europe by country https://www.eea.europa.eu/data-and-maps/daviz/municipal-waste-landfill-rates-in#tab-chart_1

134 Royte, E. (2019). Is burning plastic waste a good idea? National Geographic. https://www.nationalgeographic.co.uk/environment/2019/03/is-burning-plastic-waste-a-good-idea

135 Cullen, J. Drewniok, M., and Serrenho, A. (2020). Plastics in the UK: Practical and pervasive…but problematic. https://www.refficiency.org/wp-content/uploads/2020/10/ThePWord2.pdf

136 Hundertmark, T., McNally, C., Simons, T. J. and Vanthournout, H. (2018). No time to waste: What plastics recycling could offer. McKinsey and Company. https://www.mckinsey.com/industries/chemicals/our-insights/no-time-to-waste-what-plastics-recycling-could-offer

137 Drewniok, P. Michal, Gao, Y., Cullen, M. Johnathan, & Serrenho, C. Andre'. (2023). What to do about plastics? Lessons from a study of United Kingdom plastics flows. Environ. Sci. Technol., 57, (11), 4513–4521 https://pubs.acs.org/doi/10.1021/acs.est.3c00263

138 UK Research and Innovation (UKRI). (2020). UKRI funding puts UK at the forefront of plastic recycling. https://www.ukri.org/news/ukri-funding-puts-uk-at-the-forefront-of-plastic-recycling/

139 Santos, B. (2023). Mura Technology commissions commercial scale chemical recycling plant in the UK: The facility, based in Teesside, will have a capacity of 20,000 tonnes of recycled plastic a year. Sustainable Plastic. https://www.sustainableplastics.com/news/mura-technology-commissions-commercial-scale-chemical-recycling-plant-uk

140 Tabrizi, S. (2021). Recycled plastics balancing on a thin line with the 'mass balance approach'. Zero Waste Europe. https://zerowasteeurope.eu/2021/03/mass-balance-approach/#:~:text=Mass%20balance%20is%20a%20set%20of%20rules%20for,total%20inputs%20should%20be%20balanced%20with%20the%20outputs.

141 British Plastics Federation. (2023). BPF responds to announcement of government consultation into mass balance. https://www.bpf.co.uk/article/bpf-statement-in-response-to-announcement-of-consultation-into-m-3313.aspx

142 British Plastics Federation. (2024). About the British plastics industry. https://www.bpf.co.uk/industry/Default.aspx

143 Wrap. (2021). Employment and the circular economy. https://wrap.org.uk/resources/report/employment-and-circular-economy

144 Ibid.

145 Deloitte. (N.d). The UK circularity gap report - Virtuous circles: How the circular economy can be a key driver of business growth. https://www2.deloitte.com/uk/en/pages/risk/articles/uk-circularity-gap.html

146 GOV.UK. (2024). Extended producer responsibility for packaging: Who is affected and what to do. https://www.gov.uk/guidance/extended-producer-responsibility-for-packaging-who-is-affected-and-what-to-do

147 OECD. (2024). Deposit-refund systems and the interplay with additional mandatory extended producer responsibility policies. https://www.oecd-ilibrary.org/docserver/a80f4b26-en.pdf

148 Gov.UK. (2023). Deposit return scheme for drinks containers moves a step closer: A new cash incentive system, placing deposits on drinks bottles and cans, will boost recycling from 2025. https://www.gov.uk/government/news/deposit-return-scheme-for-drinks-containers-moves-a-step-closer#:~:text=That%20is%20why%20we%20are,even%20when%20on%20the%20move

149 Davies, P. (2023). European plastic pact- Extended Producer Responsibility (EPR) in review: A summary of key literature on the advantages, disadvantages, opportunities and limitations of EPR. https://europeanplasticspact.org/wp-content/uploads/2023/07/eurpp-guidance-on-epr-july-2023-final-draft-1.pdf

150 Tesco. (2020). Tesco introduces the first recycled food grade soft plastic packaging from materials returned by customers. https://www.tescoplc.com/updates/2020/tesco-introduces-the-first-recycled-food-grade-soft-plastic-packaging-from-materials-returned-by-customers/

151 British Plastics Federation. (2024). Plastic recycling. https://www.bpf.co.uk/Sustainability/Plastics_Recycling.aspx

152 Kingspan. (2020). What is planet passionate?- Planet passionate report 2022. https://www.kingspangroup.com/en/sustainability/planet-passionate/

153 Amazon Staff. (2022). How Amazon resells, recycles or donates unsold products. https://www.aboutamazon.co.uk/news/sustainability/how-amazon-resells-recycles-or-donates-unsold-products

154 Rosenboom, J.-G., Langer, R., & Traverso, G. (2022). Bioplastics for a circular economy. Nature Reviews. Materials, 7(117–137), 1–21. https://doi.org/10.1038/s41578-021-00407-8

155 European Bioplastics (2017). What are the advantages of bioplastic products? European Bioplastics E.V. https://www.european-bioplastics.org/faq-items/what-are-the-advantages-of-bioplastic-products/

156 Rosenboom, J. R., Langer, R., and Traverso, G. (2022). Bioplastics for a circular economy. Nature Reviews Materials, 7, 117-137. https://www.nature.com/articles/s41578-021-00407-8

157 Di Bartolo, A., Infurna, G., & Dintcheva, N. T. (2021). A Review of Bioplastics and Their Adoption in the Circular Economy. Polymers, 13(8), 1229. https://doi.org/10.3390/polym13081229

158 Cho, R. (2017). The Truth about Bioplastics. State of the Planet; Columbia Climate School. https://news.climate.columbia.edu/2017/12/13/the-truth-about-bioplastics/

159 Rezvani Ghomi, E. R., Khosravi, F., Saedi Ardahaei, A. S., Dai, Y., Neisiany, R. E., Foroughi, F., Wu, M., Das, O., & Ramakrishna, S. (2021). The Life Cycle Assessment for Polylactic Acid (PLA) to Make It a Low-Carbon Material. Polymers, 13(11), 1854. https://doi.org/10.3390/polym13111854

160 EuroPlus. (2021). Potato starch bioplastic pros and cons. https://europlas.com.vn/en-US/blog-1/potato-starch-bioplastic-pros-and-cons-top-secret-may-surprise-you-1

161 Nehls, G.(2021). NCC proposes natural fiber use for SME subterranean transport network. https://www.compositesworld.com/news/ncc-proposes-natural-fiber-use-for-sme-subterranean-transport-network

162 Coca-Cola. (2021) Coca-Cola collaborates with tech partners to create bottle prototype made from 100% plant-based sources. https://www.coca-colacompany.com/media-center/100-percent-plant-based-plastic-bottle

163 L'Oréal. (n.d.). Preserving natural resources. https://www.loreal.com/en/commitments-and-responsibilities/for-the-planet/preserving-natural-resources/

164 L'Oreal. (n.d.). L'Oréal's latest innovation for more sustainable packaging: The paper bottle. https://www.loreal.com/en/news/commitments/loreals-latest-innovation-for-more-sustainable-packaging-the-paper-bottle/

165 Robbins, J. (2020). Why bioplastics will not solve the world's plastics problem. https://e360.yale.edu/features/why-bioplastics-will-not-solve-the-worlds-plastics-problem

166 Rosenboom, J. R., Langer, R., and Traverso, G. (2022). Bioplastics for a circular economy. Nature Reviews Materials, 7, 117-137. https://www.nature.com/articles/s41578-021-00407-8

167 Zimmermann, L., Dombrowski, A., Volker, C., and Wagner, M. (2020). Are bioplastics and plant-based materials safer than conventional plastics? In vitro toxicity and chemical composition. Environment International, 145. https://www.sciencedirect.com/science/article/pii/S0160412020320213

168 Baker, A. (2023). The dirty secret of alternative plastics. Time. https://time.com/6339914/plastic-alternatives-pollute/

169 Wacket, L. P. (2019). Bio-based and biodegradable plastics. Applied Microbiology International journal. https://ami-journals.onlinelibrary.wiley.com/doi/10.1111/1751-7915.13502

170 Haigh, L. (2018). An invitation to litter? FPA calls for an end to the term "biodegradable" in packaging. Plastic Insights. https://www.packaginginsights.com/news/an-invitation-to-litter-fpa-calls-for-an-end-to-the-term-biodegradable-in-packaging.html

171 Biodegradable plastics • Plastics Europe. (n.d.). Plastics Europe. https://plasticseurope.org/plastics-explained/a-large-family/biodegradable-plastics/

172 Trung, G., Webster, P., Monzon, D., Kolk, M., Cheng, W., Srisaard, P., and Lim, S. (2022). Prism: Why the bio-based materials market is finally poised for growth. Arthur D. Little, https://www.adlittle.com/en/insights/prism/why-bio-based-materials-market-finally-poised-growth

173 Pokharel, R., Poudel, J., Dahal, R., Shivan GC. (2023). Forest Biomass Feedstock Availability and Economic Contribution of Biopower Facilities in the Lake States Region, Journal of Forestry, 121(5-6), p 393–407, https://doi.org/10.1093/jofore/fvad023

174 Gutschmann, B. et al. (2020). Native feedstock options for the polyhydroxyalkanoate industry in Europe: A review. Microbiological Research, 264. https://www.sciencedirect.com/science/article/pii/S0944501322002178

175 Interplas Insights. (2024). European bioplastics calls for action to accelerate biopolymers industrial growth. https://interplasinsights.com/plastics-industry-news/latest-plastics-industry-news/european-bioplastics-calls-for-action-to-accelerate-biopolym/

176 Cozier, M. (2023). Flue2Chem: SCI, Unilever and 13 partners launch £5.4m net zero collaboration project. https://www.soci.org/news/2023/1/flue2chem-sci-unilever-and-13-partners-launch-net-zero-collaboration-project

177 Newest-CUSS. (2023). Partner news: Carbon Clean joins Flue2Chem project to convert industrial waste gases into more sustainable consumer products. https://www.newestccus.eu/news/partner-news-carbon-clean-joins-flue2chem-project-convert-industrial-waste-gases-more

178 OECD. (N.d). Innovation on plastics. https://www.oecd-ilibrary.org/sites/bb1ff6fa-en/index.html?itemId=/content/component/bb1ff6fa-en

179 CSIRO. (2023). Recyclable-by-Design for polymers. https://research.csiro.au/ending-plastic-waste/recyclable-by-design-for-polymers/

180 European Chemicals Agency (ECHA). (N.d). Understanding REACH https://echa.europa.eu/regulations/reach/understanding-reach

181 European Commission. (2022). Commission staff working document restrictions roadmap under the chemicals strategy for sustainability. https://ec.europa.eu/docsroom/documents/49734

182 European Chemicals Agency (ECHA). (N.d). Bisphenols. https://www.echa.europa.eu/hot-topics/bisphenols

183 European Commission. (2023). Protecting environment and health: Commission adopts measures to restrict intentionally added microplastics. https://ec.europa.eu/commission/presscorner/detail/en/ip_23_4581

184 Patel, V. (2023). EU reach revision delay raises concerns over chemical industry influence and endocrine disruptors. https://www.personalcareinsights.com/news/eu-reach-revision-delay-raises-concerns-over-chemical-industry-influence-and-proliferating-endocrine-disruptors.html

185 Reihlen, A., Goulart, M., Santos, T., and Warhurst, M. (2023). Waiting for REACH: The negative impacts of delaying reform of EU chemical laws. The European Environmental Bureau and CHEM Trust Publishers. https://eeb.org/wp-content/uploads/2023/03/EEB-CT-Waiting-for-REACH_final-report.pdf

186 Fidra. (2023). UK REACH: Challenges and opportunities for improvement. https://www.fidra.org.uk/chemicals-pollution/uk-reach-challenges-and-opportunities-for-improvement/

187 Hansard-UK Parliament. (2023). REACH (Amendment) Regulations 2023. Volume 830: debated on Tuesday 13 June 2023. https://hansard.parliament.uk/lords/2023-06-13/debates/6EB72468-61F4-4B86-B1BF-21C118B38D9B/REACH(Amendment)Regulations2023

188 European Chemicals Agency (ECHA). (2023). ECHA adds nine hazardous chemicals to Candidate List https://echa.europa.eu/-/echa-adds-nine-hazardous-chemicals-to-candidate-list

189 Alexander, C. (2023). Is the Swiss system for regulating chemicals a useful model for the UK? Chem Trust. https://chemtrust.org/is-the-swiss-system-for-regulating-chemicals-a-useful-model-for-the-uk/

190 Zainzinger, V. (2021). What might UK Reach look like? Chemistry World News. https://www.chemistryworld.com/news/what-might-uk-reach-look-like/4013650.article

191 Hansard-UK Parliament. (2023). REACH (Amendment) Regulations 2023. Volume 830: debated on Tuesday 13 June 2023. https://hansard.parliament.uk/lords/2023-06-13/debates/6EB72468-61F4-4B86-B1BF-21C118B38D9B/REACH(Amendment)Regulations2023

192 Health and Safety Executive (HSE) Gov.UK. (N.d). UK REACH explained. https://www.hse.gov.uk/reach/about.htm

193 Gov.UK. (2024). Policy paper UK REACH: Rationale for priorities. From: Department for Environment, Food & Rural Affairs, The Scottish Government, and Welsh Government. https://www.gov.uk/government/publications/uk-reach-rationale-for-priorities-in-2022-to-2023/rationale-for-prioritising-substances-in-the-uk-reach-work-programme-2022-to-2023

194 UK Research and Innovation. (2023). Smart sustainable plastic packaging. https://www.ukri.org/what-we-do/browse-our-areas-of-investment-and-support/smart-sustainable-plastic-packaging/

195 Tees Valley News. (2021). Near Billion Pound investment for green energy plant at SABIC confirmed. https://teesvalley-ca.gov.uk/news/near-billion-pound-investment-for-green-energy-plant-at-sabic-confirmed/

196 Trivium Communications. (2023). Trivium Packaging I 2023 Buying Green Report. https://www.triviumpackaging.com/news-media/reports/2023-buying-green-report/

197 Ibid.

198 Parker, G. (2023). Changes to recycling label rules from 2026 to help consumers. LabelService. https://labelservice.co.uk/changes-to-recycling-label-rules-from-2026-to-help-consumers/

199 Ibid.

200 KPMG. (2024). Life cycle assessment guide: Undertaking a LCA is becoming a fundamental part of how companies are working towards net zero. https://kpmg.com/xx/en/home/insights/2023/10/life-cycle-assessment-guide.html#:~:text=According%20to%20these%20standards%2C%20a%20life%20cycle%20assessment,Impact%20assessment%20related%20to%20these%20inputs%20and%20outputs.

201 Plastics Europe. (2023). Life cycle assessment: The life cycle of plastics. https://plasticseurope.org/sustainability/circularity/life-cycle-thinking/life-cycle-assessment/ https://plasticseurope.org/sustainability/circularity/life-cycle-thinking/life-cycle-assessment/

202 European Commission. (2024). Plastic strategy. https://environment.ec.europa.eu/strategy/plastics-strategy_en

203 Marson, A., Piron, M., Zuliani, F., Fedele, A., and Manzardo, A. (2023). Comparative life cycle assessment in the plastic sector: A systematic literature review. Cleaner Environmental Systems, 9. https://www.sciencedirect.com/science/article/pii/S2666789423000132#bib50

204 KPMG. (2024). Life cycle assessment guide: Undertaking a LCA is becoming a fundamental part of how companies are working towards net zero. https://kpmg.com/xx/en/home/insights/2023/10/life-cycle-assessment-guide.html#:~:text=According%20to%20these%20standards%2C%20a%20life%20cycle%20assessment,Impact%20assessment%20related%20to%20these%20inputs%20and%20outputs.

205 British Plastics Federation. (2024). Life Cycle Analysis (LCA) - A complete guide to LCAs. https://www.bpf.co.uk/sustainable_manufacturing/life-cycle-analysis-lca.aspx#Who%20Conducts%20an%20LCA?

206 Voulvoulis, N. et al. (N.d). Examining material evidence the carbon fingerprint. Imperial College London. https://www.imperial.ac.uk/media/imperial-college/faculty-of-natural-sciences/centre-for-environmental-policy/public/Veolia-Plastic-Whitepaper.pdf

207 Ibid.

208 Finnveden, G., and Potting, J. (2014). Life Cycle Assessment In Encyclopedia of Toxicology (Third Edition). https://www.sciencedirect.com/topics/earth-and-planetary-sciences/life-cycle-assessment

209 Ciroth, A., Noi, C., Burhan, S. S., and Srocka, M. (2019). LCA database creation: Current challenges and the way forward. https://www.greendelta.com/wp-content/uploads/2020/09/LCA-database-creation.pdf

210 Hmiel, B. et al. (2020). Preindustrial 14CH4 indicates greater anthropogenic fossil CH4 emissions. Nature, 578: 409–412. https://www.nature.com/articles/s41586-020-1991-8

211 Vadenbo, C., and Notten, P. (2020). Roadmap for national LCA database development: Guidance and recommendations from around the world. https://lifecycleinitiative.org/wp-content/uploads/2020/06/INT_UNEP_LCA-Dev_June-10_sml.pdf

212 The European Commission. (2021). Commission recommendation (EU) 2021/2279 of 15 December 2021 on the use of the environmental footprint methods to measure and communicate the life cycle environmental performance of products and organisations. Document 32021H2279. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32021H2279

213 Valencia, E. (2019). The ILCD format – solving LCA data exchange problems. https://pre-sustainability.com/articles/the-ilcd-format-solving-lca-data-exchange-problems/

214 Quist, Z. (2023). The revised EPD standard 'EN15804 +A2': What's going to change? Environmental Policy & News. https://ecochain.com/blog/en15804-consequences/

215 Vadenbo, C., and Notten, P. (2020). Roadmap for national LCA database development: Guidance and recommendations from around the world. https://lifecycleinitiative.org/wp-content/uploads/2020/06/INT_UNEP_LCA-Dev_June-10_sml.pdf

216 UNEP. (2019). Development of national LCA database roadmaps. Life Cycle Initiatives. https://www.lifecycleinitiative.org/development-of-national-lca-database-roadmaps/

217 Hardy, G. A. (2015). A newcomer's guide to life cycle assessment - Baselines and boundaries. RGTW Working Paper, Number 3. https://assets.publishing.service.gov.uk/media/57a08989e5274a31e0000126/60955_A_Newcomers_Guide_to_LCA.pdf

218 GHG Protocol. org. (N.d). Quantifying the greenhouse gas emissions of products PAS 2050 & the GHG Protocol Product Standard: A short guide to their purpose, similarities and differences. https://ghgprotocol.org/sites/default/files/standards_supporting/GHG%20Protocol%20PAS%202050%20Factsheet.pdf

219 Gov.UK. (2021). Guidance: Making environmental claims on goods and services. Capital Markets Authority. https://www.gov.uk/government/publications/green-claims-code-making-environmental-claims/environmental-claims-on-goods-and-services

220 UNEP. (2022). 2022 Sustainable public procurement global review. Paris. https://www.oneplanetnetwork.org/sites/default/files/from-crm/300_I_UNEP_Global_Report_2022.pdf

221 NHS England. (2023). Carbon reduction plan and net zero commitment requirements for the procurement of NHS goods, services, and works. https://www.england.nhs.uk/long-read/carbon-reduction-plan-requirements-for-the-procurement-of-nhs-goods-services-and-works/

222 NHS England. (2023). Suppliers. https://www.england.nhs.uk/greenernhs/get-involved/suppliers/

223 Office for National Statistics. (2021). Healthcare expenditure, UK Health accounts provisional estimates: 2022- Provisional high-level estimates of healthcare expenditure in 2022 by financing scheme. Healthcare expenditure, UK. https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/healthcaresystem/bulletins/healthcareexpenditureukhealthaccountsprovisionalestimates/2022.

224 UKRI. (2022). Towards more sustainable use of plastics in healthcare. https://iuk.ktn-uk.org/news/towards-more-sustainable-use-of-plastics-in-healthcare/

225 Legislation.gov.uk . (2023). Procurement Act 2023- UK Public General Acts 2023 c. 54 Procurement Act 2023. (legislation.gov.uk)

226 SBRI Healthcare. (2023). Patients to benefit from 18 pioneering innovations that also accelerate a greener NHS. https://sbrihealthcare.co.uk/news/patients-to-benefit-from-18-pioneering-innovations-that-also-accelerate-a-greener-nhs/

227 UKRI: Innovative UK. (2023). SBRI: Circular Economy in the Welsh Public Sector. https://iuk.ktn-uk.org/opportunities/sbri-circular-economy-in-the-welsh-public-sector/

Figures

Table

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