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Eliminating avoidable plastic waste by 2042: a use-based approach to decision and policy making

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Written by: Resource Futures and Nextek

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Executive summary

Ever increasing growth in the amount of plastics produced has outpaced society's ability to manage them effectively at their end-of-life. In the UK, plastic packaging, which accounts for more than half of packaging waste, is recycled at 45% and non-packaging is thought to be recycled at a much lower rate.

Blue Planet II coverage of plastic ocean pollution started a reaction. The issue of discarded plastics and marine pollution is top of the political agenda and there is increasing pressure for business and Government to work together to 'solve' the problem.

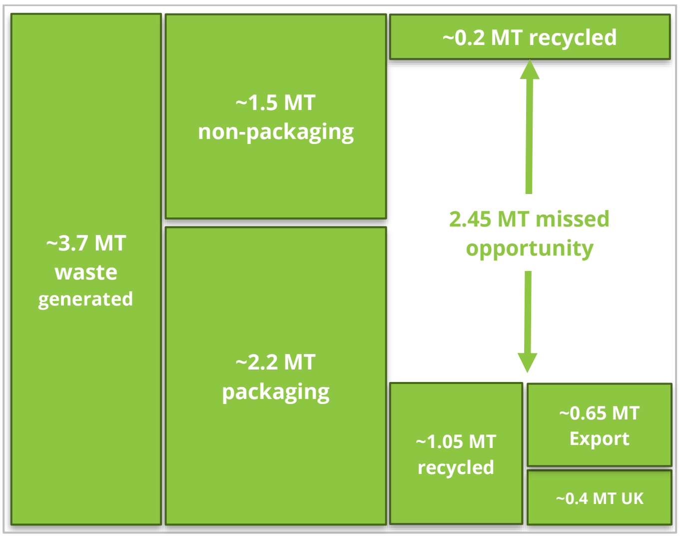

Figure ES 1: Estimated UK plastic waste generation (see Section 2.4.1 for sources)

The UK Government's recently published 25-year Environment Plan states its ambition to eliminate avoidable plastic waste by the end of 2042 and the supply chain has responded rapidly to the challenges posed by waste plastic with over 80% of supermarkets signing up to the UK Plastics Pact. This first of a kind, voluntary agreement seeks to eliminate unnecessary single-use packaging by 2025; make all plastic packaging recyclable, reusable or compostable; ensure that 70% of plastic packaging is reused, recycled or composted; and 30% recycled contestant across all packaging.

In addition, an increasing number of measures are being promoted by campaign groups, businesses and through regulation to begin to approach the plastics issue from a range of interventions. However, these actions are not always evidence based, the topic is highly complex, and decisions are heavily dependent on other stages in the lifecycle as well as regulation, global supply chains and consumer understanding.

The Resourcing the Future (RTF) partnership commissioned Resource Futures and Nextek to research and develop a framework to assist stakeholders across the plastics value chain and recycling sectors to move forward in a common direction for improving plastics resource efficiency.

The research is a rapid evolution of several weeks of research and collaborative thinking, involving feedback from more than 20 external stakeholders.

An innovative method of categorisation by the use phase provides a new approach to framing the discussion around resource efficiency for plastics by focussing attention on the dominant lifecycle impacts of different materials.

This research recognises the tremendous benefits that plastics provide and addresses some of the potential drawbacks of using alternative materials. However, some plastics are undoubtedly causing widespread marine pollution, and this has been the focus of the most attention from civil society in recent years. Ultimately, there will be a trade-off between the impacts on marine and terrestrial ecosystems; global warming; and economic and social pressures; and it is therefore important to take a proportionate and evidence-based approach to create a more resource efficient economy.

The UK secondary plastics sector has a critical role to play. Currently it is heavily dependent on global export markets, but recent market shocks, such as the ban on imports of post-consumer plastic waste by China has highlighted an opportunity to de-risk through increasing UK capacity.

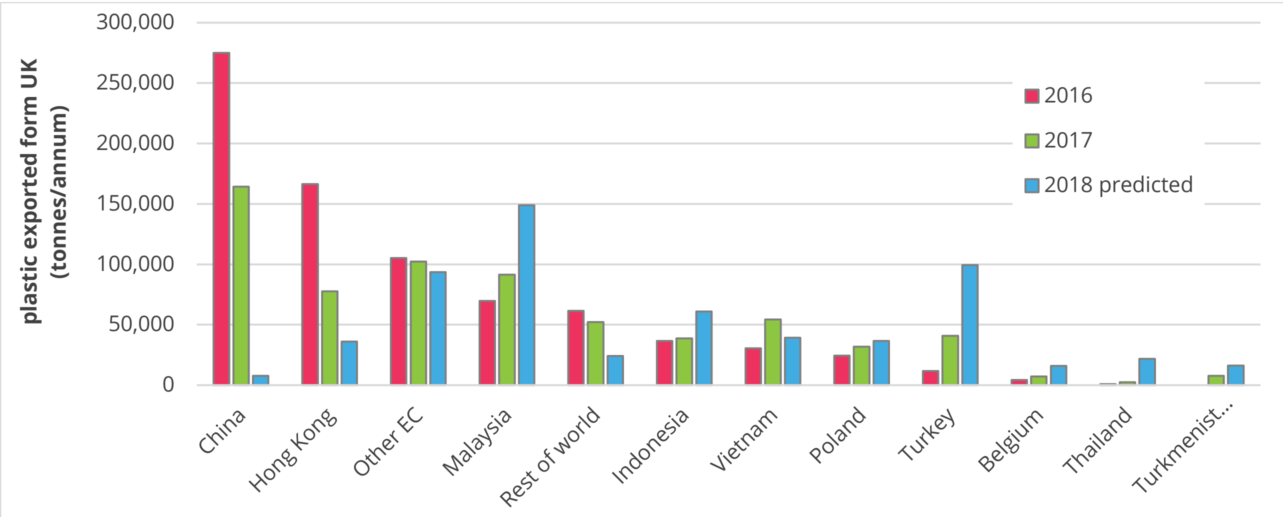

Figure ES 2: Plastic scrap exports from the exports from the UK[1]

If the aspirations of the UK Plastics Pact to achieve 70% recycling of plastic packaging by 2025 are to be achieved, then around 500,000 tonnes of additional reprocessing capacity will need to be identified either in the UK or abroad. Given the timescales involved, capital funding will be urgently required to invest in plastics reprocessing infrastructure. However, this investment will be an empty gesture unless the market, and fundamentally the value of secondary plastics, can be both increased and decoupled from the price of virgin material.

[1] Based on analysis of HMRC export data (2018), https://bit.ly/1eP80tm. Note that at the time of writing, 2018 data have only been reported for the first quarter; these were multiplied by four to predict the amount of material that will be exported to each country in 2018. Note that 'dispatches' to the EU are reported here as 'exports' for simplicity and may be further re-exported outside the EU.

A new approach - use phase categorisation

Recognising that plastics are not alike is the first step, and this research has done this by developing a new system of categorisation based on the length of time plastics are used. The five 'use phase categories' used in this research (see Table ES 1) provide a new approach to framing the discussion into resource efficiency by focussing attention on the dominant lifecycle impacts of different materials.

Table ES 1: Summary of use-phase categories used in this research (Further detail provided in Section 3.3 and detailed analysis is provided in Section 4.

Cat.	Description	Examples	Dominant lifecycle impact / Action required
1	**Very short use phase (<1 day) small format**	Cotton buds, coffee stirrers, straws, confectionery wrappers, medical, sanitary products, wet wipes, clothing tags, coffee pods	**End-of-life.** Terrestrial litter and marine debris is increasingly recognised as being harmful but difficult to quantify and compare to other environmental factors such as global warming **Action:** Eliminate or substitute use of plastics Research potential for biodegradable alternatives Education on 'non-flushable' products
2	**Very short use phase (<1 day) medium format**	Disposable plastic cups, plates, takeaway containers, plastic bags, plastic cutlery	**Production / end-of-life.** Production dominates the lifecycle from a carbon perspective as the use phase provides few functional benefits. As with cat. 1 contribute to terrestrial litter and marine debris. **Action:** Replace specific single use items with reuse alternatives More research into compostable alternatives and how to manage within the existing system Eco design standards
3	**Short use phase (>1 day <2 years)**	Food and drink containers, cosmetics, agricultural film, bags for life	**Use.** The use phase is usually most dominant as plastics are often used to protect goods which have far greater burdens from spoiling **Action:** Eco design standards including recycled content Increased sorting and separation technology Deposit return schemes Education to increase life of product being protected
4	**Medium use phase (>2 <12 years)**	Car parts, plastics in electronics, reusable distribution crates, toys, fishing	**Use.** The functional benefits provided during use usually outweigh the impacts of production and end-of-life **Action:** Design for improved durability, compatibility & modularity Improved data on current recycling rates Extended producer responsibility schemes Increased sorting and separation technology
5	**Long use phase (>12 years)**	Window frames, electrical, plumbing, insulating board, wall panels, roof tiles, carpet, soffits	**Use.** The functional benefits provided by plastics usually outweigh the impacts of production and end-of-life with a few exceptions such as water piping in construction which is dominated by production **Action:** Data on reuse and recycling rates required Improved on site separation operations Sorting and separation technology capacity Design for improved durability, compatibility & modularity Improved product information systems

The time for action is now

The use phase categories (Section 4.) analysis was used to identify priority interventions with the potential for maximum impact. Two common, overarching and interlinked themes were revealed:

1. Sustainable design & production choices; and
2. Supporting and generating demand for secondary plastics.

The research shows that with the right interventions, there are significant opportunities to address the issues arising from the widespread use and disposal of plastics. The current level of sophistication of the existing collection infrastructure and the available sorting and recycling technologies could create quick wins but there is a big question mark over its ability to meet higher ambitions without further intervention and support. Importantly, demand for recycled plastics needs to be strengthened with 'pull' factors that work alongside market forces to reduce the plastic recycling sector's vulnerability to market shocks related to oil prices or other global market price fluctuations.

With a focus on the two overarching themes this research proposes a selection of priority interventions which it is hoped will provide an improved sense of direction for stakeholders across the value chain. These are summarised here and detailed in Section 6.

Priority interventions

If all packaging in UK (approx. 2.2 million tonnes/year) used 30% recycled content, then this would be equivalent to the ~660,000 tonnes exported annually

Generating demand for secondary plastic content

Increasing demand for recycled content guarantees a market for secondary production and effectively decouples the industry from the virgin production sector.

For example, the UK Plastics Pact has already begun this process by securing commitments form stakeholders that control 80% of the packaging in the supermarket sector. If successful in achieving 30% recycled content, then the Pact's signatories will require in the order of 600,000 tonnes per annum of feedstock.

Extended producer responsibility

A well designed EPR scheme corrects the market failure of not considering the end-of-life treatment option and potentially have a role across the range of use phase categories. Recently adopted changes to the EU Waste Framework Directive provide an opportunity for the UK government to shape an ambitious and forward-thinking agenda supporting the development and growth of a resilient secondary plastics sector.

For some category 1, 2 and 3 items there are increasing calls for producers to pay for terrestrial and marine litter clean-up costs. Our research suggests that interventions linked to number of products rather than weight could be effective in recognising and correcting the impact costs.

Sorting and separation infrastructure

Increasing resource efficiency requires an increase of plastic being recycled and this will require infrastructure capacity to process. The interventions need to address the differing needs across the use phase categories incorporating packaging and non-packaging products. This requires technological innovation as well as an increase in capacity. The Government will need to work with industry to devise a range of financial instruments and mechanisms that support these dual technical requirements.

Clarification and agreement on the role of bioplastics

The UK Government's 25-year plan and the UK Plastics Pact have both included compostability as an aspirational characteristic for plastics alongside recyclability. However, the implications for the resources sector of expanding their use needs urgent strategic clarification and guidance. It is important that any future role is agreed taking into account the existing collection and treatment system and other parts of the plastics recycling sector. This research has provided clarification on some of the important issues and highlights the consequences of an unplanned influx of these novel materials into the UK's waste stream. Therefore, it is recommended that urgent research is carried out to assess the operational, economic and environmental impact of these materials and how they best support a drive for improved resource efficiency.

Section 7. closes the report by highlighting areas that were not possible to cover in this research but will play an important part in developing a truly circular and resource efficient plastics sector.

Contents

Glossary

Acrylonitrile-butadiene-styrene (ABS)	A thermoplastic polymer. Commonly used for printer housings, small domestic appliances, automobile interiors and toys.
Bio-derived	Bio-based products are wholly or partly derived from materials of biological origin. Commonly, the material has been highly processed.
Biogenic	Produced or brought about by living organisms.
Brominated flame retardants (BFR)	A family of chemicals containing bromine that are added to products to reduce their flammability.
Cellulose Acetate (CA)	A tough thermoplastic. Attractive and with a 'natural feel', CA is used for spectacle frames, tool and brush handles and "display packaging".
Ecolabel	An ecolabel identifies products or services proven to be environmentally preferable overall, within a specific product or service.
Electrical and Electronic Equipment (EEE)	Electrical items with a voltage rating not exceeding 1,000 volts for alternating current and 1,500 volts for direct current.
Electronic Product Environmental Assessment Tool (EPEAT)	A method for purchasers, manufacturers, resellers and others wanting to find or promote electronic products with positive environmental attributes.
Expanded Polystyrene (EPS)	A rigid cellular plastic. Applications include fish boxes, packaging for electrical consumer goods and for insulation panels for building.
End-of-life Vehicle (ELV)	A vehicle which is waste within the meaning of Article 1(a) of Directive 75/442/EEC.
Ethylene-vinyl alcohol copolymer (EVOH)	A plastic resin commonly used as an oxygen barrier in food packaging and in automobile fuel tanks.
High density polyethylene (HDPE)	A type of thermoplastic used for most thin gauge carrier bags, milk bottles, fresh produce bags and some bottles and caps.
High Impact Polystyrene (HIPS)	A tough, rigid plastic. Widely used for computer keyboards, television housings, refrigerator liners, toys, packaging and signs.
Low-density polyethylene (HDPE)	A semi-rigid, tough, low-cost plastic. Applications include squeeze bottles, toys, carrier bags, general packaging, gas and water pipes.
Polyamide (PA)	A plastic made from renewable resources such as corn starch. Common substitute for PET. Commonly used in plastic films and food containers.
Polybutylene adipate co-terephthalate (PBAT)	A class of biodegradable and compostable plastic. Applications include cling film, compost bags and nets.
Polybutylene terephthalate (PBT)	A strong, stiff engineering plastic. Used for food processing machinery applications due to its resistance to chlorine and caustic cleaning solutions.
Polycarbonate (PC)	A group of thermoplastic polymers. Commonly used for electronic components; construction materials; CDs and DVDs.
Polylactic acid (PLA)	A plastic made of renewable resources such as corn starch or sugar cane. Used as substitute for PET in packaging e.g. films and food containers.
Polyvinyl chloride (PVC)	A thermoplastic and one of the most widely used polymers in the world. Applications include pipes, cables, construction, signs and clothing.
Post-Consumer Recycled Plastic (PCR)	Plastic products made from plastic recovered after its first use as a consumer item.

Persistent Organic Pollutants (POPs)	Persistent organic pollutants (POPs) are hazardous organic chemical substances that break down slowly and get into food chains as a result.
Poly (methyl methacrylate) PMMA	Known as acrylic glass and by various trade names, including Plexiglas® and Perspex®. A clear plastic used as a shatterproof replacement for glass.
Polyester (PET)	The most common thermoplastic polymer resin of the polyester family. Used in synthetic fibres, plastic bottles, food containers, and in engineering resins.
Polyhydroxy alkanoates (PHA)	A class of polyesters derived from bacterial fermentation. When purified they have similar properties to thermoplastics and offer biodegradability.
Polypropylene (PP)	A versatile polymer used as a plastic and as a fibre. Major uses are for packaging, automotive components and electrical equipment.
Polyurethane (PU and PUR)	Polyurethanes may be thermosetting or thermoplastic, rigid and hard or flexible and soft, solid or cellular. Over 75% of consumption is for foams.
Polyvinylidene fluoride (PVDF)	A plastic with high purity and ability to withstand harsh chemicals. Common applications include pipe, valves, batteries, and high-purity semiconductors.
Regulations: restriction of hazardous substances (RoHS)	RoHS, also known as Directive 2002/95/EC, restricts the use of ten hazardous materials (specific heavy metals, flame retardants and plasticisers) found in electrical and electronic products.
Thermoplastic polyolefins (TPO)	Blends of polypropylene, un-crosslinked rubber, and typically a filler. Used where toughness is needed, such as in car bumpers and on flat rooves.
Thermoplastics	Polymer substances (especially synthetic resins) that can be reheated and reshaped many times.
Ultra-high-molecular-weight polyethylene (UHMWPE)	Offers a low friction surface, great impact strength, and wear and corrosion resistance. Common applications include screws, bushings and gears.
Waste Electrical & Electronic Equipment (WEEE)	EEE which the holder disposes of or is required to dispose of pursuant to the provisions of national law in force.

Single-use plastic product definitions

HM Treasury: 'includes all products that are made wholly or partly of plastic and are typically intended to be used just once and/or for a short period of time before being disposed of.'[2]

European Union: 'a product made wholly or partly from plastic that is not conceived, designed and placed on the market to accomplish within its lifecycle multiple trips or rotations by being refilled or re-used for the same purpose for which it was conceived[3]

[2] HM Treasury (2018), Tackling the plastic problem: Using the tax system or charges to address single-use plastic waste, https://bit.ly/2s39Sx1

[3] EC (2018), Proposal for a Directive of the European Parliament and of The Council on the reduction of the impact of certain plastic products on the environment https://bit.ly/2s1K45d

1. Introduction

Resourcing the Future is a collaborative partnership between the CIWM, ESA, Resource Association and WRAP. The partnership commissioned Resource Futures and Nextek to research and develop a 'framework' for improving plastics resource efficiency.

The aim is to assist stakeholders across the plastics value chain to move forward in a common direction and improve the role of the UK secondary plastics market. This report has been prepared independently and does not represent the views or position of the partnership members.

Plastics are widely used in all areas of society. The range of applications demonstrate the versatility of plastics, from transparent flexible food wrap to high strength construction materials. Plastics can allow the manufacture of goods that would not be technically possible or affordable using other materials.

The simplest categorisation of plastics is into packaging and non-packaging. In the UK, collected plastic packaging is reported to be recovered at approximately 45%. However non-packaging is thought to be recovered at a much lower rate.

Recent media coverage has lifted the issue of waste plastics higher up public consciousness and, as a result, there is increasing pressure across society for a response from both commerce and government. Marine pollution and excessive use of packaging have prompted a range of initiatives in the UK, such as 'plastic free aisles' in supermarkets, carrier bag bans, and proposed deposit return schemes. The Government's 25-year Environment Plan[4] also has a key focus on plastics, committing the UK to eliminating avoidable plastic waste by the end of 2042.

However, the negative publicity around plastics and, in particular, single use plastics, has the potential to influence decision-making without considering sound evidence. This could result in unintended consequences in terms of environmental, social and economic impacts, and work against efforts to transition towards a circular economy.

The research presented here proposes that the debate around plastics and plastics waste is reframed. It provides guidance on the decision-making processes and tools that will help identify the interventions that will be the most effective at mitigating environmental impacts and developing a strong and stable circular economy.

In overview, the framework and intervention guidance are intended to help stakeholders develop strategies to:

- Design and manufacture plastic products for longer use and better end-of-life treatment or disposal;
- Maximise environmental benefits during the use of plastic products; and

[4] HM Government (2018), A Green Future: Our 25 Year Plan to Improve the Environment, https://bit.ly/2r0iV1Z

- Increase the amount of plastics that are re-used, recycled and recovered.

This report distils information from literature and engagement with stakeholders.

2. Context

2.1 Policy and other instruments

A wide range of legislation affecting how plastics are produced, used and disposed of is in place in both EU and UK law[5]. Several strategies and voluntary agreements are also in place. The following section outlines the key UK and EU instruments that are influencing the current debate around plastics. Further details of EU legislation can be found in Appendix A.

2.1.1 UK

The UK Government's recently published **25-year Environment Plan**[6] states an ambition to eliminate avoidable plastic waste by the end of 2042. The rationale is that some plastic wastes are 'difficult to dispose of in a way which does not harm the natural world'. The key aspirations are outline below in Table 2.

Table 2: Summary of relevant commitments from 25-year Environment Plan

Production	Reforming and extending the producer responsibility system to include products not currently covered and stimulate the secondary plastics sector
	Encouraging industry to rationalise packaging and materials formats to facilitate end-of-life processing
	Building on the existing microbeads ban
	Accelerating funding from the Industrial Strategy Challenge Fund
	Encouraging development of bio-based, biodegradable and 'environmentally friendly' plastic
Use	Encouraging water refill points in business and public places
	Extending plastic bag charging to small retailers
	Explore the introduction of plastic free supermarket aisles
Waste collection	Continuing support for on-pack-labelling
	Continuing with litter strategy
	Implementing interventions to reduce commonly littered items
Waste treatment & disposal	Improve consistent collection
	Increase plastic collected for recycling
	Develop standards for biodegradable bags
	Investigating reduction of CO_2 emissions from incinerators by reducing plastics in residual waste*

* This action appears under the sub-heading for 'improving management of residual waste'

[5] It should be noted that there is potential for uncertainty arising from the proposed exit of the UK from the EU (hereafter Brexit).

[6] HM Government (2018), A Green Future: Our 25 Year Plan to Improve the Environment, https://bit.ly/2r0iV1Z

The UK Plastics Pact[7] is a collaboration between WRAP, retailers, plastics recyclers, brands, manufacturers, NGOs, Governments and local authorities. The Pact's participants are responsible for more than 80% of the UK's supermarket plastic packaging and this voluntary agreement is the first of its kind the world.[8] It sets out the following targets to be achieved by 2025:

- Eliminate problematic or unnecessary single-use plastic packaging through redesign, innovation or alternative delivery models (such as reuse)
- All plastic packaging reusable, recyclable, compostable
- 70% of plastic packaging recycled, reused or composted
- 30% recycled content across all plastic packaging

Furthermore, Defra is due to publish a national **Resources and Waste and Strategy** in 2018 which is expected to expand on many of the topics discussed in this research.

In addition to the above, two further specific interventions are noteworthy including the introduction of a deposit return scheme and also the potential for a single-use plastic tax which, at the time of writing, is the subject of a public consultation.[9] These, along with other interventions are discussed in more detail in Section 5.

2.1.2 European Union

The majority of UK environmental law affecting how plastics are made, used and managed originates from EU directives which are summarised in more detail in Appendix A.2. Three recent policy frameworks are particularly relevant to the present study:

Circular economy package – a set of proposed actions aimed at "closing the loop" of product lifecycles by retaining the maximum value and use from raw materials, products, and waste.[10] The new package requires producers to bear 80% of 'necessary costs' to achieve weight-based targets for packaging recycling.

European Strategy for Plastics in a Circular Economy - new rules on packaging will be developed to: improve the recyclability of plastics; increase demand for recycled plastic content; reduce the use of single-use plastics and microplastics in products; prevent littering at sea; provide guidance for national authorities and businesses on how to minimise plastic waste at source; and, collaborate to devise global solutions and develop international standards.[11]

[7] WRAP (2018), The UK Plastics Pact, https://bit.ly/2FiCqHp
[8] Ellen Macarthur Foundation (2018), Plastics Pact, https://bit.ly/2sTiFCf
[9] HM Treasury (2018), Tackling the plastic problem: Using the tax system or charges to address single-use plastic waste, https://bit.ly/2s39Sx1
[10] EC (2018), Circular Economy Package, https://bit.ly/2krgtxX
[11] EC (2018) European strategy for plastics, https://bit.ly/1pjhS7g

Proposal for a directive on single use plastic packaging[12] - this proposal targets 70% of items thought to contribute to marine debris through a combination of bans; producer obligations; awareness raising measures; labelling; and consumption and collection targets. At the time of writing this proposal has been agreed at the EU level and will be passed to the European Parliament and Council for adoption.

Clearly these policies represent considerable progress towards reducing pollution and improving resource efficiency for waste plastics and it is likely that further legislative changes will be proposed in line with the EU Plastic Strategy. This rapidly changing policy landscape is likely to impact on the UK's waste industry significantly in the coming years and it is therefore increasingly important for the UK to consider its own policies in line with its neighbours.

2.2 Plastic types

The production of plastics is complex, with many stages between the creation of monomers from refined crude oil or shale gas, to polymerisation and manufacture into products. They are all polymers (meaning literally "many units") and can be classified into two broad subsets, thermoplastics and thermosets, which are described briefly in the following sections. A third section discusses the topic of bio-plastics.

2.2.1 Thermoplastics

Thermoplastics account for over 90% of the mass of plastics produced.[13] [14] They remain chemically stable over a large range of temperatures and can be melted and shaped into new objects and solidified simply by cooling. This feature allows plastics to be readily recycled by grinding items to smaller sizes and then re-melting and reshaping once again. The main processes used in manufacturing are injection moulding, blow moulding, thermoforming, and extrusion.

The most commonly encountered plastics are Polyethylene, Polypropylene, Polystyrene, Polyvinyl chloride (PVC), Acrylic, Nylon, and Polyethylene terephthalate (PET). Whilst there are twenty or so commonly encountered plastics, there are many hundreds of plastics is use. Importantly, very few of these can be mixed together during recycling and require separation into mono-polymer streams. A list of the main thermoplastics used is shown in Table 18, Appendix C.

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[12] EC (2018), Directive of The European Parliament and of The Council on the reduction of the impact of certain plastic products on the environment, https://bit.ly/2scgqKM

[13] CISION (2015), Global Thermosetting Plastics Market - Segmented by Type, Industry and Geography - Trends and Forecasts (2015-2020) - Reportlinker Review, http://prn.to/2GSIpnx

[14] CISION estimates production at ~34 Mt in 2014 and Geyer (2017)**Error! Bookmark not defined.** estimates total polymer resin a nd fibre production at 367 Mt for the same year. Therefore thermosets = 9.3% global production of all plastics

2.2.2 Thermosets

Thermosets are plastics that have been chemically reacted or "set" in a way that prevents melting and are characterised by their high resistance to heat, solvents, chemicals and mechanical force. Thermosets are typically more challenging to recycle due to their inability to be melted down and reformed in the same way as thermoplastics. The manufacturing methods are typically compression and injection moulding without cooling while the chemical (crosslinking) reaction is taking place hence the name "thermo set". A list of the main thermosets in use is provided in Table 19, Appendix C.

2.2.3 Bioplastics

The term bioplastics covers a range of fossil and biological based materials which have been developed with different environmental outcomes in mind including the substitution of fossil fuels and post-use environmental impact. There are potentially interesting benefits from this group of materials which may be applicable in specific circumstances; these are discussed throughout this document.

Though they currently make up only a small proportion of plastics overall (~1%), bioplastics are worthy of more explanation in this report as they are topical and a source of ongoing confusion amongst the public and across industry.

More detail is provided in Appendix D and a short summary is provided here. There are two broad concepts for this group of materials:[15]

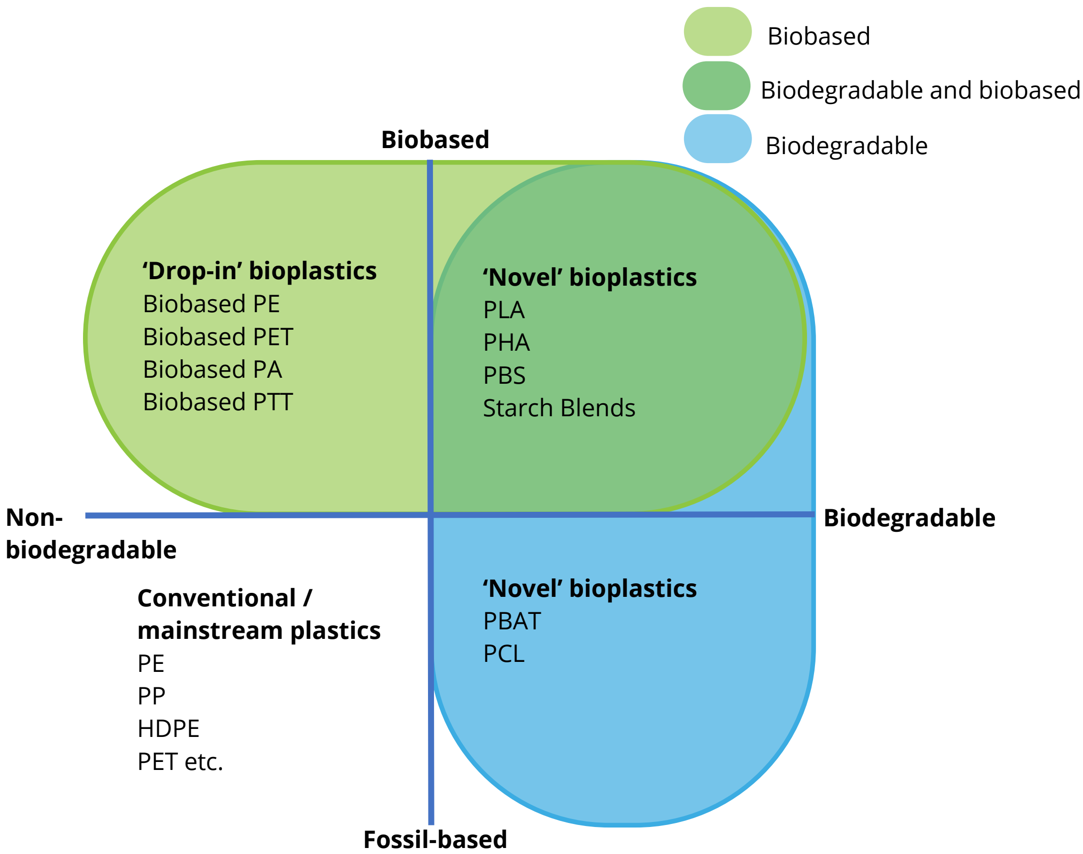
- **Bio-based plastics** have been produced from biological sources such as sugar cane, beet sugar, corn, potatoes, grains or vegetable oils. They are not necessarily biodegradable.
- **Biodegradable plastics** can be broken down by micro-organisms to make carbon dioxide and water under aerobic conditions or methane under anaerobic conditions. These plastics can be made from biogenic[16] or fossil-based material.

Within these broad groups lie several sub-categories which are described in the following sections and illustrated in Figure 3.

[15] Plastics Europe (2016), Plastics – the Facts 2016: An analysis of European plastics production, demand and waste data, http://bit.ly/2C39H7H

[16] Biogenic refers to material which is derived from plants or animals within recent history. In this context it excludes fossil material including derivatives of crude oil.

Figure 3: Interrelationship between conventional, bio-based and biodegradable plastics[17]



2.2.3.1 Bio-based plastics

There are two further sub-groups within the bio-based plastics group:

- **Novel bio-based plastics** which have relatively new chemical structures such as polylactic acid (PLA) or Polytrimethylene terephthalate (PTT);[18] and Polybutylene sebacate (PBS).
- **Drop-in plastics** such as PET (Bio-PET) and bio-based polyethylene (Bio-PE) which have the same chemical structure as their fossil-based counterparts, are miscible[19] with them and share the same characteristics.

'Drop-in bioplastics' have the advantage that they are also recyclable alongside fossil-based polymers of the same type, with special precautions. Novel, biodegradable bio-based plastics are generally designed to be biodegradable at ambient or elevated temperature conditions.[20]

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[17] Based on Perstorp, https://bit.ly/2KKo1ag

[18] Institute for Bioplastics and Biocomposites (2016), Biopolymers facts and statistics, https://bit.ly/2rZBRxy

[19] Capable of forming a homogeneous mixture that neither separates nor is altered by chemical interaction aka mixable

[20] Moss et al (2017), Sea of Opportunity: Supply Chain Investment Opportunities to Address Marine Plastic Pollution, http://bit.ly/2pxLHVf

2.2.3.2 Biodegradability of plastics

The term 'biodegradability' is commonly misunderstood and misreported. There are several standards for compostability in commercial and home composting contexts (see Appendix D) but though test methods exist, there is no agreed standard for degradability in the natural environment. This partly because the behaviour of these materials in different settings is not well understood. A UNEP report[21] concluded that compostable plastics in the marine environment would be unlikely to reduce the impacts of marine litter, in part because they may still take many years to fully break down. This issue has significant implications for the way that we classify and manage biodegradable plastics.

2.2.3.3 Recycling and incineration of biodegradable bio-based plastics

Biodegradable, bio-based plastics are often difficult to recycle because they can break down readily and because many of them are hygroscopic (absorb moisture). Water attacks the polymer during melting stages, weakening the material.[22] However, some biodegradable bio-based plastics are recyclable and at least one commercial recycler of PLA is known to operate in Belgium[23]. However, there are no currently known commercial avenues for recycling novel biodegradable bioplastics in the UK.

The main waste management route available for biodegradable bio-based plastics in the UK is incineration or landfill. If energy is recovered from incineration, this could potentially result in a net green-house gas mitigation benefit as the carbon source is biogenic (short-cycle).[24] In the case of landfill, however, any methane generated by degradation will contribute to global warming if uncaptured.[25]

As discussed in Section 2.2.3, there is significant risk of confusion amongst consumers because novel bio-based, biodegradable plastics often exhibit the same aesthetic characteristics as mainstream alternatives. The potential for novel biodegradable bio-based plastic products to contaminate and lower the quality of conventional plastics is considerable and potentially damaging to the secondary plastics market.

2.2.3.4 Compostability

Many biodegradable bio-plastics and some fossil-based plastics are also considered compostable under certain conditions. Several standards exist; the main European one being EN13432, which broadly share the same common definitions:[26]

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[21] UNEP (2015) Biodegradable plastics and marine litter, misconceptions, concerns and impacts on marine environments. http://bit.ly/2uEJLM8

[22] Defra (2015), Review of standards for biodegradable plastic carrier bags, https://bit.ly/2IC6fcm

[23] Looplife Polymers, https://bit.ly/2Hzf80Z

[24] WRAP (2010), Environmental benefits of recycling, http://bit.ly/2uricL6

[25] Estimates suggest fugitive emissions are approximately 50% from UK landfill sites: Defra (2014), Review of landfill emissions methane modelling, https://bit.ly/2LxTa1z

[26] WRAP (2010), Environmental benefits of recycling, http://bit.ly/2uricL6

- **Chemical characteristics:** it contains at least 50% organic matter (based on dry weight) and does not exceed a given concentration for some heavy metals.
- **Biodegradation:** it biodegrades by at least 90% (by weight) within six months under controlled composting conditions (temperature of 58 +/- 2°C).
- **Disintegration:** it fragments into pieces smaller than 2mm under controlled composting conditions within 12 weeks.
- **Ecotoxicity:** the compost obtained at the end of the process does not cause any negative effects.

A key limitation of compostable plastics which meet these standards is that six months is allowed to break down the material. There are more than 50 composting facilities that could potentially accept these materials; however many of them typically process material over an eight to twelve-week period. This may be adequate for highly absorbent films such as caddy liners but is unlikely to be sufficient to process other compostable plastics such as those used for beverage containers, which are designed to resist water and are therefore less easily broken down.

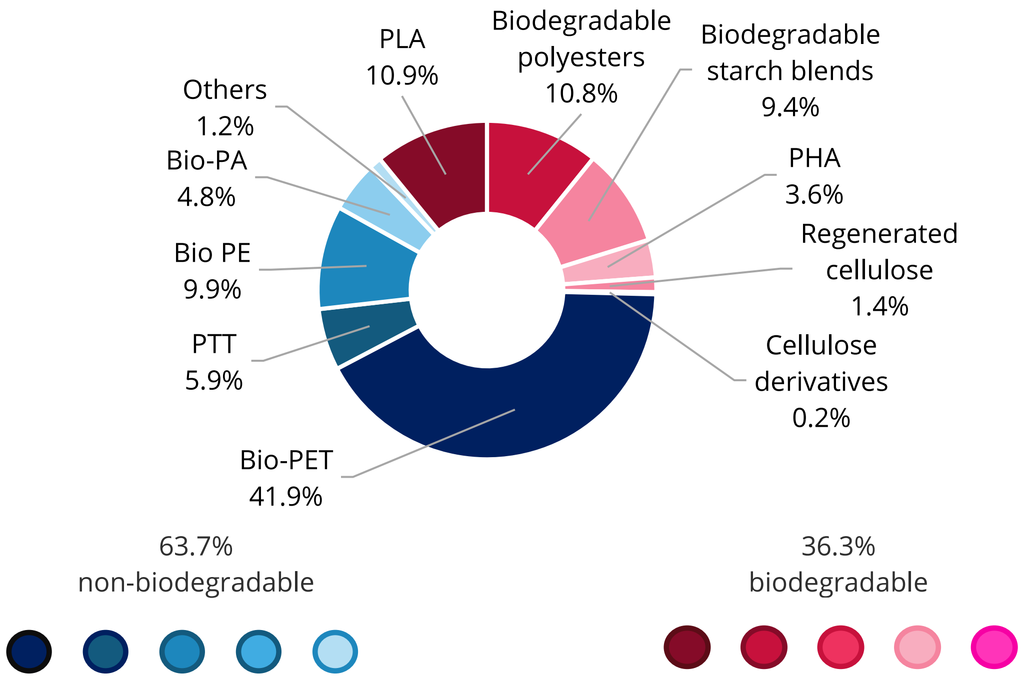
Additionally, compostable plastics tend to exhibit similar aesthetic and physical properties to non-compostable plastics, meaning that they are almost impossible to distinguish at a composting plant. Determining whether they should be accepted in the process or screened out as contamination is therefore challenging. Conversely, this same confusion arises at plastics recycling facilities which cannot differentiate between compostable and mainstream target plastics types.

2.2.3.5 Market share for bio-based plastics

As highlighted above, bio-based plastics currently make up approximately 1% of global plastics production. The largest growth area is expected to be for drop-in bio-based plastics which are anticipated to have a 75% share of the total bio-based plastics market by 2021.[27]

[27] European Bioplastics (2016), Bioplastic market data 2016, http://bit.ly/2ySHyz7

Figure 4: Bio-based plastics placed on market (IBB 2016)[27]



2.3 Technical barriers to plastics recyclability

The low recycling rates achieved for waste plastics are partly a consequence of the way that plastic products are designed and produced. Identifying and removing these barriers could have a considerable impact on creating a more circular material chain.

Several guides and tools are available to assist packaging manufacturers with designing their products to assist secondary reprocessors, and address the barriers experienced by recyclers. These include the European Plastics Bottle Platform (EBPB)[28], the Association Plastics Recyclers (APR Design® Guide) in the USA[29], the European Association of Plastics Recycling (EPRO)[30], RECOUP[31], and the RecyClass software tool[32] of Plastics Recyclers Europe[33] and WRAP.[34]

The overall message from the range of guidance documents above is that complexity in the range of polymers, colours, labels, and components impedes recycling and that simplifying and standardising these materials would be an effective intervention for recyclability. These issues are discussed further in Section 6.1.2.3.

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[28] EPBP (unknown), Design Guidelines, https://bit.ly/2gKFXnS
[29] Association of Plastics Recyclers (unknown), The APR Design Guide for Plastic Recyclability, https://bit.ly/2JANB0X
[30] EPRO (unknown), Do your own Recycling Evaluation!, https://bit.ly/2Hzkl93
[31] Recoup (2017), Recyclability by Design, https://bit.ly/1Bw1XGR
[32] Recyclass (unknown), The Recyclability Tool for plastic package, https://bit.ly/2zkhrGd
[33] Plastics Recyclers Europe (unknown), Design Guidelines for Recycling, https://bit.ly/2JBrdIn
[34] PRAG (2009), An introduction to Packaging and Recyclability. https://bit.ly/2JjhfM9

For secondary plastics to compete with virgin materials, they must not only compete on price but also on quality. Plastics are often highly mixed, contaminated and dispersed; requiring technical solutions to effectively separate, clean and then separate again before the desired quality is achieved. The specialist equipment, power, and time required all impact on the operational costs of plastics recycling and sorting.

The range of additives used in products also present a potential challenge to secondary materials markets. For example, meeting stringent food grade requirements or automotive safety standards is not easily compatible with current collection, sorting and cleaning processes.

One of the limitations of current recycling systems is the inability to distinguish between food grade and non-food grade packaging. This is necessary to satisfy EU requirement (EC No 282/2008) which mandates that only food grade materials may be reused back into the food contact applications[35]. Extensive research has been conducted on this issue, including assessment of the potential to use markers to allow the two types of plastics to be efficiently separated for recycling.[36]

This would stimulate the recycling of food grade PP[37] which is currently only recycled into non-food applications. It would also improve the yield and quality of sorting of other food grade plastics such as HDPE and PET.

The use of colourants in plastics is another factor that limits the secondary use of recycled plastics. Retail brands usually want all products to look identical and consequently, recovered coloured plastics have limited markets in new packaging[38]. The use of small labels or removable sleeves over unpigmented plastics would boost the value and applicability of recycled plastics.

As discussed above, novel bio-based plastics, which are visually and aesthetically similar to mainstream plastics (e.g. PLA and PAH), will negatively affect the quality of recycled plastics if they are not separated effectively. The use of oxo-degradable additives, which has grown steadily over recent years, will have a similar effect. The has significant cost implications for recyclers who will need to use additional technology to identify and separate these materials (for example, installing NIR spectroscopy separators to target a single novel material which may only arise in very small quantities.

[35] EC (2008), Commission Regulation (EC) No 282/2008 of 27 March 2008 on recycled plastic materials and articles intended to come into contact with foods and amending Regulation, https://bit.ly/2y2AYuA

[36] WRAP (20144), Optimising the use of machine readable inks for food packaging sorting, https://bit.ly/2MlErqY

[37] WRAP (2016), Food grade recycled polypropylene (rPP) in packaging https://bit.ly/29JCYuE

[38] Plastics Technology (2015), Colored PET: Pretty to Look at; Headache For Recyclers, https://bit.ly/2MmWeOv

2.4 The secondary plastics market

2.4.1 Plastic waste generation

An estimated 4.9 million tonnes of plastics are placed on the UK market each year, of which around 3.7 million tonnes become waste (Table 3). The remaining estimated 1.2 million tonnes is thought to accumulate as stock.[39] Three plastics HDPE, LDPE and PP account for nearly 60%; with PET, PVC and PS accounting for another 26%. The remaining seven plastic categories are relatively minor by comparison accounting for 16% in total.

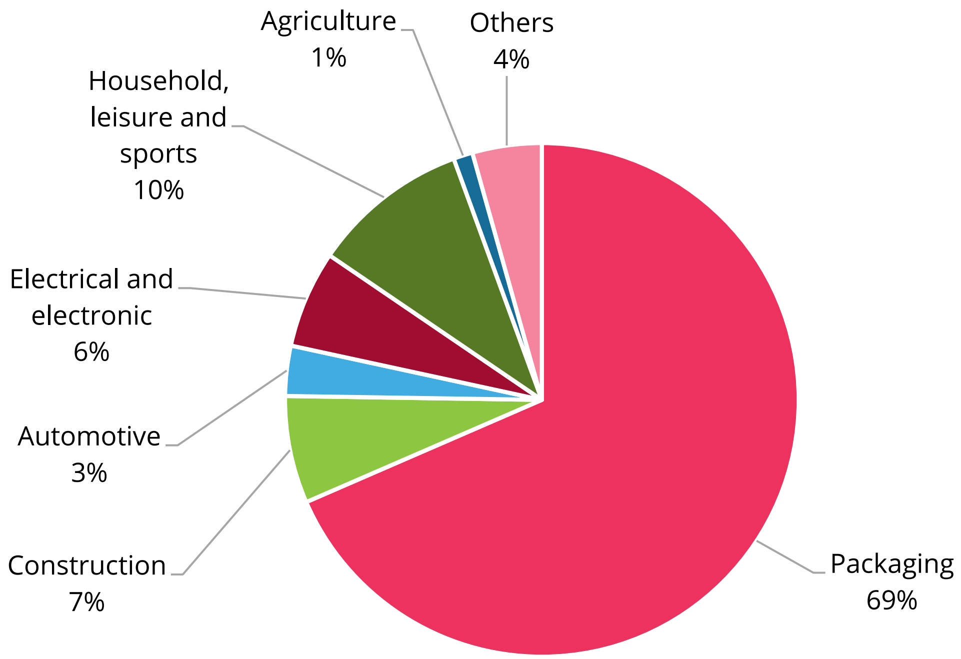
Table 3: UK plastic waste generation from all sources in 2016 (source: BPF)

Plastic polymer type	Waste generation (ktpa)	Proportion
HDPE	937	25%
LDPE LLDPE	682	18%
PP	558	15%
PET	424	11%
PVC	308	8%
PS	269	7%
Others	170	5%
PUR	92	2%
EPS	87	2%
Other thermoplastics	80	2%
ABS, SAN	65	2%
PA	58	2%
PMMA	38	1%
Total	3,768	100%

Data describing the waste estimates in Table 3 by industrial sector exist but do not necessarily align and it is not within the remit of this report to scrutinise sources in detail. However two sources are provided as an indication, which is essential to help target interventions proportionately. The first estimates are provided by WRAP-Valpak (2016)[40] and illustrated in Figure 5.

[39] Note that this 1.2 million tonnes accumulation is a speculative figure, based in part on Geyer's global analysis and through discussions with industry stakeholders. Obtaining more reliable data could form a new body of research.
[40] WRAP-Valpak (2016), Plastics Spatial Flow, https://bit.ly/2l6PcRR

Figure 5: Estimated plastic waste arisings by industrial sector

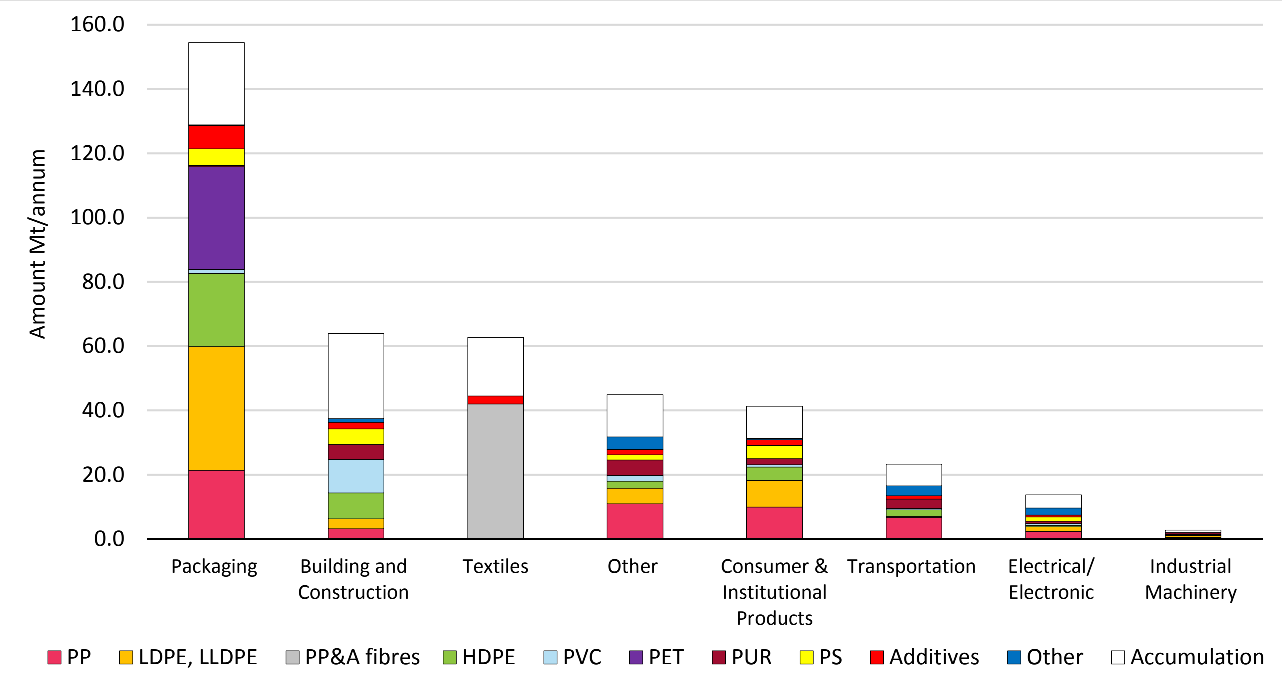


The estimates in Figure 5 provide a useful indication but are hard to verify, and the report acknowledges uncertainty. In particular, the proportion of packaging in comparison to non-packaging appears high when compared with other data.

In a recent study of global plastics production and fate[41], packaging worldwide is estimated to be just under 42% of the total plastic waste generated. These data are illustrated in Figure 6 showing waste generation and indicating the amount of material from each industrial sector which is retained as stock.

[41] Geyer et al (2017), Production, use, and fate of all plastics ever made, Science Advances, http://bit.ly/2uBs8AT

Figure 6: Global weight of plastic polymers produced by industrial sector. 'Accumulation' is approximated as an indication only (Geyer et al., 2017)[41]



2.4.2 Domestic market for secondary plastics

Data on the amount of plastic waste collected, recycled and exported is not consistently reported. Packaging data and municipal data in general are robust, but as described in Section 2.4.1, there is some uncertainty over the amount of non-packaging plastics which are produced and recycled as many of these data are not comprehensively reported This report recommends improved data collection for non-packaging waste in Section 6. Furthermore, the amount of plastic

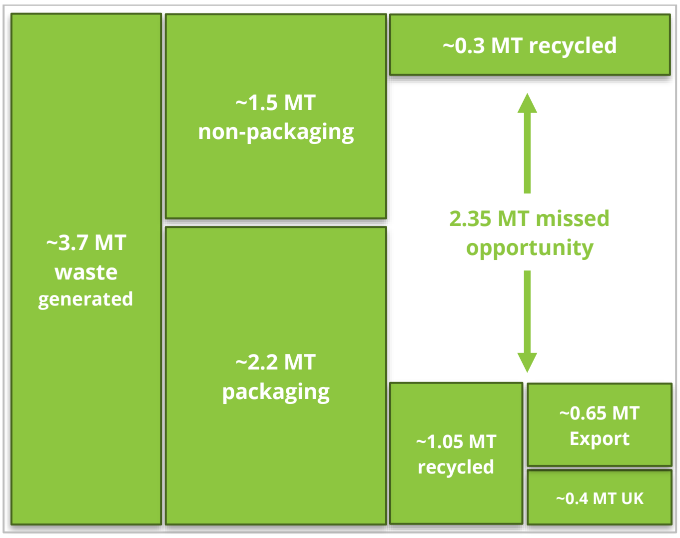


Figure 7: Estimated UK plastic waste generation[42]

[42] Estimation is a combination of the following: Resource Futures (2016) Resource Data, https://bit.ly/1IMEBPH uses SIC code data combined with survey data to estimate 200,000 tonnes per annum of waste plastics recycled in the UK from the non-packaging sector. We then estimate the combined output from MBA Polymers and Axion (both processing WEEE and ELV shredder residue) is 50,000 tonnes per annum. We also know that Recovinyl collects 117,000 tonnes per annum of PVC from construction.[42] WRAP-Valpak estimates nearly 380,000 tonnes per annum, but these data seem high in the context of other estimates. Therefore a middle ground of 300,000 tonnes has been suggested.

waste being collected for recycling is steadily increasing.

It is beyond the scope of this report to provide detailed waste data. However, several sources from 2016 and 2017 have been compared to arrive at the estimates illustrated in Figure 7. Data have been rounded to the nearest 50,000 tonnes which also indicates the accuracy of the figures.

Of the estimated 3.7 million tonnes of plastic waste produced in the UK,[15] around 400,000 tonnes of plastic packaging is collected and processed in the UK each year[43] (including unaccredited tonnage of approximately 50,000 tpa)[44] and a further ~650,000 tonnes is exported.[45] It is also estimated that 300,000 tonnes of non-packaging is recycled[42] but the data are hard to verify. Plastic material that is currently not being captured for recycling is estimated to be 1.15 million tonnes for packaging and 1.2 million tonnes for non-packaging plastics.[46]

2.4.3 Secondary plastics operational capacity

In the UK, post-consumer plastics are processed by material recovery facilities (MRFs). These separate polymers by type and bale them into a saleable product which may then be further sorted in specialised plastics recovery facilities (PRFs). These businesses are sometimes vertically integrated and process the material further by high purity sorting, size reduction and washing to produce high purity plastics flakes.

Some plastics (notably PET but HDPE, PP and PVC as well) are sold in flake form directly to product manufacturers to minimise energy costs and reduce the number of times the material is heated up (plastics properties are reduced each time they are heated). Further processing by extrusion, inclusion of additives and melt filtration is used to produce pellets with very low levels of contamination and properties suited to specific end applications including food grade PET and HDPE. Many facilities provide a complete service from sorting through to pelletising. At present there is an estimated capacity of over 1.3 million tonnes of plastic sorting, washing and flaking in the UK and pelletising capacity of at least 0.5 million tonnes making pellets from LDPE, HDPE, PET and PP. A further discussion on UK capacity can be found in Section 6.1.1.

2.4.4 Exports

The UK does not currently have sufficient capacity for recycling all the mixed plastics collected, so much of this material is exported to other countries. The costs of shipping recycled materials overseas are low because the UK is a net importer of consumer goods and there is lots of capacity on ships leaving the UK.

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[43] Environment Agency (2018) National Packaging Waste Database, https://bit.ly/2y5jXOO

[44] WRAP (2014), Plastic Packaging Market Study (Plastic Flow), https://bit.ly/2JxuFAk

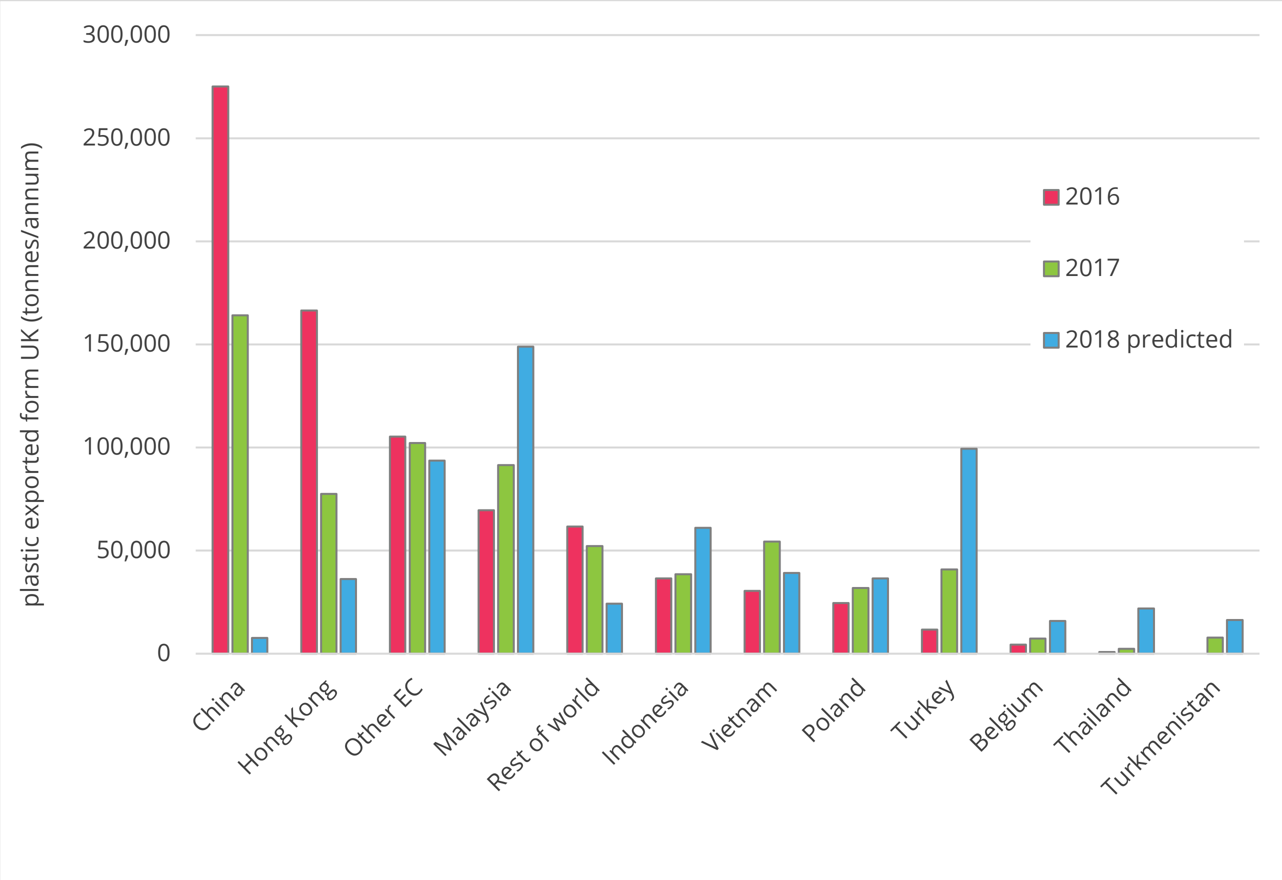
[45] HMRC (2018), UK Trade Info, https://bit.ly/1eP80tm

[46] Calculated by deduction from the other estimates

Demand for waste plastics has been dominated by China since the early part of the 21st century,[47] driven by China's manufacturing sector's demand for resources.

However, China's 2018 import restrictions have created a global shift in the secondary plastics market. As a result, the UKs waste plastics are now exported to other destinations including Malaysia, Turkey, Indonesia and, to a lesser extent, countries such as Belgium, Thailand and Turkmenistan (see Figure 8).

Figure 8: Plastic scrap exports from the exports from the UK[48]



Total waste plastic exports (including to the EU) were around 750,000 tonnes in 2014, 2015, and 2016 but dipped to 650,000 tonnes in 2017 and (based on Q1 data) are expected to maintain the same level in 2018. So, despite the Chinese restrictions, UK exporters have been successful in finding new avenues for plastic waste thus far.

However, officials in some export destinations such as Indonesia, Thailand, Malaysia and Vietnam, have begun to raise concerns over quality and there have been several suggestions

[47] Based on analysis of UN Comtrade data (2018) http://bit.ly/2jL1FIk

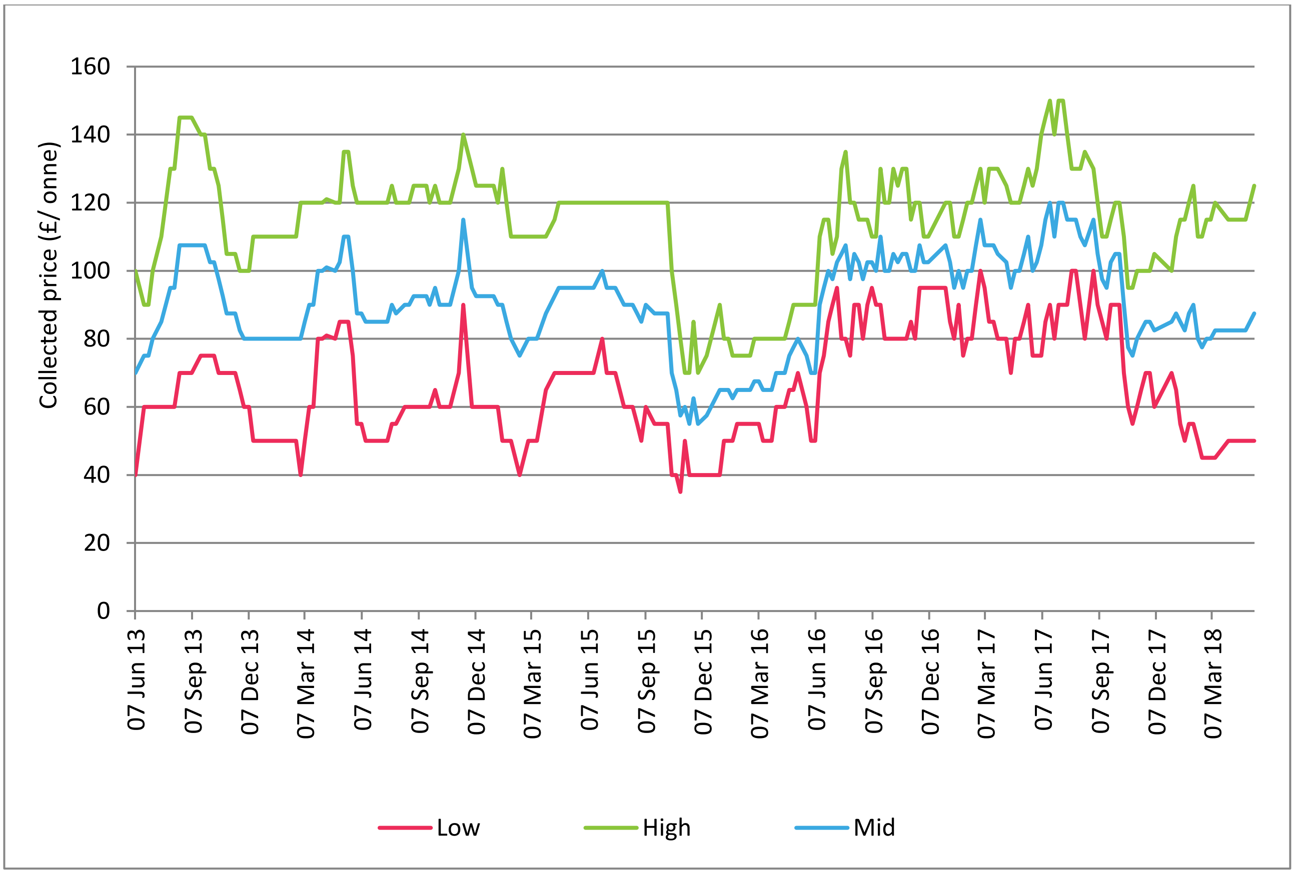
[48] Based on analysis of HMRC export data (2018), https://bit.ly/1eP80tm. Note that at the time of writing, 2018 data have only been reported for the first quarter; these were multiplied by four to predict the amount of material that will be exported to each country in 2018. Note that 'dispatches' to the EU are reported here as 'exports' for simplicity and may be further re-exported outside the EU.

of tightening import restrictions and in some cases banning imports completely as China has done.[49]

It is conceivable that a ripple effect may occur, where new end destinations are identified by exporters from western nations and utilised for a short period before the authorities decide that ongoing plastic waste imports are at odds with their environmental legislation or industrial strategies. Of course, for every country which considers these wastes a burden, there may be another one which sees an opportunity. However, it is highly likely that the international trade in these materials will remain uncertain in the coming months and years.

Finally, it is important to note that the mid-price of plastics has not changed much as a result of the Chinese import restrictions, although the range of prices paid for plastics has widened (see Figure 9). In fact, compared to some of the fluctuations experienced in the early part of the century, the price of waste plastics has experienced only temporary volatility in the last five years.

Figure 9: Price of waste plastic bottles as reported by the WRAP Materials Pricing Report (MPR)



[49] https://resource-recycling.com/plastics/2018/06/06/import-restrictions-ripple-across-southeast-asia/

2.4.5 Demand

The secondary plastics industry relies on there being demand for the materials it produces. However, its products are largely undifferentiated from the primary materials that they compete with on price[52] partly because, although cheaper, in some applications they are considered to be technically less reliable because of their thermal history (the number of times plastics are heated reduces the strength of the material). This means that when the price of virgin feedstock – oil or, in the case of PET, cotton – falls, manufacturers may choose to use more virgin than secondary material.

Table 4: UK plastics market material flow[48 50]

Material flow	Million tonnes per annum
Primary plastics production UK	1.3
Plastics 'processed'	3.2
Plastic products exported*	3.3
Plastic products imported*	7.9

* includes from EU and excludes plastics which are part of assemblies

For plastics recyclers, the impact of this lack of differentiation is profound. They are much smaller businesses than their primary producer counterparts and have much tighter margins as most of their costs are directly fixed to the collection, sorting and cleaning of the material regardless of the fluctuations in price across the wider market and the demand for their output material. These factors have, in part, resulted in the closure of several UK plastic recycling businesses in the last decade.[52]

The UK capacity for recycling is approximately 0.5 million tonnes per year, the overall UK plastics sector is much larger, processing[51] approximately 3.3 million tonnes per annum. Some crude data for the UK plastics industry are provided in Table 4, but robust information is difficult to obtain, partly because of terminology over what constitutes a 'plastics producer' and because plastic products which are produced, exported and imported are often part of assemblies, or simply recorded under a more relevant commodity code.

The issues of capacity for processing waste plastics domestically, internationally and demand for recycled plastics are discussed in more detail in Section 6.1.1.

2.4.6 Barriers in the UK secondary plastics market

Presently, mechanical recycling is often the most resource efficient end-of-life pathway for waste plastics, however recycling rates are low compared to many other materials such as steel, aluminium, paper and glass. In addition to the challenge of identifying and separating the different types of plastics, one of the other major underlying causes of these low recycling rates is the fragility and volatility in the secondary plastics sector.

[50] British Plastics Federation (2017) The UK plastics industry: A strategic vision for growth, https://bit.ly/2yfutkx

[51] The term 'processing' was provided by British Plastics Federation; its meaning is unclear

Unlike primary producers, secondary plastics producers are mostly smaller businesses that are particularly vulnerable to market shocks from global trade and oil prices since they are essentially in competition with new resin producers, as well as price and quality shifts in the supply of the collected feedstock. This fragility in the secondary plastics sector exemplifies the failure of the market to incorporate the environmental and end-of-life cost burdens into the initial price of the products.

To some extent, the secondary plastics market is supported by policy measures such as landfill tax, the producer responsibility regime and recycling targets, but these have not produced a stable enough environment to attract the investment needed to develop the market and generate sustained demand or deliver optimum environmental performance.

Table 5: Summary of the key barriers in the secondary plastics market[52]

Economic barriers	Costs of collecting, sorting and processing waste plastics are high
	Limited resilience of the sector to market shock
	Lack of differentiated demand for recycled plastics compared to virgin plastics
	Poor data on the structure and performance of the sector
Technical barriers	Waste plastics are typically contaminated and mixed with other materials
	Inability to differentiate between food and non-food packaging
	Problematic additives and pigmentation
	Biodegradable plastics mixing with other plastics
	Limited collection schemes and treatment technologies for thermosets
Environmental barriers	Hazardous additives in non-food plastics such as WEEE plastics
	Potential competition between recycling and incineration[53]
	Concerns over environmental standards for recycling in emerging markets
Regulatory barriers	Regulatory burden of materials classified as waste[54]
	Illegal trafficking in waste plastics

[52] Lerpiniere, D., Cook, E. (2018), Improving Markets for Recycled Plastics: Trends, Prospects and Policy Responses, The Organisation for Economic Co-operation and Development, https://bit.ly/2klBHx5

[53] Clarification: This point highlights that incineration and landfill subsist on income from gate fees and therefore create a demand for feedstock which competes with material which could be recycled. This point does not suggest that incinerators are not an important part of our waste management infrastructure and are a viable pathway for material which is currently unrecyclable.

[54] When a product is classified as 'waste', it becomes regulated and significant costs are required to meet the requirements of permits, carry out administrative processes required by the regulator, train staff and build and maintain infrastructure that would not otherwise be required for non-waste materials

2.5 Impacts

Plastics are used in all areas of society, providing tremendous benefits to the public and industry through the function, durability and versatility of plastic products. However, since their widespread commercialisation beyond the 1950s, society has lacked a coherent plan for managing them when they become waste. Impacts are evident over the whole lifecycle of plastic products, from extraction, through manufacture, use and final disposal. However, they can be particularly marked and visible where plastics are used in short life, single use applications. The way we perceive and measure impacts is a key influencer in decision making. However, robust data on the impact of the products we buy across the lifecycle is not readily available or understandable by the consumer.

2.5.1 Lifecycle thinking

Lifecycle thinking provides a framework to effectively compare the environmental performance of plastics products throughout their entire lifecycle. As with all materials, examples of negative externalities and environmental harm exist, such as fossil fuel extraction and leakage of waste into the terrestrial and aquatic environment. However, in many cases, plastics may outperform alternative materials both on functionality and environmental outcomes. For example, a light weight material can reduce transport and fuel use and protect products which have greater environmental burdens themselves, limiting their wastage.

Design choices also affect the benefits of a material during the use phase. A lighter, less durable design for a plastic ready meal container may reduce the environmental burden of the packaging. However, if it results in a marginal increase in food products damaged during transit, the environmental benefit will be reversed as the food production typically has much greater environmental impact than the impacts of packaging.[55]

Considering alternatives such as non-plastics and reusable containers can result in counterintuitive consequences. A good example of this is found in the Environment Agency's[56] lifecycle assessment of carrier bag usage. The results (Table 6) indicate how many times reusable bags must be used to have a net benefit on climate change. Perhaps unexpectedly, they suggest that cotton bags must be used hundreds of times to surpass the benefit of using disposables. The paper bags, which are often perceived to be more environmentally friendly,[57] [58] need to be used up to nine times before they outperform disposable HDPE bags (used three times) but it is unlikely that a paper bag would survive nine uses.

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[55] For example, comparing greenhouse gas impacts of plastics and food, given that food will be many times the weight of the plastic packaging in this example (UK Government GHG Conversion Factors for Company Reporting).

[56] Environment Agency (2011), Life cycle assessment of supermarket carrier bags: a review of the bags available in 2006 https://bit.ly/2ql2xsv

[57] https://science.howstuffworks.com/environmental/green-science/paper-plastic.htm

[58] https://ecomyths.org/2014/05/27/myth-paper-bags-are-greener-than-plastic/

Table 6: The number of times bags need to be used to result in the same CO2eq emissions as single-use HDPE bags (Environment Agency, 2011)[56]

Type of carrier	Example	HDPE bag (No secondary reuse)	HDPE bag (40.3% reused as bin liners)	HDPE bag (100% reused as bin liners)	HDPE bag (Used 3 times)
Paper bag		3	4	7	9
LDPE bag		4	5	9	12
Non-woven PP bag		11	14	26	33
Cotton bag		131	173	327	393

The plastic bag example highlights the difficult choices faced by consumers when considering the most sustainable purchasing choices.

In another example, a study by OVAM[59] compared the lifecycle impacts of disposable and reusable beverage cups (Table 23, Appendix C). The research found that second-hand crockery had the lowest lifecycle impact, followed closely by disposable, recycled PET. However, new glass and metal cups had considerably higher burdens associated with their use, indicating that the production and washing of these items is highly significant contributor to the overall lifecycle impact.

2.5.2 Comparison of treatment and disposal

It is beyond the scope of this report to discuss differences between end-of-life treatment options for plastics. However, as the energy mix changes in the UK, this will affect the comparators used in lifecycle analysis. As fossil fuel use reduces, energy recovery from combustion of waste plastics will perform less favourably than it does today. As such, the relative benefit of energy recovery from waste plastics compared to landfill will reduce.

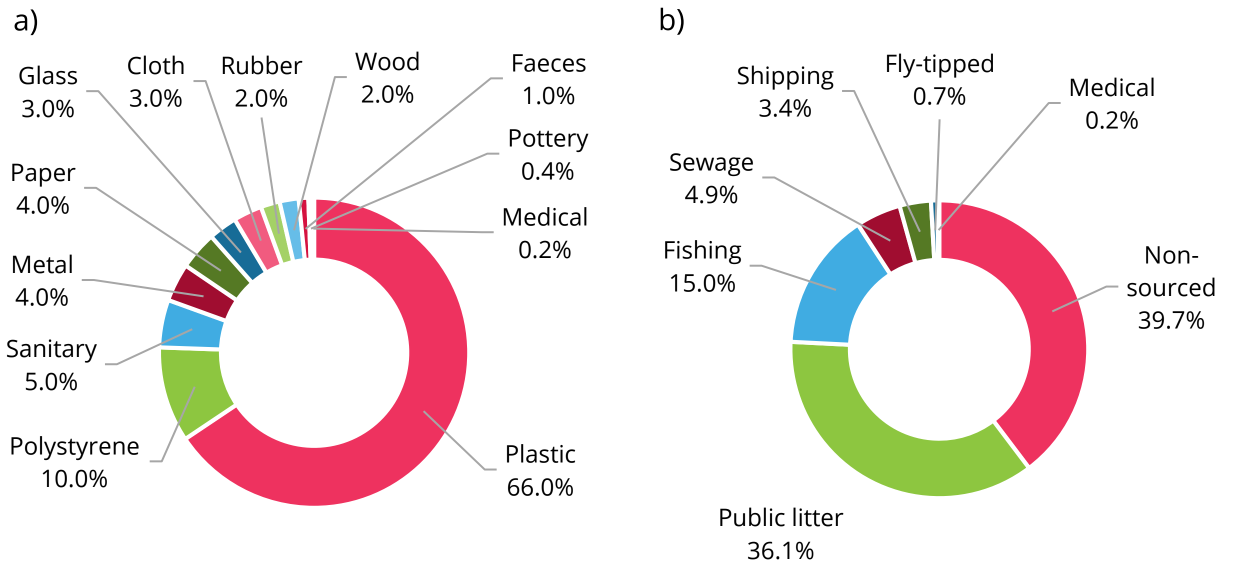
2.5.3 Aquatic pollution

Marine debris pollution has been investigated since the 1970s, but the number of studies has increased considerably over the last ten years and is now a major research area. However, although our understanding of the issue is growing, the impacts of marine debris are not fully understood and comparisons with well-established environmental threats such as climate change are problematic.

[59] OVAM (The study Roadmap Drinking and Eating Utensils on Events

The Marine Conservation Society (MCS) monitors litter arising on British beaches through a network of volunteers who survey debris by item count. Recent analysis by Nelms et al (2017) shows the proportion of items surveyed and attributes the sources based on MCS categorisation (see Appendix A); these data are shown in Figure 10.

Figure 10 a) Twelve most common litter items identified on British beaches between 2005 and 2015 b) sources attributed to items[60]



Understanding the sources of marine litter is of importance for the present study to target interventions proportionately and whilst the MCS categorisations provide insight into the source of litter, they do not necessarily attribute the pathway. In addition, clarifying the sources and pathways of marine litter and communicating this across civil society is particularly important to help reduce misunderstandings about which materials are causing harm.

Jambeck et al. (2015)[61] estimated plastic loss to the marine environment in the UK at between 10,000 and 27,000 tonnes per annum. Whilst these estimates are based on an unvalidated model, they offer a useful indication of the magnitude of the challenge. Broadly, debris enters the aquatic environment through the following routes:

- Direct discards onto beaches and waterways
- Rubbish thrown overboard from vessels

[60] Nelms et al. (2017), Marine anthropogenic litter on British beaches: A 10-year nationwide assessment using citizen science data, https://bit.ly/2KqFzbT

[61] Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R. & Law, K.L. (2015). "Plastic waste inputs from land into the ocean", SUPPLEMENTARY DATA TABLE, Science, vol. 347, no. 6223, pp. 768-771.

- Fishing and aquaculture industries accidentally or deliberately discarding gear into the marine environment
- Discards to the foul sewer (mainly into toilets) and subsequent:
    - Overflow of sewage from treatment works (a necessary and built in feature of many treatment plants)
    - Smaller particles such as cotton buds suspended in treated water and then passing through screens prior to discharge into the environment[62]
    - Direct sewage discharge (from small rural locations)[63]
    - Overflow of foul-water into surface water in combined sewerage
    - Microplastics from clothing, toiletries and paint
- Terrestrial litter or directly discarded litter enters the surface water drains which flow, usually unfiltered, directly into rivers and streams
- Microplastic pollution from paints, vehicle tyre dust, pre-production plastics pellets and cosmetics enter surface water drains that flow into rivers and streams[64]

On a global level, most of the marine debris entering the oceans is thought to originate from households which have no access to solid waste collection.[65] The amounts are not known but have been estimated to be in the region of 4 – 12 million tonnes per year.[61] It should be noted that these estimates are based on 2004 data; China is implicated as a major contributor but since then it has improved its waste collection enormously and is thought to have significantly reduced its levels of uncontrolled disposal to water.[66]

2.5.4 Terrestrial pollution

Despite local government spending roughly £682m[67] on street cleansing annually the most recent Local Environmental Quality Survey of England (LEQSE) found that 10% of sites were found to be of an unacceptable standard in terms of litter.[68]

Littered plastic impacts mainly on the visual characteristics of streets and countryside. However, there are also significant environmental concerns including ingestion by wildlife, and persistence in the environment. Littered plastics are likely to cause most environmental damage when they are washed away into the sea via surface water drains (discussed in Section 2.5.3.

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[62] Personal communication with Laura Foster, MCS; Sarah Archer, Fidra; and Tony Harrington, Welsh Water and 21st Century Drainage
[63] The Urban Waste Water Treatment Directive requires treatment of wastewater arising from 'agglomerations' (population centres) of <10,000 people
[64] https://bit.ly/2cBsYGk
[65] CIWM (2018), From Land to Sea, https://bit.ly/2uaBfte
[66] Wilson, D (2018), China: Coming full circle, https://bit.ly/2t79Wwq
[67] DEFRA (2018) Litter and littering in England 2016 to 2017, https://bit.ly/2jSPCuq
[68] Keep Britain Tidy (2015), How clean is England? The local environmental quality survey of England 2014/15.

Plastics are not commonly reported as a separate category in litter collection surveys[69] however some indicative data are available from Resource Futures[70] and Zero Waste Scotland[71] which estimate plastic waste at 17% and 19% by weight respectively.

Although some materials persist on land or are washed into watercourses, most litter is collected by local authorities. Little is recycled however, as the focus of cleansing teams is to improve aesthetics. Therefore, littered plastics are not only a pollutant but also represent a missed opportunity to recover valuable materials for recycling.[72]

3. Reframing how we think about plastics

It is recognised that current behaviours around plastic use and management need to change. The plastics sector is fast evolving and hugely innovative, but one that is fragmented. Responses to market challenges have been implemented at varying levels - from individual business to sector wide – and, as a result, solving a problem in one part of the value chain has often resulted in it simply be shifted elsewhere.

The first aim of the research was to research whether there was a new way to frame the discussion on plastics that would align the various stakeholders across the value chain. The following sections describe the process undertaken in arriving at the proposed new categorisation.

3.1 Industrial sectors

We reviewed classification of plastics by industrial sector as one way of illustrating the distribution of plastics across the UK economy. As indicated by the global plastics production data in Figure 6 (Section 2.4.1), the polymer types and amount of materials used by each sector vary considerably. This type of classification enables a focus on interventions on areas that will have greatest impact.

Several industrial classifications were considered for this project. The Plastics Europe classification best represented the themes being pursued. The sectors are:

- Packaging
- Building and construction
- Automotive
- Electrical and electronic
- Household leisure and sport
- Agriculture

[69] Keep Britain Tidy (2014), Litter composition study of England, https://bit.ly/2iw97LM

[70] Results from litter composition of four UK local authorities, awaiting publication.

[71] ZWS (2010), The composition of municipal solid waste in Scotland. Study compares datasets from Scotland, Wales and two English authorities from 2002 to 2009

[72] in England around 150,000 tonnes per annum of litter (of all types) could recycled if disposed of correctly, based on national recycling rates - Eunomia, Keep Britain Tidy (2014), Exploring the Indirect Costs of Litter in England

- Others (includes appliances, mechanical, furniture, engineering, medical)

The notable omission from this list is textiles as it is beyond the scope of this report. However, readers may find the Ellen Macarthur Foundation's New Textiles Economy[73] as a good first source of information about plastics in textiles.

3.2 Lifecycle phases

Lifecycle thinking considers the impact of a product at each stage of its lifetime from design through to disposal to ensure that all environmental burdens are accounted for. The current consultation by Defra on the Resources and Waste strategy is proposing applying lifecycle phases and this approach has been used through this report. They are:

1. Production (for our report we call it design & production);
2. Use; and
3. Waste management.

These lifecycle phases help refine the proposed categorisation framework by identifying where the biggest improvements could be made and which stakeholders needed to be engaged.

3.3 A new framework: Use phase categories

The use phase of a product represents the functional lifetime of that product. A set of products with a similar use phase typically has a similar lifecycle and, as a result, similar impacts associated with different phases of the lifecycle.

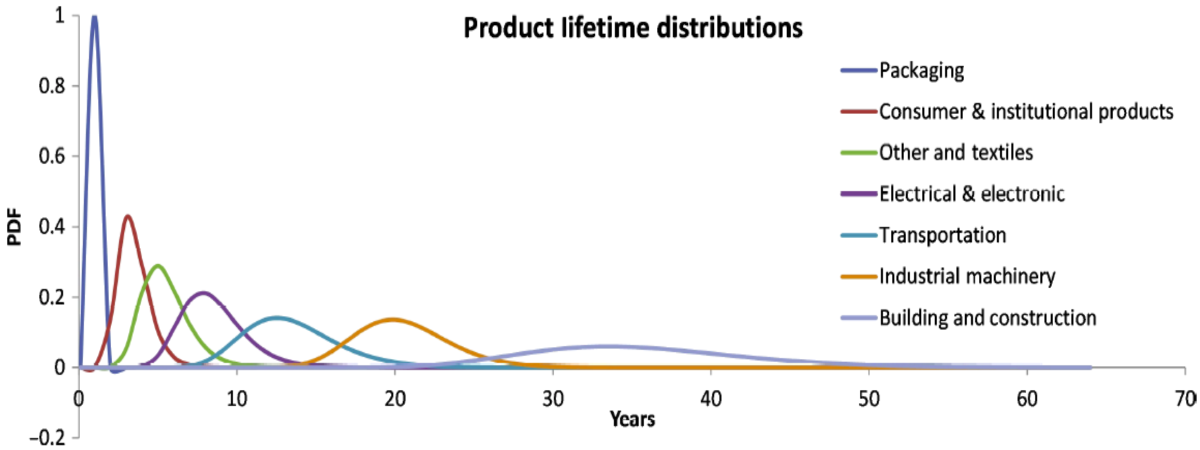
For plastics that remain in use for a short period of time ('single use' or 'disposables'), the relative impact of production and end-of-life (more likely to be littered) is more significant. Furthermore, an intervention that is relevant for a single or short use product is likely to be different to one which is appropriate for products which are in use for longer periods.

Consequently, there is benefit in considering the use phase as a framework for assessing the relative impacts of different products and defining the range of potential interventions.

Examples of typical product lifetimes (i.e. use phase) are shown in Figure 11. The figure presents the log normal of the product lifetime distribution for different industrial sectors. It indicates the length of time products in each sector typically exist from point of manufacture to end-of-life.

[73] https://bit.ly/2idboMb

Figure 11: Log normal product lifetime distribution of products by sector (Geyer et al. 2017)[41]



Note: PDF = probability distribution function

To examine these two factors more closely, we have grouped products by length of use phase. The following examples help to define the term 'use phase':

1. A single portion yogurt is packaged in high impact polystyrene (HIPPS). The use phase is the time from when the pot is filled and sealed, through to when the yogurt has been eaten and the plastic pot is discarded.
2. A sheet of polyurethane foam is used as building insulation. The use phase is the time from when the board is installed, through to the time it is removed and discarded.

Our research presents the following five use phases as a new way to frame the discussion around plastics. This new concept gives us a platform from which to assess priority interventions for products in each use phase. The five use phases are listed in more detail in Section 4.

Table 7: Use Phase Plastics categorisation

Cat.	Description	Examples	Note
1	**Very short use phase (<1 day) small format**	Cotton buds, coffee stirrers, straws, confectionery wrappers, medical, sanitary products, wet wipes, clothing tags, coffee pods	Designed to be disposable, used for seconds (coffee stirrer), up to a few hours (sanitary towel). Unlikely to be separated or disposal by users, and unlikely to be viable for separation in a sorting facility. Due to their place of use, they have a high potential for being littered or discarded via domestic bathrooms into sewers and thus entering the marine environment. We therefore assume that these products will be discarded improperly or at best, disposed of in residual waste. Impact is centred on production phase.
2	**Very short use phase (<1 day) medium format**	Disposable plastic cups, plates, takeaway containers, plastic bags, plastic cutlery	Conversely, these single-use/or disposable plastics are larger in size and have the potential to be recycled if facilities and infrastructure exist. They are less likely to be disposed of via the sewer network and though prevalent in litter composition, less likely to escape normal disposal routes. The products are also made up of fewer plastic types and therefore more suited to sorting, collection and recovery. Impact is centred on the production phase.
3	**Short use phase (>1 day <2 years)**	Food and drink containers, cosmetics, agricultural film, bags for life	These products are mostly used in the home or by businesses and offer prolonged functional benefit during the use phase. There is less risk of them being improperly discarded and they are easily separable and mechanically sorted in most cases. Impact is centred on the production phase.
4	**Medium use phase (>2 <12 years)**	Car parts, plastics in electronics, reusable distribution crates, toys, fishing	These larger format products are often employed to reduce energy use or perform other beneficial functions over longer periods. They are less likely to escape normal waste disposal routes, however, complexities around components and multi-material formats can make recycling difficult. Impact is centred on the use phase.
5	**Long use phase (>12 years)**	Window frames, electrical, plumbing, insulating board, wall panels, roof tiles, carpet, soffits	These products are designed for durability and performance over their long lifetime. Again, their impact is dominated by their use phase and they are less likely to be improperly disposed of. Due to their extended lifetimes, future proofing for end-of-life recycling is a key consideration. Impact is centred on the use phase.

4. Analysis of products by use phase

The following sections explore the characteristics of plastic products by use phase. For each category, we have provided a summary of the prevalent situation, indicated where the key lifecycle impacts occur and discussed where action could best be taken to improve resource efficiency. At the end of each subsection, we highlight potential interventions aimed at key stakeholders.

During the analysis, two anomalies were identified: fishing and medical waste. These two categories did not fit comfortably into their categories and were therefore omitted from the research. It is recommended that further research is carried out into resource efficiency for these two product types in the future (see Sections 7.2.1.2 and 7.2.1.3).

4.1 Cat. 1: Very short use phase (<1 day), small format

These products are: small, lightweight and generally designed for single-use; are unlikely to be recycled; and have a high chance of being improperly disposed (littered or flushed) due to their size and place of use. They include some packaging, household products and food service disposables. Given the low production burdens and the small amount of time they are used for (sometimes less than a minute), the end-of-life phase is generally the most important. It is estimated that the plastic component of products in this category weights between 100,000 and 400,000 tonnes per annum (mostly made up of sanitary products and wet wipes). Examples are shown in Table 8.

Table 8: Examples of very short use phase (<1day), small format

Plastic type	Application	
PP	Cotton buds	
PP	Straws	
PS	Drinks stirrers	
PP, PE	Sanitary towels	
PE, PP	Wet wipes	

4.1.1 Production and design

The high likelihood of these products entering the marine or terrestrial environments through improper disposal suggests that they should either be prevented or produced from materials that will not cause harm. Several novel biodegradable plastics may fulfil the latter objective in future, however as discussed in Section 2.2.3.2, most biodegradable plastics do not break down fast enough and can still be ingested by wildlife.

Alternative non-plastics such as paper and wood, could be used in place of plastics, however the rates of biodegradation in the environment in a 'manufactured format' [74] would warrant investigation before placing these products on the market. Whilst alternative materials are being considered, it is also logical to consider whether reusable alternatives are feasible such as metal spoons in place of disposable plastic stirrers and flannels in place of wet-wipes.

As discussed in Section 2.5.1, lifecycle assessment sometimes results in counterintuitive conclusions that indicate that reuse is more impactful than single-use disposables.[75]

Some of these single-use plastic products are currently under discussion through the tax system or charges.[2] Therefore careful consideration is required around what would be deemed 'non-essential' or 'unnecessary'.

4.1.2 Use

The functional benefits of disposable items in this category are generally small except in the case of some medical products (not discussed here) and some packaging (e.g. confectionery wrappers which protect food).

Reduction of impacts during the use phase should be focussed on encouraging people to discard single-use products in bins rather than littering or flushing to the sewer.[76] These communication campaigns could be carried out voluntarily by brand owners or mandated by central government.

4.1.3 Waste management

Reducing the impact of these products at the end-of-life calls for traditional waste management practices of collection, containment, treatment and disposal. Interventions should focus on prevention of harm following littering or discharge to the sewer. Three broad pathways to the environment are most significant:

1. Combined sewerage systems are designed to overflow in to watercourses during heavy rain, and in some cases, raw sewage is discharged into the sea which contains plastic items (see Section 2.5.3)
2. Treated water from sewage treatment plants is not filtered sufficiently to capture straight lightweight items such as cotton bud sticks which constitute ~3% of items surveyed on British beaches
3. Terrestrial littering

The magnitude of inputs to the marine environment via the first two pathways is unclear. However, an indication is provided by the MCS, which estimates that

[74] For instance, paper may be biodegradable in sheet form but when tightly rolled into a tube (e.g. cotton earbud stem), it will take much longer to degrade as the fibres are less bioavailable to microorganisms

[75] It should be noted that some reusable alternatives may perform the same or even worse depending on the behaviour of the user. For instance, disposable nappies have been shown to perform just as well as reusable nappies depending on the amount of hot water used and the method of drying if reusable nappies are used.

[76] City to Sea (2018), Unflushables, https://bit.ly/2Eof573

approximately 5% of beach litter originates from sewage treatment facilities (Figure 10; Section 2.5.3).[77]

It is beyond the scope of this report to assess sewerage engineering solutions, however two solutions are suggested as follows:

- Increase storage for the additional water in tunnels or tanks until treatment works can catch up and treat the excess water[78]
- Improve filtering of treated water discharge to capture floating plastic objects

As a first step, it is important to understand the quantity of material entering these pathways at source is vital for assessing the magnitude of the problem and designing interventions proportionally.

Reducing terrestrial littering of items in this category is relatively costly as they are small and dispersed. The recent EU proposal for a Directive on single use plastics suggests charging producers for the cost of cleaning up these materials if they are improperly discarded. Historically producer responsibility regimes have been linked to the weight of materials. However, this system would be ineffective for curbing marine pollution from items in this use phase category as they have an extremely high number of units for their weight as demonstrated by the data in Table 9.

Table 9: Estimates of quantity by item and weight of several plastic products in the very short use phase (<1day), small format category (UK) [79]

Type	Billion units per annum	Tonnes per annum
Cotton buds	1.8	135
Stirrers	0.2	110
Large drinking straws	3.5	210

Member states can choose how costs are recovered from producers. So it is therefore suggested that consideration is given to building the system linked to the number of items put on the market, rather than weight. There are likely to be complex calculations to determine the number of these items which are improperly disposed of and it is beyond the scope of this report to suggest these.

[77] It is noteworthy that beach litter prevalence is only an indication of a much larger debris mass on the ocean surface, in the water column, and on the sea bed.

[78] https://bit.ly/2kWtzUd

[79] Defra (Unpublished). A preliminary assessment of the economic, environmental and social impacts of a potential ban on plastic straws, plastic stem cotton buds and plastics drinks stirrers. Researched by Resource Futures.

4.1.4 Summary

The following interventions are recommended for this use phase category:

- Consideration should be given to **removing from sale products which continue to cause environmental damage**, and **replacing with reusable alternatives,** where viable.
- **Alternative materials** which are designed to break down in the terrestrial and aquatic environments **should be investigated** and, if effective, then used in products which have a high chance of leakage. Since there are currently no standards to certify biodegradability in the environment, standards for these characteristics should be developed with some urgency.
- Educating and informing the public to dispose of items responsibly by **labelling products as non-flushable** and linked to a national campaign.

4.2 Cat. 2: Very short use phase (<1 day), medium format

Products in this category mainly include packaging which is designed to contain loose food or drinks and prevent spillage during consumption. Lots of these products are consumed 'on the go'. They are designed for single-use from a few seconds to several hours. These products are mainly lightweight, rigid and flexible but larger in size than those described in Section 4.1. Examples are shown in Table 10.

Table 10: Examples of very short use phase (<1 day), medium format products

Plastic type	Application	
PP, PS or EPS, PET and occasionally PLA.	Plastic cups	
PS	Plastic plates	
	Takeaway containers	
LDPE or LLDPE.	Plastic bags	

The quantity of products in this use phase category isn't clear but it is likely to represent a small proportion of the overall 2.2 million tonnes of packaging arising each year in the UK.

In general, products in this category do not increase life of other products (i.e. food freshness), therefore the main carbon impacts occur during production. The majority are not recycled widely and are frequently littered when consumed 'on the go'.

4.2.1 Production and design

Current practice is to design these products for the lowest cost for single-use functionality, balancing the aesthetic experience of the user. However, the fate of these products is not typically a significant consideration, resulting in improper disposal and low recycling rates. Several approaches to design are currently either considered or applied to address these issues which are discussed briefly in the following sub-sections.:

- Design for recyclability by simplifying polymers to HDPE, PET, PP, or LDPE (for bags) or choosing alternative materials
- Design for compostability so that products can be treated in commercial composting plants
- Remove single-use products from sale and replace with reusable alternatives

4.2.1.1 Design for recyclability

Many products in this category are not designed and produced with recycling in mind such as expanded polystyrene (EPS) or multiple layers of different polymer grades and types. These 'difficult-to-recycle' plastics should be replaced with single polymer alternatives that are commonly recycled in the UK and that have comparable performance to provide the same functionality (see Recoup guidelines for designers).[31]

Labelling of polymer types and recyclability is often discrete and misleading so a more clearly, regulated system would also assist users with classification when the products are being discarded.

4.2.1.2 Design for compostability

The use of compostable packaging aims to reduce challenges posed by surface food residues which create additional work for plastics recyclers who must remove them for separation and recycling. The desired treatment pathway for these products is in-vessel composting, so products need to be designed to break-down within a timeframe which is commensurate with current composting practices which in the UK is between 8 and 12 weeks.

Some films such as kitchen waste food caddy liners break down in this timeframe. They contain plasticisers such as glycerol which allows them to absorb moisture readily, are comparatively thin and are therefore more easily consumed by microbes. However, food contact materials (packaging) are generally thicker and designed to withstand water absorbency and hence microbial attack, which means that they take longer to break down and are thus rarely accepted at composting facilities in the UK due to the increased time required to process.

Public understanding of how to classify these products is extremely difficult as they often have identical aesthetic characteristics to non-compostable alternatives. Therefore product designers need to think carefully about how to label these products, so they are discarded correctly.

4.2.1.3 Design for reuse

Circular economy principles such as 'product as a service' can transform the business model in which these products are used. For example, a lunchtime delivery services to offices, utilising reusable containers that are delivered and collected each day.

In many cases, reusable alternatives may reduce environmental impacts however this is not always the case. A recent meta-analysis[80] of cup use in the events sector found that disposable plastic cups manufactured from recycled material and captured for recycling compared favourably and in certain scenarios better than several reusable cups such as glass, ceramic and steel cups. This was largely due to the very high impact of production and the use of hot water used to wash the cups.

4.2.2 Use

As single-use items, products in this category have very little impact in the use phase. The challenge is to encourage the public to separate materials so that they can be recycled once they have become waste. Labelling is the responsibility of the producers and this will largely address the issues. Education and engagement can be effective.

A decision to implement reusable alternatives may not only be based on carbon emissions or litter, but as a tool for communicating resource efficiency and good practice for civil society. If these systems are chosen, then the focus should be on the behaviour of the users, reducing burdens associated with washing and transport.

4.2.3 Waste management

4.2.3.1 Conventional plastics

All the plastics in this category are recyclable with viable established markets, but most lack suitable collection methods in public places (on the go) where they arise. Since approximately 17% of street litter (by weight) is thought to be plastic,[81] there is a clear argument for the provision of comprehensive, standardised and well signed on-the-go facilities to capture these materials; alternatively, part of the current debate about a deposit return scheme is focused on how it could support and fund better capture of this plastic waste

4.2.3.2 Compostable plastics

A functioning model for collecting these materials would involve them being mixed with food waste and composted, but in practice, adequate facilities are rarely provided for this level of separation, and public comprehension of how to classify them is problematic as they often have identical characteristics to non-compostable alternatives.

These issues of classification mean that these products are likely to enter the waste management system and be processed in a variety of ways which are summarised in Table 11.

[80] https://bit.ly/2sFTfc1

[81] Resource Futures Composition study 2018 (confidential).

Table 11: Treatment pathways and consequences for compostable packaging

Treatment pathway	Consequence
Landfill	Will generate methane
Incineration	As the carbon is biogenic, energy recovered will have neutral impact on global warming
Recycling	Technically possible but only one commercial facility globally in Belgium (Looplife Polymers). Separation would require additional optical separation units to be installed across the UK's plastics sorting facilities which would incur tremendous cost
In-vessel composting	Most industrial composting processes have material residence times of eight to twelve weeks to make their operations profitable; for food contact materials, this is not long enough to break down most currently available novel compostable bio-based plastics[82] Differentiation between compostable and non-compostable products is highly problematic without advanced sorting equipment (NIR) leading to potential downgrading of output materials which would otherwise have benefit as fertiliser
Anaerobic digestion	Will be removed via repackaging unit. Undesirable material for AD operators
Improper disposal to land or sea	Materials will break down eventually, but it is not considered to be fast enough to mitigate ingestion by wildlife; there is limited data on decomposition in the environment and no standards exist

Both the Government's 25-year plan and the Plastics Pact have indicated support for compostable packaging, however the treatment pathways are unclear, and these products are already entering the waste stream in increasing quantity. This is a highly significant issue which needs to be urgently addressed by policy-makers as there is a risk that both composting and plastics recycling operations will experience increased levels of contamination and that that biodegradable additions to landfill will increase.

4.2.4 Summary

The overarching question for this use phase category is which treatment system to choose. Whilst compostability of products addresses the challenges of surface contamination, the end-of-life pathways are broadly linear, and they do not mitigate marine pollution. Composting facilities could be reconfigured to include sorting equipment and increased residence time. But the feedstock would need to be consistent and ubiquitous as a mixed system of conventional and compostable plastics would create chaos for composting plants and recyclers who would need to purchase additional sorting equipment to separate novel plastics from their feedstock.

[82] Standards such as (EN13432), and the US (ASTM D400 and D6868) specify time taken for the materials to break-down (i.e. <2 mm within 12 weeks and 90% by weight after six months). Most industrial composting processes operate residence times of eight to twelve weeks to make their operations profitable. As such, suitable processes that can compost end-of-life bio-based polymers to these standards are not typically commercially viable.

The following interventions are recommended for this use phase category:

- Eliminate single-use plastics where possible and **replace with reusable alternatives.**
- **Investigate** the full feasibility of an **entirely compostable bioplastic-based system,** quantifying the cost of introduction and ongoing management and the environmental consequences.
- If conventional plastics are chosen, **design for recyclability** which requires rationalisation of plastics and probable exclusion of novel bioplastics.

4.3 Cat. 3: Short use phase (>1 day <2 years)

These short use phase products are designed for either single or multi-use and make up the majority of the 2.2 million tonnes of packaging placed on the market each year in the UK (examples in Table 12). Many are already collected for recycling, being a focus of local authority household collections. These products tend to be similar in size and weight as the products in Category 2 but are often discarded at home or in businesses where they can be placed in recycling bins.

Table 12: Examples of short use phase (>1 day <2 years) products

Plastic type	Application	
PET, HDPE and PP	Packaging	
	Toiletries	
LDPE film to cover fields, LDPE or PP tarps to cover feed or equipment,	Agricultural	
PET, LDPE and PP.	Bags for life[83]	

The use phase dominates the lifecycle from a carbon perspective as these products extend the life of others which have significantly greater environmental burdens. But some products, notably beverage containers, are also commonly littered and therefore impact on both marine and terrestrial environments.

4.3.1 Production and design

Functionality is a key criterion for this category and, to deliver this, some products in this category are currently manufactured with material combinations that are difficult to recycle.

Barrier layers are common in food packaging and perform an important function by reducing spoilage of food. However, when a separate plastic (e.g. Nylon) or metallic (e.g. aluminium) layer is part of the multi-layer structure, recycling is made more difficult.

[83] Bags for life were used as an example of an alternative to a single use item for the very short use phase items in Section 4.1.2. They appear in this section as an example of a product which has had is use phase extended.

Multilayer packaging using a single material type (or compatible plastic materials) should be implemented whenever possible.

Thermoformed PET food trays are often black in colour which makes them hard to detect by the optical sorting. The use of other black colourants that do not absorb NIR radiation have been commercialised and could be considered as a replacement for the use of carbon black in these products[84]. However, the waste management industry has expressed preference to move away from black plastics where possible as their ongoing presence adds to the cost and complexity of sorting operations.

On-pack labelling is common in UK supermarkets, but is not practised widely outside the big brands and is not always consistent or clear. Improved labelling could improve recycling rates for some short use phase products.

One instrument to encourage more sustainable purchasing of products and thus improve the way they are used is to use Environmental Product Declarations.[85] These statements enable the sustainability of products to be assessed on an even keel with other products, empowering and enabling consumers to make better choices.

4.3.2 Use

Most of these products, especially packaging, protect something else, including food, medicines and cosmetics from being wasted. The contents are almost always more valuable than the surrounding packaging in terms of resource use and emissions. Imported products, which contribute 40% of our food, are particularly susceptible to wastage without plastic packaging. Packaging is also used purely for marketing purposes, and in such cases its use may be reduced or avoided.

Therefore, the storage and care of the products contained within plastic packaging should be the focus of intervention during this lifecycle phase. Looking to interventions that have been successful in food waste sector such as removal of best before dates and providing better instructions on how to store refrigerated goods, not only reduces the wastage of food but also the surrounding packaging.

Feasibility of moving to refillable packaging for more products warrants further investigation. There are some examples where refill is unviable, and any move to refill will require investment from retailers, but there is momentum to reduce packaging and increasingly retailers and brands are recognising the potential benefit of customer loyalty from take back and other circular business models. There are challenges with contamination, cross contamination, stock control, theft and food wastage[86] but a

[84] https://bit.ly/2Jlvi3V, accessed May 13, 2018.
[85] https://bit.ly/2HskjQs
[86] Food products can be purchased in bulk in many grocery stores in the USA, though most of purchases (other than large fresh fruits and vegetables which are nearly always sold in bulk) are in individualized packing. Most customers utilize thin walled LLDPE bags for bulk food purchases as these are supplied for free by the grocery stores.

growing number of examples are reaching the high street including washing up liquid, fruit and vegetables, herbs, rice, and pasta.

Rebuilding the network of water fountains, and encouraging shops, cafes and restaurants to offer free refill points, is also being implemented in some cities in the UK to discourage single use water bottles.

4.3.3 Waste management

Household collection systems are comprehensive for rigid plastics such as beverage bottles and increasingly other rigid plastic packaging. However, the collections are limited for household films and other flexible packaging.

Whilst designing products to fit in with waste management processes is important, the waste management industry must continue to engage with designers to understand the packaging market and innovate the technological processes required to separate polymers that are less prevalent or technically more problematic to separate, such as films.

More than anything, this issue is one of cost versus benefit for purchasing expensive separation equipment, allocating space to sort and store the material, and then marketing a separate product for which currently there may be limited market demand. Commonly, the focus of plastics sorters and recyclers is on the high volume easy to market materials (i.e. HDPE and PET bottles and increasingly PP pots, tubs and trays).

Improving the business case for upgrading separation and recycling technology requires financial support or investment and it is evident from current reprocessing capacity that the market will not provide this without external intervention. Two broad options are therefore available:

1. Increasing the value of secondary waste plastics
2. Capital investment

The obvious choice for the first of these is to mandate the private sector to cover its own costs through the use of producer responsibility instruments (the EU circular economy package is already proposing this to a certain extent). This is arguably the most sustainable intervention and provides greater assurance for new market entrants that they will have an on-going source of income to compensate them for the effort of managing more complex material mixtures.

However, increasing the value of the feedstock may not engender action in sufficient time for the UK to meet its aspirations, and therefore capital investment from either government of the private sector will be necessary.

The introduction of deposit return schemes is anticipated[87]. However, it is unclear which products will be in scope. Certainly the inclusion of all types of packaging (including film) would guarantee a sustainable source of high quality feedstock for the reprocessing industry, encouraging new market entrants and expansion of existing operations.

4.3.4 Summary

This category contains the largest amount of material by weight and should therefore continue to be the focus of attention.

The following interventions are recommended for this use phase category:

- As with Category 2 (Section 4.2), products should be **designed for recyclability** by rationalising polymer types, simplifying/reducing composites and following guidelines on the inclusion of components.
- Voluntary or statutory **recycled content targets** for specific items generating pull through demand for secondary plastics
- Support through **financial investment funds/mechanisms** to increase **capacity and technical capabilities** of sorting infrastructure to process commonly recycled and difficult to recycle plastics increased supply in UK
- **Improve the labelling of products** and education **to increase the life of the product** being protected by packaging (see Section 4.3.2).
- **Deposit return schemes** for beverage containers are expected and should make an important contribution if well designed.

[87] See https://www.theguardian.com/environment/2018/mar/27/bottle-and-can-deposit-return-scheme-gets-green-light-in-england accessed May 13, 2018.

4.4 Cat. 4: Medium use phase (>2 <12 years)

Products in this category include automobile components, electrical and electronic equipment (EEE), pallets and crates, toys, and some agricultural products.[88] The plastic components of these products are estimated to weigh between 500,000 and 800,000 tonnes per year.[15 89]

Compared to the shorter use phase categories, these products are typically much larger format and are often composites or assemblies of items and other materials including metals, rubber and ceramics.

Many of them (especially automobiles, EEE and toys) are manufactured outside of the UK. Because of this, circular supply chains are less feasible compared to products produced domestically (e.g. cat. 3 packaging).

Table 13: Examples of medium use phase (>2 <12 years) products

Plastic type	Application	
PP, TPO, ABS, HDPE, PC, blends of PC with ABS PC/ABS, PA, PUR seat foam, TPO, PU foam, PET	Transport	
ABS, HIPS, PP, PC, PC/ABS, PA	Electronic and electrical equipment (EEE)	
PP, HDPE	Crates, pallets and buckets	
ABS, HIPS, HDPE, PP	Toys	
HDPE storage tanks /barrels, PP, ABS, PVC or HDPE for plumbing, drainage or ground stabilization	Agricultural	

As with cat. 5 longer phase products, the use phase is the most dominant in the lifecycle.

4.4.1 Production and design

4.4.1.1 Designing for recyclability

This category includes a wide variety of plastic types (especially for automotive) and while it is desirable to rationalise materials to facilitate recycling, in many cases this is not feasible given the specific requirements for each component or item. Virtually all the products in this use phase category are designed with safety and durability as high priorities.

The use of additives to improve safety can also affect recyclability. For instance, EEE, automotive and aeronautical products require inclusion of flame retardants in some components. This has implications for end-of-life treatment as historically some of these additives were of toxicological concern such as brominated flame retardants (BFRs) and certain heavy metals from pigments. Some of these are now prohibited by

[88] NB: it is acknowledged that many aeronautical products will last longer than 12 years, however for the purposes of the likely interventions and the category descriptions, it is more logical to include in the medium use phase category.

[89]

the Restriction on the Use of certain Hazardous Substances (RoHS[90] and RoHS2[91]) Directives, however it is important to note that future additions to this list (and other restrictions globally and by EEE brand owners) may limit the recyclability of plastics found in EEE in the future.

Whilst legislation has encouraged designers to consider making vehicles more easily recyclable, shredding is still the dominant treatment technology requiring matching investments in technologies that can recover the component materials at high rates.

Therefore, designing for recyclability should focus on the ease with which individual plastic types can be extracted from other parts of assemblies, or components. Presently, there are few drivers for this change, as producer responsibility for EEE focusses on ensuring that hazardous goods are treated responsibly rather than ensuring that the output constituent materials (including plastics) are recycled. Targets for reuse or recovery range from 50 – 80% depending on the type of product, but the amount of plastics actually separated for recycling is not widely reported.

In modern vehicles, plastics make up between 7% and 10% by weight[92] and this may increase in the future with the proliferation of electric cars. The End-of Life Vehicle Directive sets an 85% target of recycling and reuse and 95% including recovery and, although the latter has been reported as being surpassed in the UK,[93] it is unclear whether the recycling and reuse target has been met.

Data on the amount of plastics separated for recycling in both the automotive and EEE[94] sectors is scant, and it is likely that the majority are incinerated. The degree to which vehicle and EEE manufacturers are designing for dismantling is also unclear, however it seems that the drivers for this are weak. Further research is recommended to fill these data gaps which could be followed by proportionate legislative change to drive resource efficiency.

4.4.1.2 Designing for extended use

Whilst recyclability is important, it is the use phase which is most dominant. This is discussed in more detail in Section 4.4.1.3, but there are some things designers could do to lengthen the use phase as follows:

- Design for modularity and dismantling. This helps with repair/reuse as well as aiding recycling;

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[90] Directive 2002/95/EC of the European Parliament on restriction of the use of certain hazardous substances in electrical and electronic equipment

[91] Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast)

[92] Q. Dai, J. Kelly, and A. Elgowainy, "Vehicle Materials: Material Composition of U.S. Light-duty Vehicles", Systems Assessment Group, Energy Systems Division, Argonne National Laboratory, September 2016.

[93] https://www.smmt.co.uk/wp-content/uploads/sites/2/SMMT-Sustainability-Report-2017-online.pdf

[94] http://www.newinnonet.eu/?artid=6

- improving compatibility of basic components to make them interchangeable with other manufacturers;
- extending the life of plastics during their use and beyond so that they are suitable for a second cycle in another product; for instance by increasing the quantity of stabilisers used.

4.4.1.3 Use of post-consumer content

The use of post-consumer content in automotive, EEE and toys is uncommon as they are designed for safety as a first priority. Strict standards, a lengthy and expensive material qualification process, aversion to risk (e.g. for mechanical properties, heat resistance and volatile emissions/odours) results in manufacturers using virgin materials.

Toys with potential oral contact should not use recycled plastics unless they go through an approval system similar to food contact.

However, there are applications where post-consumer recycled content can be maximised that do not require strict mechanical properties, thermal stability or volatile emissions/odours.[95] [96]

There is increasing demand for post-consumer recycled content, particularly in EEE products and also in reusable packaging such as crates and pallets for which the aesthetic characteristics are less important.

In the US some large purchasers,[97] are required to use the Electronics Products Environmental Assessment Tool (EPEAT)[98] which incentivises the use of post-consumer recycled material. UK government institutions could adopt EPEAT for preferential purchasing of its EEE to boost the market.

4.4.2 Use

The functional benefits of most products in this category means that the use phase dominates the lifecycle. This is especially true for EEE and automobiles as both types consume energy during their long lifetimes. In automotive applications, increasing the use of plastics (replacing metals) improves fuel efficiency and as electric cars become more prevalent, the amount and types of plastics used is expected to increase in the future.[99] The use of plastics in EEE is also more efficient than alternatives such as metals in terms of production burdens as the weight of material and environmental impact can be considerably less.

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[95] Riise BL. "Designing Electrical and Electronics Equipment for the Circular Economy by using Recycled Plastics", SPE ANTEC, Anaheim, CA, May 10, 2017. https://bit.ly/2K9FwAl

[96] J. Drummond, "Implementation of Post-Consumer Recycled Plastic in Electronic Products", Society of Plastics Engineers, ANTEC 2015.

[97] See https://bit.ly/2nqZ780 accessed May 5, 2018.

[98] See https://bit.ly/2IKnWXy accessed May 5, 2018.

[99] Plastics and Polymer Composites Technology Roadmap for Automotive Markets, American Chemistry Council, March 2014. Accessed at https://bit.ly/2LsZLKP on May 5, 2018.

The most effective interventions during the use phase are those which extend the lifetime of the products. Ensuring that that the products are cared for and that they are repaired or upgraded rather than replaced.

An extension of this approach is to implement 'servitisation', extended product stewardship or product service system models where producers retain ownership of the product and are therefore encouraged to design for longevity. This approach could be applied to many of the products in this category and has already been applied to some EEE and tertiary packaging for example.

4.4.3 Waste management

Since products in this use phase category are designed for durability and functionality, the main opportunity for reducing environmental impacts is through preparation for reuse. This happens to a large degree in the automotive sector but less so in the EEE sector as products become obsolete much more quickly. Thriving informal reuse platforms on the internet such as Gumtree and eBay facilitate this, however more organised systems for reuse are still lacking.

Opportunities to recycle materials in this category are limited due to the following barriers:[100]

- Composite products or assemblies that are hard to dismantle and thus shredded
- Plastics may be painted with substances that are problematic to remove
- Strong colours are used which limits future applications
- Hazardous legacy substances still present in EEE and automotive products

New technology is being developed all the time, and both Axion polymers, MBA Polymers UK and several companies in Europe are using separation technologies to recover PP, HDPE, ABS and HIPS from shredded ELVs. For WEEE, MGG Polymers in Austria has been recovering high quality plastics ABS, HIPS, PC/ABS and PP from shredder residue since 2006.[101,102]

Removal of easily dismantlable products prior to shredding can reduce the amount of material which has to be recovered or disposed from shredder residue. To a certain extent this already happens in that bumpers and fuel tanks are sometimes removed from ELVs, but the latter are not currently suitable for reprocessing due to residual contamination from fuel.[103]

[100] P. A. Wäger and R. Hischier, "Life cycle assessment of post-consumer plastics production from waste electrical and electronic equipment (WEEE) treatment residues in a Central European plastics recycling plant", *Science of the Total Environment* 529 (2015) 158–167.

[101] US Pat. No. 7802685

[102] Lee (Hamos), "Wonderfully Engineered, Efficient and Effective (WEEE) Electrostatic Separation Technologies for WEEE", Electronics and Cars Recycling, 15 – 18 November 2016, Macau, China

[103] However, the technical difficulties of fuel tank decontamination have been addressed successfully by the EU funded RECAFUTA Project. See https://bit.ly/2Lvc8pK accessed May 5, 2018.

As discussed in Section 4.4.1.1, some WEEE plastics contain brominated flame retardants (BFRs) and other banned substances (e.g. cadmium) which are problematic because they cannot be used in new products.[104]

4.4.4 Summary

The following interventions focused on extending the use lifecycle phase are recommended for this category:

- **Designing and producing goods to be more durable, compatible and modular** including eco design standards around recycled content would reduce the need for and aid replacement while generating demand pull through
- **Encouraging care, maintenance and repair** as well as replacement of parts rather than whole assemblies
- **Extended producer responsibility schemes** for an expanding range of products with re-use and recycling targets incorporated
- **Robust data on the recycling rates for plastics from shredder residues** is required to understand whether the regulatory framework is sufficient to ensure plastics are separated for recycling
- Whilst shredding remains the dominant treatment method for ELVs and WEEE, **developing, funding and implementing new technology to separate and sort plastics** from the residues should be the focus of interventions
- **Designing products to be** more easily **dismantlable** would result in a significant increase in plastics without the need to shred and then sort using specialist equipment

[104] These restricted substances can be removed to below current limits using sink-float and other separation processes, though there is some loss of yield. Proposed regulations in the EU that define certain BFRs at Persistent Organic Pollutants (POPs) may result in extremely low limits (e.g. 50 ppm) on these BFRs in waste streams of shredded WEEE and ELVs. If such limits are enacted, recycling of these streams could become economically unfeasible due to the added costs of additional sorting, logistics and testing of shredded fractions.

4.5 Cat. 5: Long use phase (>12 years)

Products in this category include building and construction or those used in industrial applications (see Table 14). They are designed and manufactured for durability and performance over their long lifetime and therefore the use phase dominates the lifecycle due to the functional benefits of the product over an extended period.

These products are estimated to weigh between 300,000[110] and 700,000[105] tonnes per annum.

Table 14: Examples of long use phase (>12 years) products

Plastic type	Application	
PVC	Soffit	
	Wall panels	
	Piping	
	Window trim	
PMMA	Glazing	
EPS	Insulating board	
PA & PET	Carpet	
PP	Carpet backing	
PUR	Carpet padding	
PP	Roof tiles	

4.5.1 Production and design

Products are typically designed for cost effective functionality during use, but with limited consideration for end-of-life treatment or disposal. Increasingly there is a trend towards the use of plastics as a replacement for wood, metal and concrete as they are more cost effective and less prone to degradation over time.

Unsurprisingly, extending the lifetime of products in this category reduces the burden associated with production of new ones and therefore designing them with reuse, repair and refurbishment in mind will lead to more sustainable use.

Whilst the use of secondary starting materials[106] increases circularity, it is not appropriate in some applications for which performance design specifications are stringent. Stimulating the market for recycled content not only reduces the burden of the overall lifecycle but will have additional impact if it stimulates recycling of materials from other industrial sectors. Physical, electronic or chemical markers would help to improve this; however, at present, these are the exception.

4.5.2 Use

Although the use phase is dominant for this category, it is the design and production of the materials which is most significant in extending the functional benefits. In addition,

[105] https://www.bre.co.uk/filelibrary/pdf/rpts/waste/Roadmap_final.pdf

[106] The term 'starting material' refers to a material which is ready to be formed into a shape or used as an additive. They differ from 'raw materials' which require processing or transformation. The raw material for plastics is usually crude oil, however a plastic starting material would describe a polymer which has been extruded into a pellet, or in the case of a secondary material, a comminuted fragment or 'flake'.

the way that products are cared for following their installation contributes to their longevity. Buying or specifying a durable product, keeping it clean and well maintained throughout its life, can extend the use phase significantly. In a commercial setting, applying this logic could result in highly significant carbon reduction and cost savings.

Increasing the use of plastics may, under some circumstances, have some benefits in this use phase category. In particular, the thermal properties of plastic foams in small spaces outstrip some other materials and reduce energy use in buildings. Plastic pipes, as well as being easier to install, result in less leakage (and associated repair costs) and cost less, however they can also lead to significantly more carbon during production compared to concrete alternatives depending on whether they are used for pressurised supply or for waste water.[107] [108]

4.5.3 Waste management

Waste plastics are generated during production and construction, repair and replacement, and during demolition.

Plastics separation on construction sites is increasing but not universal and there is still little financial incentive as plastics are comparatively low weight materials. By exception, PVC from pipes and window trim are both highly recyclable products, with the resultant secondary material being use for the inner core of new windows. The European PVC industry has established a voluntary programme (VinylPlus) to look at improving sustainability[109].

Often many years if not decades have passed by the time plastics in this use phase category become waste. They may have degraded, and the polymer type may be problematic to determine and, in any case, represent less than 0.1% by weight of material used in construction.[110] For this reason, recovery of plastics on demolition sites is thought to be minimal. Legacy materials like cadmium, lead (stabilisers) and phthalates (plasticizers) also limit the use of PVC in new products, though exemptions exist for these substances in recycled PVC.[111]

During replacement operations and repairs, PVC is also being more commonly recovered for recycling and there is considerable opportunity in this sector to utilise reverse logistics networks involving suppliers.

For PU insulation foam, there are few markets, and little value for energy recovery. EPS building foam is also challenging to recycle because it often contains BFRs (including hazardous pentabromodiphenyl ether) however, some innovation is being carried out

[107] https://bit.ly/2IF0U4e

[108] https://bit.ly/2xd1Gjo

[109] https://vinylplus.eu/ VinylPlus® is the voluntary sustainable development programme of the European PVC industry. It aims at creating a long-term sustainability framework for the entire PVC value chain.

[110] Construction Resources & Waste Platform (2008), Overview of Demolition Waste in the UK, https://bit.ly/1GMw9xl

[111] http://www.recovinyl.com/

by the Polystyrene Loop Foundation which has been working on a process to recover EPS building foam.[112]

Carpet with PA, PP or PET fibres can be recycled[113] using mechanical[114] or chemical processes.[115] Further development of the chemical processes, along with extended producer responsibility or other incentives, could increase recycling of these materials.

Improving separation on construction and demolition sites could aid the recovery of plastics. Identification of reuse opportunities such as modular building components is key. The development of technological processes for deconstruction and the creation of markets for recovered construction plastics should be a priority.

4.5.4 Summary

The following interventions are recommended for this use phase category:

- **Data on reuse and recycling rates for plastics during construction, demolition and repair is urgently required** to understand the size of the opportunity in each sector and thus prioritise interventions
- Improved **on site separation operations** combined with increased **sorting and separation technology capacity**
- As with medium use phase products (Cat. 4), interventions should focus on extending the use phase. **Designing and producing goods to be more durable, compatible and modular** would reduce the need for replacement
- **Encouraging care, maintenance and repair** of buildings and discouraging demolition in favour of upgrade if justified by lifecycle thinking
- Standardised **labelling or marking** for materials to indicate compatibility, care, composition and recyclability should be implemented so that future generations can **manage products better during use and at the end-of-life**

Table 15 below draws together the key information and facts for each of the five use phase categories. It includes an indication of the most dominant life cycle phase which helps to inform the priority interventions required to drive both plastic prevention and recycling in each category.

[112] See https://polystyreneloop.org/ accessed May 12, 2018.
[113] See http://www.carpetrecyclinguk.com/ accessed May 12, 2018.
[114] See http://wellmanam.com/ accessed May 5, 2018.
[115] See http://www.aquafil.com/sustainability/econyl/ accessed May 5, 2018.

Table 15: Characteristics of use phase categories

Cat.	Use phase	Industrial sector	Plastic types	Size / weight of items	Est. waste (tpa)	Examples	Notes	Dominant life cycle phase
1	Very short: <1 day (small format)	Household/ leisure packaging,	➢ PS, PP, CA, PET, PP	Small format - low size /weight	100,000 - 400,000	Cotton buds, coffee stirrers, straws, confectionery wrappers, medical, sanitary products, wet wipes, clothing tags, coffee pods	Unlikely to be separated and too small to consolidate and mechanically separate. Avoidable in some cases	**End-of-life** Terrestrial litter and marine debris is increasingly recognised as being harmful but difficult to quantify and compare to other environmental factors such as global warming
2	Very short: <1 day, (medium format)	Packaging	➢ Cups: PP, PS, EP ➢ Containers: EPS, PET, PLA ➢ Plastic bags: LDPE, LLDPE ➢ Packaging for shipping: LLDPE bubble wrap, EPS, bio-derived materials	Medium format - small size / weight	2,200,000	Disposable plastic cups, plates, takeaway containers, plastic bags, plastic cutlery	Separable, sortable. Avoidable in many cases	**Production / end-of-life** Production dominates the lifecycle from a carbon perspective as the use phase provides few functional benefits. As with 1a, terrestrial litter and marine debris are important but difficult to compare against global warming
3	Short: >1 day <2 years	Packaging	➢ Food and drink containers: PET, HDPE, PP ➢ Plastic food film: LDPE, HDPE, multilayers ➢ Ag film: LDPE (UV degraded) ➢ PPE: PET, PA fibres	Medium format, small size / weight		Food and drink containers, cosmetics, agricultural film, bags for life	Separable and sortable mechanically in many cases, material types easily understood	**Use** The use phase is usually most dominant as plastics are often used to protect goods which have far greater burdens from spoiling
4	Medium: >2 <12 years	Automotive, household/ leisure, packaging, agricultural, electrical and electronic	➢ Automotive: PP, ABS, TPO, PC, PC/ABS, PA ➢ WEEE: ABS, HIPS, PP, PC/ABS, PC, HIPS-FR, ABS-FR, others ➢ Toys: ABS, HIPS, HDPE ➢ Pallets/Crates/Buckets: PP, HDPE ➢ Agricultural: LDPE film, HDPE rotomolded, PP, TPO ABS in plumbing ➢ Fishing gear: PA nets, EPS buoys	Large format	500,000 – 1,000,000	Car parts, plastics in electronics, reusable distribution crates, toys, fishing	Less commonly recycled thermoplastic polymers, thermosets and composites. Assemblies of items, often including non-plastic materials	**Use** The functional benefits provided by plastics usually outweigh the impacts of production and end-of-life
5	Long: >12 years	Building and construction, agricultural, industrial machinery	➢ Building/ Construction: PVC piping, PVC window trim, EPS insulating board, PA and PET / PP/ PUR in carpet ➢ Aeronautical: ABS-FR, PC/ABS interior components, Glass filled plastics, composites ➢ Industrial machinery: ABS, others	Large format	300,000 - 700,000	Window frames, electrical, plumbing, insulating board, wall panels, roof tiles, carpet, soffits	Manufactured for durability and performance over lifetime	**Use** The functional benefits provided by plastics usually outweigh the impacts of production and end-of-life with a few exceptions such as water piping in construction which is dominated by production

5. Decision making support tool

Section 4. presents a discussion of the range of interventions and priorities in terms of different use-phase categories. Many, and sometimes competing factors, will need to be considered when deciding to improve the resource efficiency of a specific product. To provide a direction of travel through this decision-making process, two decision trees (Figure 12 and Figure 13) were developed for:

1. Very Short and Short use products (Cat. 1-3)
2. Medium / long use products (Cat. 4 & 5)

Stakeholders can use the decision trees to tailor the decision-making process to their own product or situation.

The decision trees in this section begin to address the thought process that designers and product makers can go through to address these issues. Broadly they need to consider the following:

- Rationalisation
- Detection and selection
- Removal of labels, sleeves and adhesives
- Dismantlability of assemblies
- Separability of components, sub-components

The decision trees provide a step-by-step framework are can be amended to suit different parts of the value chain. They are focused on the desired outcome of improving secondary markets for recyclate in the UK. However, it is clear from the research, that other factors such as carbon may heavily influence this decision-making process.

Short use phase products

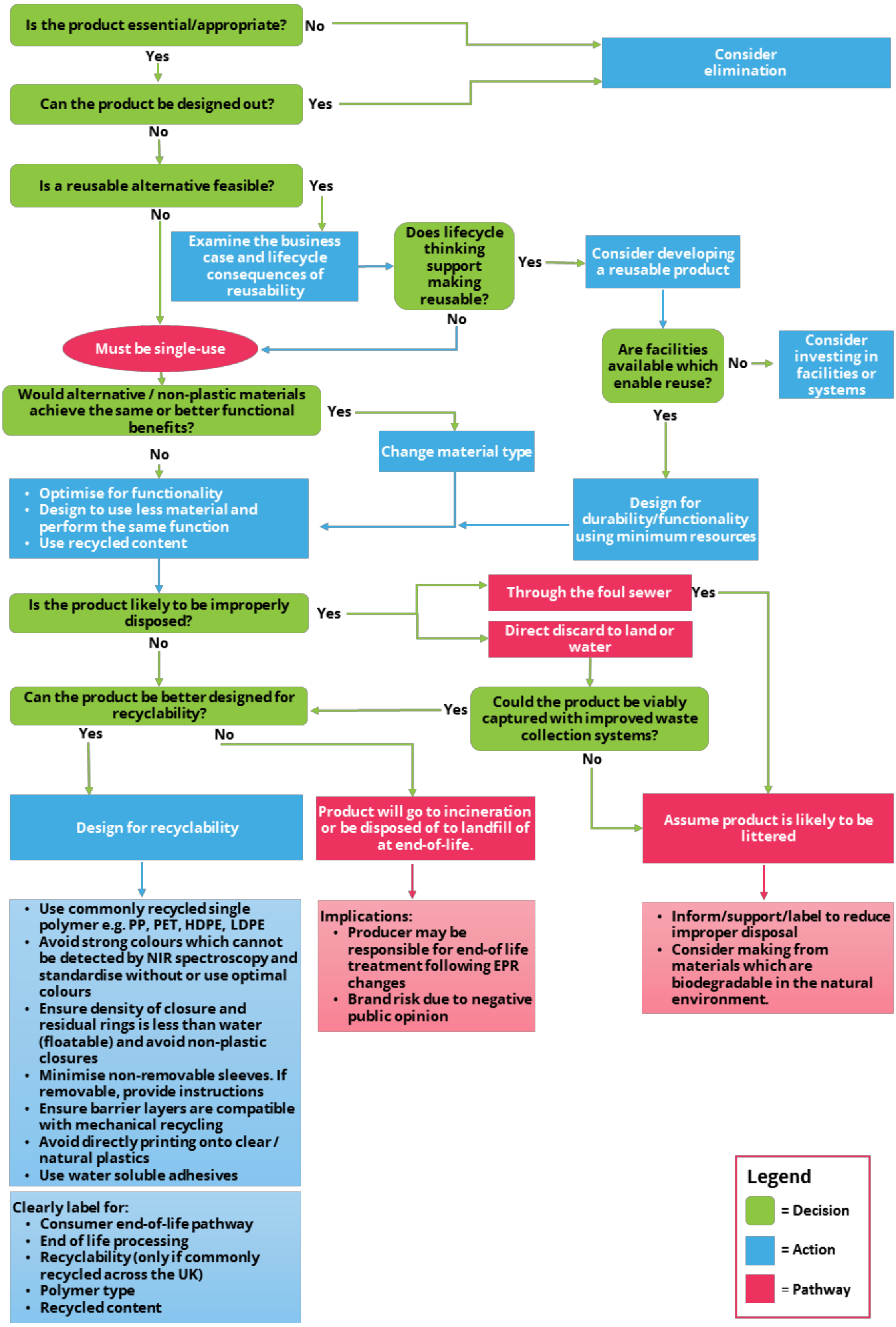


Figure 12:Resource Efficiency decision tree for short use phase plastic products

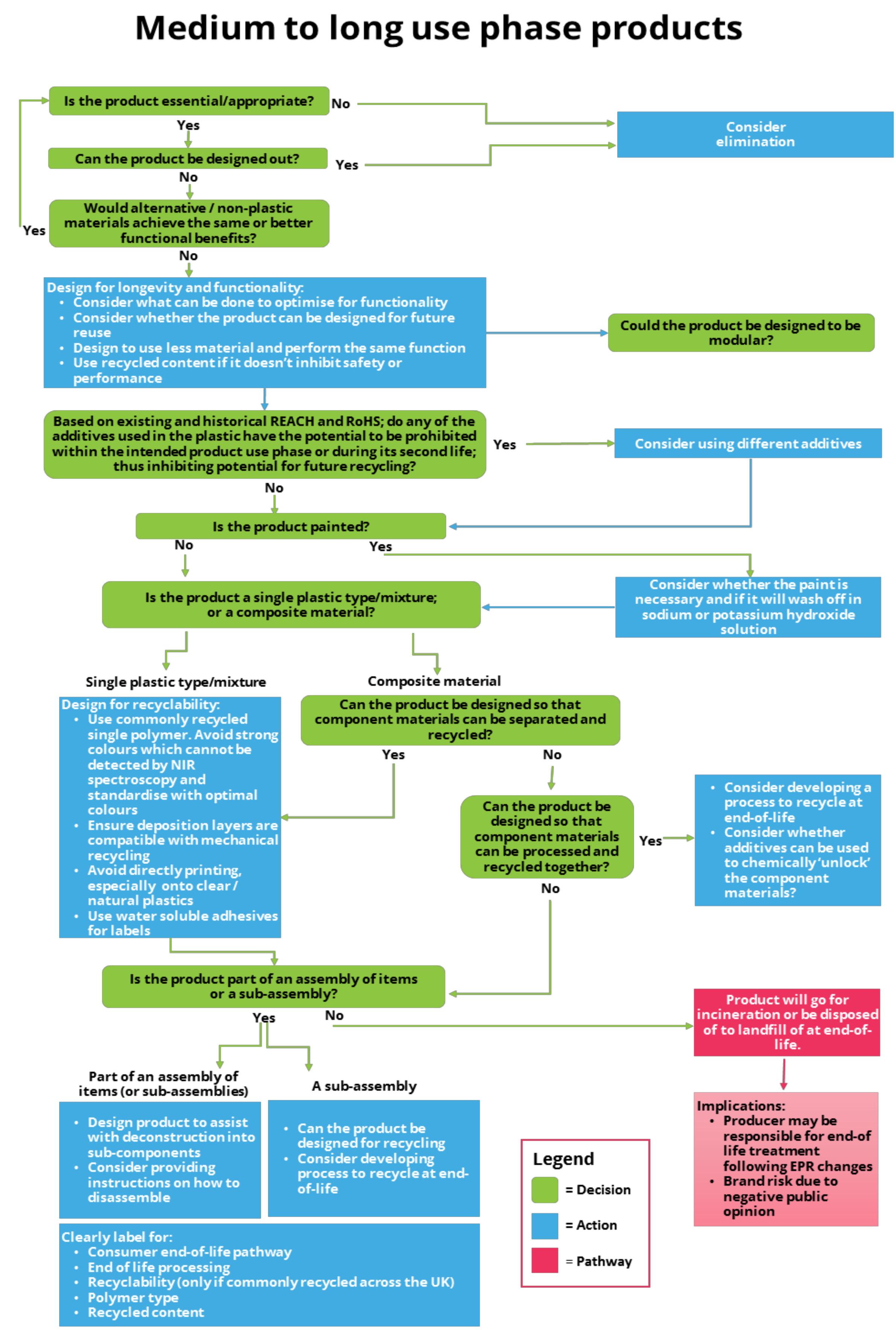


Figure 13: Resource efficiency decision tree for long use phase plastic products

6. Interventions to improve resource efficiency

This section of the report pulls together the analysis presented thus far to identify the types of interventions needed to improve resource efficiency.

A wide range of potential interventions was identified during the research, including through stakeholder engagement, and a long-list of these is provided in Appendix H. It was not the intention of the study to devise new interventions or define in detail existing examples; rather through the development of the use-phase approach, this study has sought to highlight the types of intervention that are considered to offer the greatest opportunity for improving plastics resource efficiency. As we would expect in an area of such complexity and diversity, the findings have raised new questions, and some of these are summarised in Section 7.2.

The aim is to contribute to the discussion on how the plastics sector meets the challenge of transitioning to a zero avoidable plastic waste by 2042 and enable evidence-based decisions to be made which develop our understanding of the global challenge ahead.

6.1 Overarching intervention themes

Two overarching and interlinked themes are drawn out of this research for improving the resource efficiency of plastics:

1. Sustainable design & production choices; and
2. Supporting and generating demand for secondary plastics.

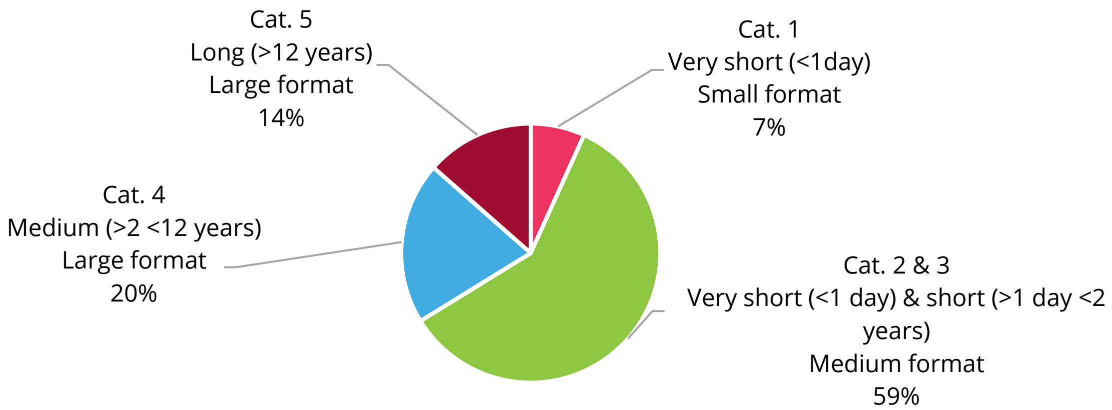
Viewing plastics through the use phase categorisation framework provides a new basis for making design decisions. As shown in Section 4, as items remain in use for longer, the interventions would potentially focus on different lifecycle phases to avoid the material becoming waste.

Our research estimates that approximately 60% plastics by weight are designed to be in use for less than 2 years (Figure 14) and these are already the main target of measures to improve resource efficiency. But whilst these products are arguably the lowest hanging fruit in the waste plastics orchard, there is still a significant amount of material in these categories going to waste.

In addition, the other use phase categories incorporating non-packaging items (cat. 4 & 5) represent a considerable proportion of the plastics market and should be central to developing future policy around plastics resource efficiency.

The interventions, where possible, are aimed at preventing the items becoming waste as that is viewed as the ultimate market failure.

Figure 14: Approximate proportion of plastics (3.7 million tonnes) arising in each use phase category[116]



6.1.1 Stimulating the UK secondary plastics market

Thus far, the UK's domestic plastics reprocessing market has failed to grow significantly; a situation which seems unlikely to change without external corrective intervention. Investment in reprocessing infrastructure is essential as a first step, but several projects[117] have demonstrated that without a strong and stable end market, capital investment is not enough to sustain functioning operations in the long-term.

Interventions are needed that generate demand for secondary plastics and increase the value to incentivise the development of more and improved collection, sorting and reprocessing infrastructure and support awareness raising and communications to influence consumer buying and recycling behaviour.

6.1 Intervention types

No single intervention is a silver bullet. This research, and the stakeholder engagement undertaken to support it, identified the need to consider multiple interventions to ensure that action in one area does not have unintended consequences in another. Sustainable solutions involve stakeholders collaborating across the value chain, something that has been reflected in responses such as The UK Plastics Pact.[7]

Potential priority interventions are discussed below. These are categorised as follows:

- Command & control (e.g. regulatory such as extended producer responsibility).
- Technical (e.g. sorting technology capacity and/or innovation)
- Economic (e.g. financial instruments e.g. innovation funds, deposit return scheme)
- Communicative (e.g. supporting the market make informed decisions).

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[116] Estimates derived from a variety of sources[15504479132] – please note these estimates are not the result of robust analysis but intended to provide an indication of the magnitude of plastic waste arising in each category

[117] Closed Loop Recycling in Dagenham and Plastics Sorting in Wales received funding for infrastructure, but both ran into financial difficulties and were subsequently closed

6.1.1 Command and control

These interventions should be used to support the development and evolution of more resource efficient business practices combined with generating demand for secondary plastics.

6.1.1.1 Extended Producer Responsibility

An array of enhancements has been proposed to the producer responsibility regime in recent years, particularly by stakeholders in the resource and waste industry. These are aimed at correcting the failure of the market to incorporate the costs of environmental impacts or reward measurable environmental benefits of plastic products. It was beyond the scope of this project to analyse these potential measures in detail. However, expanding the range of products covered by EPR schemes should be considered.

At the time of writing, the EU has adopted number of changes to the Waste Framework Directive which will financially compel producers to cover at least 80% of the costs of separate collection, transport, and treatment of waste, as well as the costs of data gathering and reporting. Member states will have a degree of freedom as to how the provisions of the changes to the Directive are incorporated into their domestic regulations, therefore an opportunity exists for the UK government to shape an ambitious and forward-thinking agenda supporting the development of resilience in the secondary plastics sector.

For some category 1 and 3 items in particular, there are increasing calls for producers to pay for terrestrial and marine clean-up costs. Our research suggests that interventions linked to the number of items produced rather than by weight would be more effective in recognising and correcting the impact costs.

6.1.1.2 Recycled content

Increasing the amount of recycled content in products would generate demand. Section 2.4.5 on the secondary plastics markets highlight lack of differentiation between some secondary and primary plastics.

Ensuring a reliable demand for recycled material by either mandating its use or securing commitments from converters and brand owners would generate sustained demand.

If all packaging in UK (approx. 2.2 million tonnes/year) used 30% recycled content, then this would be equivalent to the ~660,000 tonnes exported annually

6.1.2 Technical interventions

These interventions are focused around improving: collection, sorting and separation technology and capacity. They will need to cover all use phase categories including packaging and non-packaging, biodegradable plastics and additives.

It is the case that these interventions often need to be supported by other types e.g. command and control and economic, as they are effectively enabler interventions that need to take place if the UK is going to improve the resource efficiency through growing the secondary plastics sector.

6.1.2.1 Bioplastics and biodegradable plastics

Novel biodegradable plastic food packaging products such as those described in Category 2 (very short use <1day - medium format) have the potential to radically change the way that waste is processed as a feedstock to be mixed with food and composted in one of the UK's 50+ composting facilities. These products are already widely available and for the public, are considered a logical response to marine and terrestrial litter. However, the currently available biodegradable plastics do not degrade sufficiently or rapidly enough in the natural environment to mitigate the environmental damage or the costs of disamenity; a view backed up by the industry itself.

However, an unplanned introduction of these products into the waste stream risks quality reduction for both the composting industry and plastics recycling industry alike. At present some of these products are virtually un-processable in the UK under current conditions.

The consequences for the waste and resources industries are potentially severe. Widespread contamination of both recyclate streams and composting plants may significantly impact on the business case for both treatment sectors. The costs of retrofitting sorting equipment would require significant investment. It is therefore recommended that the situation is urgently investigated to formulate a clear strategy on these materials.

It is recommended that the impact of introducing novel bio-based plastics into the value chain is urgently investigated to understand in detail the potential costs, disruption and environmental impacts of the introduction of this new group of materials.

A thorough evaluation of these materials would ensure that their potential is realised appropriately; indeed our research indicates that there are products and situations where biodegradable plastics could be considered i.e. Category 1 (very short phase (<1day) small format) products, and that future innovation could find further applications for these materials in the fight against plastic waste.

Another example where bio-based-plastics could be considered is 'drop-in' plastics, which are a fast-growing category of polymers and are expected to dominate the bio-based plastic market in the future. These plastics are chemically identical to their fossil counterparts, can be used interchangeably, and are therefore fully recyclable. More research, however, is needed to understand the impacts of these plastics on land use in comparison to depletion of crude oil, bearing in mind that just 4% of global oil production is used to create mainstream plastics.

6.1.2.2 Collection, sorting and separation development

There is a lot of innovation in the types and uses of plastics across a growing range of products. Improving the collection and sorting practices and technology would address the issue of quality of collected secondary plastics. The need to address contamination and identification is getting more complicated as the range of plastics increases. This includes the identification of biodegradable plastics as detailed above as well as additives used in certain products to achieve performance characteristics.

A significant amount of resource to date has been allocated to recycling packaging waste however, it is important that the significant opportunity in the non-packaging sector is addressed as well as the market is under performing at present in regard to recycling. It is unlikely that significant progress will be made towards improving the recycling rates without significant investment and linked demand generating interventions.

6.1.2.3 Design for recyclability

Reducing the number of plastic types on the market and thus simplifying the management, collection and sorting is likely to have a significant impact on recyclability.

Certainly, reducing the number of plastic types on the market in some product categories and use phases is possible and could simplify recycling, leading to larger scale operations and higher yields as a result of improved quality of secondary material and therefore better economic return from recycling.

There are few technical barriers which prevent rigid plastics rationalisation. HDPE, PP and PET are suitable for almost all applications (use phase category 2 and 3). However, PS is still used in some products and is not generally recycled as it has a tendency to shatter in bales and be rejected as fines. Theoretically, reducing the number of polymers used in rigid packaging (cat. 3 - bottles, pots, tubs and trays) should be straightforward; HDPE, PP and PET are suitable for almost all applications. Therefore, understanding the reasons why this hasn't happened thus far should be investigated further.

Films are more problematic to rationalise, and many consist of multi-layer materials which cannot be separated or alloyed (i.e. they are immiscible). New processes have been undertaken to utilise EVOH barrier layers as a replacement for multi-layer structures and these have been shown to be acceptable in mechanical recycling.

The potential for rationalisation of additives also needs to be considered.

6.1.3 Economic interventions

These are often used in combination with other types of interventions and fall in to two categories. The first are mechanisms to support investment in the collection, sorting and recycling capacity and technical capability and efficiency. The second are financial instruments to address market failures such as taxes or trading mechanisms to differentiate between primary and secondary plastics (e.g. if a certain product was mandated to contain a target % of recycled content you might also tax the use of primary plastics to send a clear signal to the market on the value).

6.1.4 Communicative interventions

For the market to correct failures behaviour change is required and based on appropriate data. Improving the quality and flow of robust, objective and transparent information about the sustainability of products would remove many of the current misconceptions about plastics and empower consumers to make more informed choices about how they buy, use and discard products.

The current debate around waste plastics has focussed on the impacts on marine pollution and bring some people to question the long-term viability of single-use throw-away society. However, this research finds that some of the alternatives to single use plastics may be more impactful on climate change and the functional benefits of plastic products are not well understood across society. A system of Environmental Product Declarations could be used to communicate this important information to civil society.

6.2 Priority interventions

Based on the analysis above, we have chosen a range of priority interventions which we feel have the greatest potential for impact and would benefit from further analysis. These are listed in Table 16, with some analysis on why they are suggested, their effectiveness and potential unintended consequences of their implementation. Appendix H lists all the different types of interventions that the research found.

Table 16: Analysis of priority interventions to improve plastics resource efficiency

Intervention (type)	Use phase category relevance (H, M, L) & impact	Why and what needs to happen	Potential issues or conflicts
Extended producer responsibility system (command & control)	1. Low. 2, 3, 4 & 5. High. Increase supply secondary plastics	**Why** ➢ Drive circularity ➢ Correct market failure i.e. end-of-life treatment not included in up-front costs ➢ Generates income to pay for collection & sorting ➢ Generates income to mitigate environmental damage ➢ Encourages producers to apply eco design principles **What** ➢ Bring more producers into regime ➢ Include packaging & non-packaging ➢ Improve data for informed decisions	➢ Financial and organisational burden on producers ➢ Timeline to implementation ➢ Fragmented solutions resulting in efficiencies ➢ Uncertainty around system running costs ➢ Focus on end-of-life may conflict with improving functional benefits during the use phase (use cat. 3-5) ➢ Light weighting of products may conflict with reuse and durability aims ➢ Scheme costs passed onto consumers
Deposit return scheme (command & control)	1, 4 & 5. Low 2 & 3. High. Increase supply secondary plastics	**Why** ➢ Reduce litter and associated costs & environmental impacts ➢ Increase recycling ➢ Improve quality of recyclate ➢ Educate public ➢ Potential savings for local authorities **What** ➢ 'Rewire' UK recyclate logistics to channel maximum material through a scheme which redeems deposits for 'in-scope' materials	➢ Not applicable to all use phase categories ➢ Logistics network would require restructuring for redemption centres located in shops, and public spaces ➢ Potential lost income for local authorities ➢ Unknown impact on recycling performance of non-DRS products ➢ High set-up costs ➢ The 'threshold effect' i.e. beverages above or below certain size not included - leads to over or under-weighted products and objectives not met
Development of a Standard for plastic biodegradability in the open environment and guidance on use (command & control)	1, 2 & 3. High. 4 & 5. Low	**What** ➢ Support the use of bio-based biodegradable plastics ➢ Set standard for production and performance for land based and aquatic biodegradability ➢ Work with packaging and product designers and composting facility operators to agree standards.	➢ Agreement across stakeholders ➢ Aligning performance of use with end-of-life ➢ Time to market – develop a PAS in the interim

Intervention (type)	Use phase category relevance (H, M, L) & impact	Why and what needs to happen	Potential issues or conflicts
Implementation of eco design standards (command & control)	1, 2 & 3. High. Decrease in fossil potentially increase biodegradable 4 & 5. High. Increase supply secondary plastics	**Why** ➢ Enables all plastics to be technically recycled ➢ Increases the length of service for items ➢ Reduces the need to replace items, reduces obsolescence ➢ Improves production efficiency ➢ Reduces product's carbon footprint **What** ➢ Improve the lifecycle performance of products by ensuring that all products are designed with a focus on circularity ➢ Polymer rationalisation ➢ Products designed for: ▪ for recyclability (cat. 2-5) ▪ to be durable (cat. 4 &5) ▪ to include recycled content (cat. 2-5) ▪ with modular components (cat. 4 & 5) ➢ Use less material	➢ Consumers may pay more for products i.e. durable products ➢ Complexity around what durable / separable ➢ Reality around compatibility of branded products ➢ There is a potential conflict between light-weighting and more durable, reusable products
Consider eliminating specific single use items (command & control)	1-3. High. Decrease use. 4-5. Low.	**Why** ➢ Reduce environmental burdens through litter and carbon emissions by removing non-essential single use items **What** ➢ Reusable packaging mandatory ➢ Unnecessary flushable items banned ➢ Food, water etc. to be sold loose / on refill basis	➢ Food wastage may increase though contamination, spoiling and 'end-of-barrel' ➢ Increased costs for importers ➢ Potential higher carbon lifecycle impact of reusable product compared to disposables
Consider reducing plastic products to landfill and thermal treatment by decreasing targets (command and control)	1. Low 2-5. High	**Why** ➢ Encourages circularity ➢ Drives recycling and reduce environmental burdens ➢ Gradually decreasing targets ➢ Reduced space required in landfill	➢ Investment needed to adapt incinerators to burn different feedstock composition (i.e. one with less plastic) ➢ Problematic to introduce unless implemented with products being designed for recyclability and without supporting additional recycling and reprocessing infrastructure

Intervention (type)	Use phase category relevance (H, M, L) & impact	Why and what needs to happen	Potential issues or conflicts
Increase recycled content in products (Command & control and technical)	1. Low. 2-3. Med-high. 4-5. High-Med.	**Why** ➢ Decouple secondary plastics from primary plastics market ➢ Creates a market for secondary plastics ➢ Strengthen domestic industry to protect from market shocks and reduce reliance on overseas reprocessing capacity ➢ Supports domestic producers ➢ Increased UK GDP and jobs **What** ➢ Minimum post-consumer recycled content in products	➢ Relies on sustainable supply of feedstock ➢ Problematic to regulate / verify ➢ Impacts on primary plastics market whose stakeholders have yet to diversify operations into the secondary market
Development of improved bio based biodegradable polymers (technological & economic)	1, 2 & 3. High. 4 & 5. Low	**Why** ➢ Residence time that is appropriate to current composting infrastructure. ➢ Provides a solution for food contamination on the surface of plastics which creates challenges for mechanical recyclability ➢ Reduces the need for sorting and reprocessing as it's a single, simplified stream ➢ If fully biodegradable in aquatic environment within a reasonable timescale, may reduce the impact of pollution ➢ Enables end-of-life treatment pathway (i.e. composting) for currently unrecyclable plastics ➢ Soil mass/fibre available for farms **What** ➢ Develop suitable polymers from bio-based sources that perform the same functions as conventional plastics but that are compostable to agreed standard ➢ Restrict use of fossil-based plastics where alternatives exist ➢ Re-arrange logistics for household, on-the-go, and commercial waste collection systems	➢ Require large network of in-vessel composting facilities to process material and associated investment ➢ Packaging would be unrecyclable in current systems ➢ Unlikely to eliminate short term risk of marine / terrestrial pollution ➢ Methane generation from landfill may increase but would be off-set by reduced fossil CO_2 from incineration ➢ During the transition both recyclates and composting feedstock would be heavily contaminated with products which look similar ➢ Potential for ecological pressure on country of origin - producers of bio-based plastics ➢ Land use pressure and reliance on imports for feedstock ➢ Conflicts with other measures to increase recycling as materials are inherently unrecyclable

Intervention (type)	Use phase category relevance (H, M, L) & impact	Why and what needs to happen	Potential issues or conflicts
Technological sorting innovation (technical and economic)	1. Low. 2-5. High	**Why** ➢ Increase capture of plastics through: o Identification and separation of different plastic types o Identification and treatment of additives o Economical sorting of low value and contaminated plastics from residual waste ➢ Understand the context of the system the product is used and disposed in ➢ Creates jobs and provides links to wider industrial strategy **What** ➢ Collaboration across value chain including universities ➢ Develop innovative new processes to carry out the above	➢ Time to market ➢ Lack of data on product properties and uses ➢ Conflicting needs across the value chain
Investment in domestic mechanical recycling infrastructure capacity (Economic)	1. Low. 2. Low-Med. 3-5. High.	**Why** ➢ Support UK industry and protect from market changes ➢ Critical opportunity if overall resource efficiency is targeted ➢ Creates jobs and boosts the economy ➢ Provides assurance that materials are being processed sustainably and ethically ➢ Reduces reliance on overseas recycling capacity and vulnerability to market changes **What** ➢ Central government would create investment funds the development of a network of plastics recycling facilities to ensure that domestic reprocessing capacity is sufficient for xx% of plastics placed on the market ➢ Wider industrial strategy to drive UK demand for recyclate	➢ Large capital cost ➢ Potentially higher operating costs and therefore reduced competitiveness with exports ➢ International trading rule compliance

Intervention (type)	Use phase category relevance (H, M, L) & impact	Why and what needs to happen	Potential issues or conflicts
Consider tax on single use items (economic)	1-3. High. 4 -5. Low.	**Why** ➢ Reduction in marine and terrestrial pollution ➢ Potential reduction in carbon emissions if lifecycle impacts reduced **What** ➢ Reduce the use of single use items and improve the business case for reusable alternatives through financial disincentive ➢ Tax at point of production or use for single use items	➢ Increased costs to the consumer ➢ Difficulty in defining 'single use' ➢ Unintended consequence of greater impacts from 'reusable' products ➢ Conflict with deposit return scheme which may target same products
Financial mechanisms to support secondary plastics use and production (economic)	1-5. Med	**Why** ➢ Improve resilience to market shocks. ➢ Differentiate secondary plastics demand ➢ Internalise the externalities associated with primary plastic production **What** ➢ Support technological innovation and infrastructure development ➢ Research opportunities for futures trading in secondary plastics	➢ Lack of data ➢ Impact of country monopolies ➢ International trading rules conflict
Improved product information (communicative)	1. Low. 2-5. Low-Med. Supports other interventions	**Why** ➢ Enable better informed procurement, use and discard decisions **What** ➢ For cat. 4 & 5 products ensure that information is provided to enable modular replacement, compatibility, repair and or recycling in the future ➢ Enable informed waste management decisions ➢ Product labelling will include: ▪ A proven pathway for reuse, recycling or end-of-life ▪ Recycled content ▪ Sustainable use information ▪ Care for longevity / maintenance ➢ Target certain sectors/products first	➢ Potential high cost to set up, run and regulate ➢ Requires complex rules to make comparisons fair and to prevent misleading claims ➢ Potential to confuse consumers

6.3 Intervention scenario conflicts

It is the case that to achieve the significant changes across the value chain required interventions will need to be used together to ensure the right market conditions are established. For example, making sure that the collection and sorting infrastructure can meet demand while at the same time ensuring there is a viable end market for the products.

Through the analysis of the interventions the research did identify some potential conflicts between interventions and these are summarised below:

- Extended producer responsibility focus on end-of-life may conflict with improving functional benefits during the use phase;
- Extended producer responsibility focus on end-of-life and light weighting of products may conflict with reuse and durability aims;
- Designing with recycled content potentially conflicts with reusability because recycled plastics may not have the same level of durability as virgin plastics;
- Designing with recycled content potentially conflicts with increased recyclability because polymer quality may be compromised over a number of cycles;
- Eco design standards to increase durability and reuse could conflict with any future weight-based waste prevention targets as a result of increased material use;
- Biodegradable products conflicting with increased recycling as a result of contaminating feed stock;
- Producing products to be biodegradable adding to consumer confusion around plastics and increasing contamination;
- A tax on single use items, a deposit return scheme, and a remodelled extended producer responsibility framework could potentially target same products, creating a disproportionate burden on business;
- Multiple interventions resulting in the need to collect and manage different plastic products differently conflicts with the aim of simplifying recycling.

The potential conflicts above highlight the importance of working across the plastics value chain to ensure that interventions of one type do not have unintended consequences or direct conflict with interventions elsewhere.

7. The way forward

7.1 Concluding remarks

The aim of this report is to contribute to the discussion on how the plastics sector can transition to a zero avoidable plastic waste by 2042. Improving plastics resource efficiency is about using the right plastics, designed for the right job, in the right place; keeping the material in use for as a long as possible as well as having a clear pathway for reusing the material at the end of its intended lifetime.

Achieving the aspirations outlined in the Government's 25-Year Plan and those in The UK Plastics Pact will require a fundamental shift in the way that waste and resources are viewed, and a future scenario where all waste that is not part of a circular economy is viewed as a market failure, not just certain types.

Importantly, the challenges are not simply for the waste and resources sector to solve on its own, but stakeholders across the whole supply chain will need to collaborate to implement measures which result in the most sustainable outcome.

The complexity of the challenge posed by the wide use of plastics can be daunting and this research has highlights the need to take action which is proportionate, and specific to each problem. Over-simplification of issues without recognising the uniqueness of each plastics application, and its associated impacts, risks pursuing ineffective and costly interventions.

Categorising products by the five use phases has identified the 'sweet-spot' which acknowledges the complexity of plastics but allows a wide range of products, sometimes from different industrial sectors but with similar impact profiles, to be grouped together in the search for solutions. These groupings can be then used to frame the discussion on how interventions can be implemented within a holistic policy framework.

The issue-attention cycle is presently at the intensity associated with level 2 in Figure 15 and the speed with which the Government, business and institutions have responded is welcomed, from consultations to major supply chain commitments like The UK Plastics and unilateral action by brands looking to demonstrate that they are taking the problem of plastic waste seriously. However, this means that the debate is changing all the time and it should be acknowledged that this report is

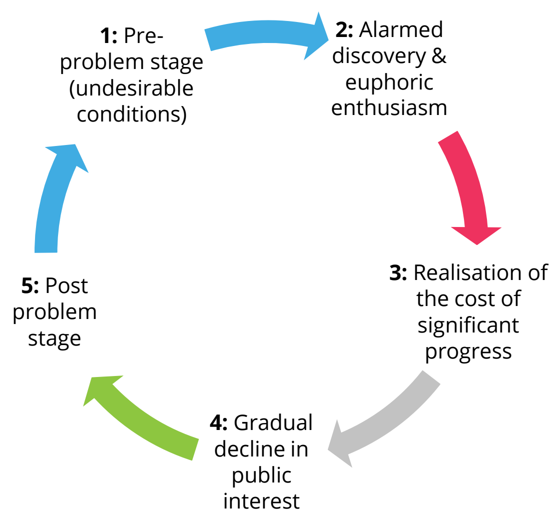

Figure 15: Downs' 'issue-attention cycle'[118]

[118] Downs, A (1972), Up and Down with Ecology-the Issue-Attention Cycle, Public Interest, 28 p.38, https://bit.ly/2JlmYHO

a snapshot in time which is intended to spark debate and provide a catalyst for action. Some of the priorities it identifies are already being looked at; for example, The UK Plastics Pact will be exploring a number of the challenges and interventions discussed as part of its work.

The UK will need to implement a range of interventions to deliver on its expressed commitment to reducing plastic waste, and whilst voluntary commitments and big brand engagement are strongly welcomed, there will also be a need for pragmatism regarding political, wider industry and consumer willingness to change and it is likely that voluntary commitments will need to be complimented by both economic and regulatory drivers.

This research has presented several priority interventions which have been chosen because they have the potential to be shaped to incentivise sustainable design and production choices, and to stimulate demand for secondary plastics.

The UK plastics recycling sector is optimistic yet cautious under the current conditions. If the amount of plastics collected increases, then it will require considerable rapid investment or a greater degree of certainty in the sustainability of overseas markets. Stimulating UK demand for recycled plastics will reduce the risk profile and improve the value proposition to underpin the additional reprocessing capacity; providing more certainty for the secondary plastics sector and potentially encouraging new market entrants.

It is also critical that we have a much clearer roadmap for bioplastics. These materials have potential to provide solutions in some areas, but their desired role and capabilities need to be clearly articulated to allow informed decision making and reduce confusion about their properties and environmental performance.

For disposable items such as cotton ear buds and straws, the resources and waste landscape is changing. The public attention following Blue Planet II has highlighted the impact that these and other items have when they escape from the expected waste pathway and the recent EU Proposal for a Directive on Single use Plastics has sought to address these by charging producers for clean-up costs.

Weight-based metrics are not always the most appropriate method of implementing producer responsibility where the principle impact of concern is caused by very light or small items of debris in the natural environment. The use-phase categorisation method has highlighted this in this report and proposes that charging producers for clean-up costs linked to the number of items they produce may be more appropriate.

Packaging waste has become a very potent image and has shaped the current debate, but renewed focus needs to acknowledge the impacts and benefits of non-packaging plastics which make up more than half of plastics and for which the UK has considerably less capacity to process for recycling. The data for this group of materials is far less robust than for packaging and its improvement would be an important first step towards prioritising action.

Future interventions for the end-of-life management of these non-packaging materials will require innovation in processes but must be supported by a focus on designing for recovery at the production phase. Importantly many of the non-packaging products are designed for a much longer use phase and their impacts are therefore mainly in benefits they provide during that time; a point which isn't acknowledged in much of the current debate around the use of plastics in society.

Providing improved information on the benefits of plastics in society as well as clarifying the difficulties of handling some of the (short term) applications will be an important step towards improving how they are used and cared for. Education, empowerment and enablement of civil society is a theme which underpins this research and the categorisation by use phase is an important step towards devising an approach to target these aspirations.

7.2 Further research

Several research areas have already been discussed in the rest of the document, and it is not the purpose of this section to repeat them. Instead, the following sections highlight some of the areas which were not discussed or only mentioned and suggests opportunities for further work.

7.2.1 What was not included

7.2.1.1 Textiles

At the start of this research project is was decided to exclude spun plastics (textiles) from the study to allow the team to focus on resins. However, this is a huge group of plastic materials; accounting for 15% of global plastics production, which has complex supply chains and a wide range environmental and economic impacts. The textiles business has also been a historic sink for PET from many countries; recycled and spun into fibres globally. Therefore, it is recommended that a further, similar study to the present is carried out to encompass textiles into future decision-making by stakeholders across the industry.

7.2.1.2 Medical

These products were originally included in several of the shorter use-phase categories for this project. However further analysis found a lack of synergy with the other products, not least because public health hazards require different treatment pathways compared to non-medical materials. In principle a significant fraction of medical plastics could be recovered post-sterilisation without public risk however the current economics for recycling to stringent standards lessens the enterprises prepared to invest. They were therefore excluded from the research during the project.

One important finding was that because many medical products are incinerated anyway, and rarely recycled, that the use of bio-based plastics may find its niche provided that the technical attributes can be satisfied. The rationale is that bio-based plastics don't emit fossil carbon when combusted unlike conventional plastics which make a net contribution to global warming.

7.2.1.3 Fishing

These products were included in Category 1 and 4, but, as with the medical products, the impacts and thus interventions did not fit well with other products in these categories. Although this sector is a comparatively small consumer of plastics, the potential impacts on marine ecosystem are of concern, and the sector is reported to be responsible for 15% of beach litter by item count. Extended producer responsibility schemes based on tagging of fishing products have been suggested to encourage improved stewardship by the fishing industry.

In a similar vein to medical products, a niche for biodegradable plastics may be found in this category. However, as mentioned throughout this research, there is no standard for biodegradability in the marine environment; something which is urgently required. Furthermore, it is unclear whether there are biodegradable plastics with sufficient durability and ductility to be used in all fishing applications, and it is recommended that this is also addressed to mitigate against marine pollution.

7.2.2 Other research gaps

7.2.2.1 Understanding environmental impacts

The impact of plastics on the marine environment is not well understood and is hard to compare with the impact of climate change.

Therefore more research is required to enable informed decisions for proportional interventions between mitigating the impacts of marine pollution versus emissions contributing to climate change. The research needs to enable decisions to be made on whether small increases in global warming potential (such as exploring materials to replace plastics) may be acceptable in the context of long-term harm to marine ecosystems.

7.2.2.2 Bio-based and fossil sources

Sourcing feedstock from bio-based sources seems like a logical progression as our oil reserves deplete. However, the impact on land use and food security needs to be thoroughly investigated. Given that plastics consume just 4% of annual oil extraction, one potential scenario is that oil reserves are no longer combusted but set-aside for plastics only.

7.2.2.3 Chemical recycling

Technology for non-mechanical plastics reprocessing has been on the horizon for many years and is now beginning to be implemented commercially. These processes need to be operated at scale to become commercially viable and for many years collection of the feedstock was seen as an obstacle for the chemical companies. Collection systems have now improved but the economic viability needs to be tested. In the long-term chemical recycling has the potential to work as a silver bullet for achieving 100% recycled content without compromising on physical properties. Important steps in this direction have been taken recently with major developments and investments in PET[119] and PP[120] chemical recycling. More information on the commercial efficacy of the current technology is needed as well as more research aimed at lifting these technologies higher up the technological readiness scale.

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[119] https://www.petcore-europe.org/sites/default/files/generated/files/news/14.%20Chemical%20Recycling_Wim%20Hoenderdaal.pdf

[120] https://www.prnewswire.com/news-releases/purecycle-technologies-and-pg-introduce-technology-that-enables-recycled-plastic-to-be-nearly-new-quality-300491368.html

Appendix A. List of stakeholders

Table 17: List of stakeholders who responded for this research

Category	Name of stakeholder	Contact at organisation
Business	Ball Packaging	Marcel Arsand
	Carpet Recycling UK - Reuse network	Jane Gardner
	BBIA	David Newman
Compliance scheme	Ecosurety	Robbie Staniforth
Individual	Gev Eduljee	
	Prof. David Wilson	
	Phillip Ward	
NGO	OPRL	Stuart Lendrum
Packaging manufacturer	Aquapack	John Williams
Supermarkets	M&S	Phil Cumming
	Waitrose	Ben Thomas
Trade association	BPF	Barry Turner
	Recoup	Stuart Foster

Appendix B. Policy and other instruments

A.1 UK policy context in detail

Historically, UK waste and resources policy has been dominated by weight-based targets, driven by European regulations and producer responsibility schemes.

A key UK financial instrument aimed at reducing waste being disposed of to landfill is the **Landfill Tax.**[121] Organisations (including local authorities) pay tax on top of disposal fees when depositing waste at landfill sites.

The Waste (England and Wales) Regulations 2011 compel the use of **the European Waste Hierarchy**[122] by waste producers in all decision-making. An amendment in 2012[123] required waste collectors to collect plastics separately from residual waste.

Producer responsibility aims to ensure businesses bear some of the financial burden for the end-of-life environmental impact of the products they place on market. In the UK, regulations require businesses to design products using less material; enhance their reusability and

[121] Landfill Tax primary legislation is contained in the Finance Act 1996
Landfill Tax primary legislation is contained in the Finance Act 1996
e sustainably in the Revised Waste Framework Directive
[123] Waste (England and Wales) Regulations 2012

recyclability; and ensure that waste from products are treated to meet recovery and recycling targets. Relevant UK legislation includes:

The Packaging (Essential Requirements) Regulations 2015;
The Waste Electrical and Electronic Equipment Regulations 2013; and,
The End-of-Life Vehicles (Producer Responsibility) Regulations 2005.

More recently, the UK Government has published strategies which indicate its ambitions to increase national income whilst reducing greenhouse gas emissions. For instance, the Department for Business, Energy & Industrial Strategy's (BEIS) **Clean Growth Strategy**[124] includes the following commitments which are relevant to plastics resource efficiency:

- Work towards zero avoidable waste by 2050, maximising value from resources minimising carbon impacts for production, use and disposal;
- Publish a new Resources and Waste Strategy to make the UK a world leader in terms of competitiveness, resource productivity and resource efficiency[125]; and,
- Invest £99 million in innovative technology and research for agri-tech, land use, greenhouse gas removal technologies, waste and resource efficiency.
- 70% of plastic packaging recycled, reused or composted
- 30% recycled content across all plastic packaging

A.2 EU policy context in detail

The majority of UK environmental law affecting how plastics are made, used and managed originates from EU directives; the key directives are summarised below:

Directive 2008/98/EC on waste (Waste Framework Directive) - all wastes, including plastics, are covered. It sets the basic concepts and definitions related to waste management, such as definitions of waste, recycling, recovery and disposal. It explains when waste ceases to be waste and becomes a secondary raw material (so called end-of-waste criteria), and how to distinguish between waste and by-products. It requires waste to be managed without endangering human health and harming the environment.[126] The directive established:

- the waste hierarchy;
- the polluter pays principal;
- extended producer responsibility;
- new recycling and recovery targets to be achieved by 2020; and,
- adoption of waste management plans and waste prevention programmes.

[124] BEIS (2017), The Clean Growth Strategy: Leading the way to a low carbon future, https://bit.ly/2yiDY3R
[125] The Resources and Waste Strategy is expected to be published in the second half of 2018.
[126] http://ec.europa.eu/environment/waste/framework/

The Directive specifies plastics in its requirements separate collection and the overall recycling target of household wastes of 50% (by weight) by 2020. Further revisions to the Directive (as part of the Circular Economy Package, see below) are anticipated in 2018. The UK is expected to adopt the revisions although this has not yet been formalised in UK legislation.[127]

Directive 94/62/EC on packaging and packaging waste - measures aimed at limiting the production of packaging waste (including plastic packaging) and promoting recycling, re-use and other forms of waste recovery. The directive was later amended to include consumption of lightweight plastic carrier bags.

Directive 2000/53/EC on end-of-life vehicles (ELVs) – introduced a ban on the use of certain hazardous substances; that collection systems and treatment facilities for ELVs are established; which storage and treatment methods are used; and re-use and recovery targets. The plastic content of cars is around 10% by weight[128] and car manufacturers are increasingly using plastic components to reduce vehicle weight and improve fuel efficiency.

Directive 91/271/EEC concerning urban waste-water treatment - aims to protect the environment from the adverse effects of urban waste water discharges and discharges from certain industrial sectors. The directive requires that that all agglomerations with a population equivalent of 2,000 and above are provided with collecting systems and be subject to secondary (or equivalent) treatment. The European Strategy for Plastics in a Circular Economy calls for "evaluation of the Urban Waste Water Treatment Directive: assessing effectiveness as regards microplastics capture and removal."[129]

Directive 2009/125/EC establishing a framework for the setting of ecodesign requirements for energy-related products (Ecodesign Directive) - provides rules for improving the environmental performance of products, such as household appliances, ICT and engineering.[130] The directive states that product designers must identify significant environmental impacts throughout the product's lifecycle. The choice of materials, influences its environmental performance, including embodied energy, packaging, energy use (plastic may be lighter or more insulating than an equivalent metal component), longevity and options for dismantling and management.

Directive 2006/7/EC concerning the management of bathing water quality (Revised Bathing Water Directive) – aims to safeguard public health and protect the aquatic environment in coastal and inland areas from pollution. In relation to plastics, the

[127] https://bit.ly/2KTg2HT

[128] Plastics Makes It Possible (2 October 2014) Use of Recycled Plastics in Cars is Shifting into Overdrive

[129] https://bit.ly/2DnsTP7

[130] "In so far as they relate to product design, significant environmental aspects must be identified with reference to the following phases of the lifecycle of the product: (a) raw material selection and use; (b) manufacturing; (c) packaging, transport, and distribution; (d) installation and maintenance; (e) use; and (f) end-of-life

directive requires that "Bathing waters shall be inspected visually for pollution such as tarry residues, glass, plastic, rubber or any other waste. When such pollution is found, adequate management measures shall be taken, including, if necessary, information to the public."

A.3 Withdrawal of the United Kingdom from the European Union

The UK is presently scheduled to leave the EU on 29 March 2019. It is the UK Government's policy that the UK will remain bound by existing EU environmental law, subject to possible future review, but this is not legally straightforward.[131] There is currently no clarity as to what status Commission guidance will have post-Brexit.

Appendix C. Types of plastics and their uses

Table 18: Summary of the main thermoplastics used (approximate order of prevalence)

Name	Characteristics	Applications	Implications for recycling
LDPE and LLDPE Low Density Polyethylene and Linear Low-Density Polyethylene	➢ Tough and flexible ➢ Waxy surface ➢ Good transparency ➢ Low melting point ➢ Stable electrical properties ➢ Good moisture barrier properties	➢ Films, fertiliser bags, refuse sacks ➢ Packaging films, bubble wrap ➢ Thick shopping bags ➢ Wire and cable applications	➢ Thermally stable for recycling ➢ Film is difficult to wash and dry mechanically ➢ Throughputs of films are reduced due to low bulk density
HDPE High Density Polyethylene	➢ Excellent moisture barrier properties. ➢ Excellent chemical resistance ➢ Hard and strong ➢ Waxy surface ➢ Permeable to gas ➢ Stress resistant	➢ Detergent, bleach and fabric conditioner bottles ➢ Milk bottles ➢ Cereal box liners ➢ Rigid pipes, crates, ➢ Plastic wood, garden furniture ➢ Wheeled refuse bins	➢ Thermally stable for recycling ➢ Antioxidants can boost resistance to oxidation caused by melting ➢ Excessive heating causes gel formation and cross-linking
PP Polypropylene	➢ Excellent chemical resistance ➢ High melting point ➢ Hard, but flexible ➢ Waxy surface ➢ Translucent Strong	➢ Meat Trays ➢ Yoghurt and butter tubs ➢ Potato crisp bags, biscuit wrappers ➢ Crates, plant pots ➢ Drinking straws ➢ Fabric/ carpet fibres ➢ Heavy duty bags	➢ Thermally stable for recycling ➢ Antioxidants can boost resistance to oxidation caused by heat exposure ➢ Excessive heating causes reduction in strength and brittleness
PS and HIPS Polystyrene and High Impact Polystyrene	➢ Glassy surface ➢ Hard but brittle High clarity (PS) ➢ Tough Opaque (HIPS) Affected by fats and solvents ➢ Can be foamed (EPS)	➢ Yoghurt containers (HIPS) ➢ Clear egg boxes (PS) ➢ Fast food trays (EPS) ➢ Video cassettes (PS) ➢ Hard Vending cups and disposable cutlery (PS and HIPS) ➢ Low cost brittle toys (PS)	➢ Thermally stable for recycling ➢ Excessive heating causes yellowing and ultimately de-polymerisation and brittleness

[131] UKEA (September 2017) Brexit and Environmental Law, The UK and International Environmental Law after Brexit

Name	Characteristics	Applications	Implications for recycling
PVC Polyvinyl Chloride	➢ Excellent clarity ➢ Hard, rigid (flexible when plasticised) ➢ Good chemical resistance ➢ Stable electrical properties ➢ Low gas permeability	➢ Pipes and fittings ➢ Wire and cable sheathing ➢ Window and door frames, guttering ➢ Credit cards ➢ Synthetic leather products	➢ Thermally stable for recycling when adequately stabilised. ➢ Excessive heating causes degradation, acid evolution and blackening
PET Polyethylene Terephthalate	➢ Excellent clarity ➢ Good gas & moisture barrier properties ➢ High heat resistance ➢ Hard and tough ➢ Microwave transparency ➢ Solvent resistant	➢ Fibre for clothes and carpets ➢ Carbonated drinks and water bottles ➢ Clear household cleaning bottles ➢ Yoghurt Tubs, fruit trays ➢ Pre-prepared food trays and roasting bags ➢ Strapping	➢ Thermally stable for recycling. but must be pre-dried ➢ Excessive heating causes yellowing and brittle behaviour ➢ Solid State Polymerisation can rebuild material strength ➢ Can be chemically recycled to new plastic
PA Polyamide or "Nylons"	➢ Hard and tough ➢ solvent resistant ➢ Excellent fibre properties ➢ Good barrier properties to gas and moisture	➢ Fibres for clothes and carpets ➢ Toothbrush bristles ➢ Fishing line, bike wheels ➢ Car radiator manifold and engine parts	➢ Thermally stable for recycling but must be pre-dried ➢ Excessive heating causes yellowing and brittle behaviour ➢ Can be chemically recycled to new plastic
ABS Acrylonitrile Butadiene Styrene	➢ Rigid and tough ➢ Resistant to corrosive chemicals	➢ Computer monitors, printers, keyboards ➢ Appliance housings ➢ TV frames ➢ Car interior components. ➢ Pipes for chemicals.	➢ Thermally stable for recycling but must be pre-dried ➢ Excessive heating causes yellowing and brittle behaviour
PBT Polybutylene terephthalate	➢ Rigid and tough ➢ Opaque ➢ Stretchy fibre	➢ Car interior components ➢ Computer body shells ➢ Appliance outer housing ➢ Heavy duty mechanical components like pumps	➢ Thermally stable for recycling but must be pre-dried ➢ Excessive heating causes yellowing and brittle behaviour ➢ Can be chemically recycled to new plastic
PC Polycarbonate	➢ Rigid and very tough ➢ Transparent ➢ High Strength	➢ Glass replacement, safety glass lenses and frames ➢ Compact discs ➢ Skylight domes ➢ Appliance housings ➢ Car components ➢ Bullet proof glazing	➢ Thermally stable for recycling but must be pre-dried ➢ Excessive heating causes yellowing and brittle behaviour
PMMA Polymethylmethacrylate or "Acrylic"	➢ Rigid and brittle transparent ➢ Scratch resistant ➢ Weather resistant	➢ Glass replacement ➢ Skylight domes ➢ Car rear lights	➢ Thermally stable for recycling but must be pre-dried ➢ Excessive heating causes de-polymerisation
EVOH Ethylene vinyl alcohol copolymer	➢ Good oxygen barrier properties	➢ Multi-layer barrier films and laminates in LDPE, HDPE, PP and other plastics	➢ Can be recycled in films ➢ Not thermally stable at high temperatures. ➢ Excessive heating causes decomposition
PVDC Polyvinylidene Chloride	➢ Clear, Good barrier properties ➢ Glossy surface ➢ Resistant to chemicals ➢ Thermally unstable above 125 ° C.	➢ Multilayer films to improve barrier properties of LDPE, HDPE, PP and other plastics	➢ Not thermally stable at high temperatures ➢ Excessive heating causes decomposition and difficult to recycle

Table 19: Summary of the main thermosets used[132]

Name	Characteristics	Applications	Implications for recycling
PU Polyurethane	➢ Can be formulated to be rigid or flexible and thermoset or thermoplastic. ➢ Often foamed. ➢ Tough, abrasion and solvent resistant.	➢ Wide variety of applications depending on formulation. ➢ Foams for bedding and carpet backing. ➢ Wheels ➢ Gears Coatings ➢ Moulded auto parts.	➢ Thermoset PU difficult to recycle except by chemical recycling. ➢ Thermoplastic PU behaves like Polyamides and is recyclable with drying.
MF Melamine Formaldehyde	➢ High temperature resistance. ➢ Strong but brittle. ➢ Solvent resistant.	➢ Dinnerware, picnic ware and cutlery. ➢ Bench tops. ➢ Heat resistant coatings	➢ Does not melt and not recyclable. ➢ Can be ground up and used as filler in new products.
Unsaturated polyester (UP)	➢ Liquid resins that are reacted to make hard materials. Used with fibres and fillers	➢ Fibreglass reinforced plastics used for boating, automotive and building panels. ➢ Sheet moulding compound, bulk moulding compound and the toner of laser printers ➢ Adhesives-fibreglass reinforced plastic	➢ Does not melt and not recyclable ➢ Pyrolysis can be used to remove the resin and recover the fibres
Epoxy Resin	➢ Usually in the form of two reactive liquid components that set on mixing. ➢ Often combined with glass or carbon fibres	➢ Adhesives ➢ sports equipment ➢ electrical and automotive components	➢ Does not melt and not recyclable ➢ Pyrolysis can be used to remove the resin and recover the fibres
Phenolic resins	➢ Dark in colour ➢ High temperature resistance. ➢ Strong but brittle. ➢ Solvent resistant.	➢ Electrical switches ➢ Oven knobs ➢ Toaster end panels, ➢ Saucepan handles ➢ Laminates for benches	➢ Does not melt and not recyclable. ➢ Can be ground up and used as filler in new products.

Appendix D. Degradation of plastics

A.4 Degradability

Most conventional plastics are considered to be degradable under the right conditions and timeframe. However, as it is unlikely that significant degradation will take place within human lifetimes; most of them are considered (biologically) inert.[133]

Degradability describes all processes which contribute to the breakdown of plastics as a result of externalities such as UV light, oxygen and biological attack (which is specifically biodegradability). Degradation also includes oxo-biodegradation which causes plastics such as PE (polyethylene), PP (polypropylene), and PS (polystyrene) to fragment in the open

[132] Lerpiniere, D., Cook, E. (2018), Improving Markets for Recycled Plastics: Trends, Prospects and Policy Responses, The Organisation for Economic Co-operation and Development, https://bit.ly/2klBHx5

[133] Note that there is limited empirical evidence for plastics biodegradation and the long-term fate of plastics is not known

environment. Oxo-degradable additives for plastics have attracted criticism[134] due to their propensity to fragment into small particles and non-recyclability; however, proponents[135] argue that fragmentation is accelerated which provides greater surface area for microbial action to take place thus accelerating the degradation process. However, there is lack of robust proof that biodegradation actually happens in oceans or landfills[136].

A.5 Compostability

Many biodegradable bio-plastics and some fossil-based plastics are also considered 'compostable' under certain conditions. Several standards exist; the main European one being EN13432, which broadly share the same common definitions:[137]

- **Chemical characteristics:** it contains at least 50% organic matter (based on dry weight) and does not exceed a given concentration for some heavy metals.
- **Biodegradation:** it biodegrades by at least 90% (by weight) within six months under controlled composting conditions (temperature of 58 +/- 2°C).
- **Disintegration:** it fragments into pieces smaller than 2mm under controlled composting conditions within 12 weeks.
- **Ecotoxicity:** the compost obtained at the end of the process does not cause any negative effects.

A key limitation of compostable plastics which meet these standards, is that six months is allowed to break down the material. This is unlikely to be realistic for composting facilities in the UK which typically process material over an eight to twelve-week period.

Additionally, compostable plastics tend to exhibit similar aesthetic and physical properties as non-compostable plastics meaning that they are almost impossible to distinguish at a composting plant. There is no way for the plant operators to determine whether they should be accepted in the process or screened out as contamination. Conversely, this same confusion arises at plastics recycling facilities which cannot differentiate between compostable and mainstream target plastics types.

7.2.2.4 Biodegradation in the environment

Biodegradation of plastics in the environment is not well understood, partly because most mainstream plastics are thought to take many years to break down. Some research has been carried out into the behaviour of biodegradable plastics in the marine environment, however a UNEP report[138] concluded that compostable plastics in the marine environment would be

[134] EMC (2017), Oxo-degradable plastic packaging is not a solution to plastic pollution, and does not fit in a circular economy, https://bit.ly/2IGhUmr

[135] Oxo-Biodegradable Plastics Association (2017), PRESS RELEASE, https://bit.ly/2s5Ryn8

[136] http://www.symphonyenvironmental.com/opa-responds-european-commission/

[137] WRAP (2010), Environmental benefits of recycling, http://bit.ly/2uricL6

[138] UNEP (2015) Biodegradable plastics and marine litter, misconceptions, concerns and impacts on marine environments. http://bit.ly/2uEJLM8

unlikely to reduce the impacts of marine litter, in part because they still take many years to fully break down.

A summary of the main types of plastic degradability is provided in Table 17.

Table 20: Types of plastics degradability20

Term	Definition
Degradation	The partial or complete breakdown of a polymer as a result of e.g. UV radiation, oxygen attack, biological attack. This implies alteration of the properties, such as discolouration, surface cracking, and fragmentation.
Biodegradation	Decomposition of organic matter, which is completely or partially converted to water, CO_2/methane, energy and new biomass by microorganisms (bacteria and fungi).
Mineralisation	In the context of polymer degradation, the complete breakdown of a polymer as a result of abiotic and microbial activity, into CO_2, water, methane, hydrogen, ammonia and other simple inorganic compounds.
Biodegradable	Capable of being biodegraded.
Compostable	Capable of being biodegraded at elevated or ambient temperatures in soil under specified conditions and time scales (standards apply).
Oxo-degradable	Containing a pro-oxidant that induces degradation. Complete breakdown of the polymers and biodegradation have still to be proven.

A.6 Recycling and incineration of bio-based plastics

Bio-degradable, bio-based plastics are often difficult to recycle not least because they tend to break down but also because many of them absorb water (hygroscopic) which attacks the polymer during extrusion; weakening the material.[139] Some biodegradable bio-based plastics are recyclable and at least one commercial recycler of PLA is known to operate in Belgium,[140] however there are no commercial avenues for recycling bioplastics in the UK.

Bio-degradable bio-based plastics in the UK must currently therefore undergo a linear treatment pathway to incineration or landfill. If energy is recovered from incineration, a net positive impact on global warming will be produced as the carbon source is biogenic (short-

[139] Defra (2015), Review of standards for biodegradable plastic carrier bags, https://bit.ly/2IC6fcm
[140] Looplife Polymers

cycle).[141] In the case of landfill however, methane will be generated which if uncaptured will contribute to global warming.[142]

As discussed in Section 2.2.3, there is significant risk of confusion amongst consumers because novel bio-based plastics often exhibit the same aesthetic characteristics as mainstream alternatives. The potential for novel bio-based plastic products to contaminate and lower the quality of conventional plastics is considerable and potentially damaging to the secondary plastics market.

Appendix E. Marine debris prevalence

Table 21: Proportion of materials by item count in top 20 items surveyed on British beaches between 2005 and 2015 (after Nelms et al., 2017)

Item category	Proportion
Plastic fragments (large; >2.5 cm)	0.13
Plastic fragments (small; <2.5 cm)	0.10
Plastic caps	0.07
Polystyrene (small; <50 cm)	0.07
Crisp packets	0.06
Fishing net (small; <50 cm)	0.05
Plastic string	0.05
Plastic drinks bottles	0.04
Cotton buds	0.03
Fishing line	0.03
Cigarette stubs	0.03
Plastic cutlery	0.02
Glass fragments	0.02
Cloth pieces	0.02
Plastic bags	0.02
Polystyrene foam	0.02
Metal Drinks can	0.02
Plastic rope	0.01
Fishing net (large; >50 cm)	0.01
Wood pieces	0.01

[141] WRAP (2010), Environmental benefits of recycling, http://bit.ly/2uricL6

[142] Estimates suggest fugitive emissions are approximately 50% from UK landfill sites: Defra (2014), Review of landfill emissions methane modelling, https://bit.ly/2LxTa1z

Table 22: Marine Conservation Society categorisation of beach litter source

Pathway						
Non-sourced	**Public litter**	**Fishing**	**Sewage**	**Shipping**	**Fly-tipped**	**Medical**
Cloth: Cloth	Cloth: Clothing	Metal: Fishing	San: Buds	Glass: Bulbs	Cloth: Furnishings	Med: Inhalers
Cloth: Other	Faeces: In_bags	Metal: Lobsterpots	San: Condoms	Metal: Aerosol	Metal: Batteries	Med: Other
Cloth: Sacking	Faeces: Not_bags	Plastic: Fishboxes	San: Nappies	Metal: Food	Metal: Car	Med: Plasters
Metal: Other	Glass: Bottles	Plastic: Fishing_line	San: Other	Metal: Oil	Metal: Scrap	Med: Syringes
Metal: Wire	Glass: Glass	Plastic: Fishing_net_large	San: Tampons	Paper: Purepak	Plastic: Cones	
Paper: Cardboard	Metal: Bbqs	Plastic: Fishing_net_small	San: Toilet	Plastic: Cleaner	Pottery: Ceramic	
Paper: Other	Metal: Caps	Plastic: Floats	San: Towels	Plastic: Foreign	Rubber: Tyres	
Plastic: Other	Metal: Drink	Plastic: Lobsterpots	San: Wipes	Plastic: Industrial		
Plastic: Plastic_large	Metal: Foil	Plastic: String		Plastic: Meshbags		
Plastic: Plastic_small	Paper: Bags	Poly: Buoys		Plastic: Oil		
Poly: Fibreglass	Paper: Cig_packets	Poly: Fishboxes		Plastic: Rope		
Poly: Foam	Paper: Cig_stubs	Rubber: Boots		Plastic: Strapping		
Poly: Other	Paper: Cups	Rubber: Gloves_heavy		Wood: Pallets		
Poly: Packaging	Paper: Newspapers	Rubber: Tyres_holes				
Poly: Poly_small	Paper: Tetrapak	Wood: Lobsterpots				
Rubber: Gloves_light	Plastic: Bags					
Rubber: Other	Plastic: Caps					
Rubber: Rubber_small	Plastic: Cigarettelighters					
Wood: Brushes	Plastic: Combs					
Wood: Other	Plastic: Crisp					
Wood: Wood	Plastic: Cutlery					
	Plastic: Drinks					
	Plastic: Food					
	Plastic: Pens					
	Plastic: Shoes					
	Plastic: Shotgun					
	Plastic: Toiletries					
	Plastic: Toys					
	Plastic: Yokes_					
	Poly: Food					
	Rubber: Balloons					
	Wood: Corks					
	Wood: Lolly					

Appendix F. Results of cup and utensil carbon impact

Table 23: Comparison of cups and utensils used at events for meta-analysis of 16 LCA studies carried out by OVAM[143]

Material type	Reuse - high (>150)	Reuse - low (<150)	Recycling	Residual waste or compost
Second-hand crockery (glass, ceramic, metal)	A	A		C
RPET (recycled PET)	A	A	B	C
PLA (poly lactic acid) & C-PLA	A	A	B	C
Bio-PE (polyethylene) BIOGENIC	A	A	A	B
PP (polypropylene)	A	B	C	D
PET (polyethylene terephthalate)	A	B	C	D
PS (polystyrene)	A	B	C	D
PC (polycarbonate)	B	C	D	E
Copolyester	B	C	D	E
Modified starch				D
Cardboard (recycled)			B	C
Form of cardboard (moulded fibre)				B
Sugar Cane fibre (bagasse)				B
Wood				C
Cellulose pulp				D
Glass (recycled)	B	C	E	G
Metal	B	D	G	G
Ceramics	C	E		G

Letters A – G represent the lowest to highest carbon impact of each cup (underlying data is shown in Table 24 (note that this was not professionally translated into English and therefore some terminology may be inaccurate)

Table 24: Key to scoring of impacts in Table 23

Grams of CO_2	Low	High	Central value
A	3	6	5
B	6	14	10
C	14	26	20
D	26	54	40
E	54	106	80
F	106	214	160
G	214	-	>200

[143] http://www.ovam.be/wegwijzer-cateringmateriaal

Appendix G. Long-list of current and aspirational practices

Table 25: Long-list of current and aspirational practices used as the basis for this research

Use phase	Size/ weight of items	Industrial sector and examples	Lifecycle phase current practices and aspirations					
			Production		Use		Waste management / secondary markets	
			Current practice	Aspirational practice	Current practice	Aspirational practice	Current practice	Aspirational practice
1: Very short: <1 day	Small format - low size low weight	Packaging, household/ leisure: Cotton buds, coffee stirrers, straws, confectionery wrappers, medical, cigarette butts (cellulose acetate), sanitary products, wet wipes, clothing tags, fruit tags, bag twist closures, coffee pods	➢ Product designers rarely consider end-of-life; is rarely included in the product design brief ➢ Products are generally not biodegradable despite widespread concern over leakage into aquatic and terrestrial environments ➢ Design and manufacture of medical products is focussed on the use phase (safety and efficacy) ➢ Products are sometimes deliberately designed to remain separate from the dominant item (e.g. straws on food and drinks cartons) ➢ Plastic cutlery is sometimes produced from compostable plastics. This is only a minority of such cutlery, though, and usually at higher end grocery chains (e.g. Whole Foods), at Universities or in National Parks	➢ Design products to be reusable if it reduces the overall environmental burden over the life cycle ➢ If reuse is not an option, accept that these products will be likely to be disposed of to residual waste and incinerated or improperly discarded (littered). Produce from sustainable materials that compost (aerobic or anaerobic) in natural environment. Ideally these should be bio-based to reduce end-of-life burden if incinerated. Also, could be fossil based if incineration is unlikely (e.g. PBS, PHA, PHB) ➢ 'Lightweight' single use products to reduce the impact of production and distribution ➢ Ensure non-toxic/non-persistent additives are used to reduce potential for release into the environment when improperly disposed ➢ Plastic-free products may be unfeasible for many medical applications which use single use items for safety. Since the end-of-life fate is incineration, renewably resourced bioplastics are again logical if these are sustainably-sourced	➢ Almost entirely single-use and for extremely short time (< minutes) - many are potentially unnecessary (straws, except disabled groups) or replaceable with reusable alternatives ➢ Medical products benefit human health and increase longevity of samples (blood for instance)	➢ Assess the necessity of items in this class	➢ Mostly disposed to incineration or landfill ➢ High rate of leakage into foul sewerage systems in comparison to other products (fatbergs) ➢ Blocked sewerage and heavy rain events lead to overflow by design with storm drains transport items directly into watercourses ➢ These products are the main constituent of terrestrial and marine litter by item count ➢ Medical waste is well collected; unlikely to leak out of the system and is usually incinerated or landfilled post-sterilisation ➢ Coffee pods can sometimes be returned via take-back schemes funded by the brand and managed by third parties (e.g. Terracycle)	➢ Where unpreventable, accept that many of these products are unrecoverable for recycling due to their size and composition and that they will therefore be incinerated, landfilled or improperly littered ➢ Educate for more responsible disposal (not into sewerage system/littering)

Use phase	Size/ weight of items	Industrial sector and examples	Lifecycle phase current practices and aspirations					
			Production		Use		Waste management / secondary markets	
			Current practice	Aspirational practice	Current practice	Aspirational practice	Current practice	Aspirational practice
2. Very short: <1 day	Medium format – larger size / weight	Packaging: Disposable plastic cups, plates, takeaway containers, plastic bags, plastic cutlery	➢ Design is improving but many products are not designed and produced with recycling in mind. For example, materials such as expanded polystyrene (EPS), high impact polystyrene (HIPS), extruded polystyrene (XPS). HIPS modified with rubber to make tougher is used in single portion yogurts so that they can be 'snapped' apart easily ➢ Some products produced in multiple layers of different polymer grades and types	➢ Reusable replacement products should not have greater environmental impact than disposable alternatives. Aim for lighter and durable products ➢ Where continued use of single-use plastics is considered necessary, products would be manufactured to ensure recyclability (see RECOUP guidelines for designers) ➢ Products should be made from mono-polymers not multi-layer structures ➢ Simplify polymers to those commonly recycled to avoid cross contamination during recycling (i.e. PET, LDPE, HDPE, PP) ➢ Design products where possible using Polymers for which the widest possible range of secondary markets already exist – this will favour the Polyolefins, PE and especially PP ➢ Eliminate polystyrene (HIPS, EPS, XPS) because of unrecoverability ➢ Potential for edible packaging or other rapidly degrading plastics such as those made from seaweed, that are truly compostable in the natural environment or in existing commercial composting practice; addresses the challenge of food and oil contamination	➢ Used across much of society in public places (on-the-go) as more convenient than washing up ➢ Reuse is uncommon, although coffee cup reuse initiatives are now more prevalent in coffee shops and at events ➢ In general, items in this category contain products, prevent spillage or loss during consumption, but do not increase life of other products (i.e. food freshness). ➢ Many food service disposables are contaminated with food and oils which increase effort required during washing and can impede separation (increasing adhesion between items and increasing weight)	➢ As products are potentially preventable in many contexts, consideration given to re-useable alternatives should be given where environmentally beneficial and practicable to do so. Life cycle impacts of cleaning e.g. hot water can be significant ➢ Provision of reusable products in favour of single-use disposables may encourage more responsible and positive behaviour and attitudes towards materials regardless of whether the life cycle impact is worse	➢ Little recycling occurs for these products due perceptions of low recycling value and convenience. However, for rigid PP, PET and HDPE there are many outlets in the UK ➢ Polystyrene is widely used but not commonly recycled. Expanded polystyrene reprocessors do not operate at commercial scale. Rigid (PS) materials crack and fragment in bales and are almost entirely lost as fines during sorting ➢ On-the-go facilities are scant in the UK despite legal obligation to provide them ➢ Items are a significant visual component of terrestrial pollution ➢ Items are transported into watercourses by direct discard and storm-drains ➢ Collection of PE bags at grocery stores and drug stores. Often recycled into plastic lumber	➢ Use reusable products - crockery and cutlery where impacts of cleaning are low and is practicable ➢ Take-back schemes may be effective at large scales ➢ Items can and should be easily separated and recycled with minimum thermal recovery and disposal ➢ Comprehensive, standardised, consistent provision of on-the-go recycling systems ➢ Co-disposal with compostable materials may be an aspiration in controlled environments however this is not currently technically feasible ➢ Programs such as the Energy Bag program in the US (sponsored by chemical industry) could be implemented and expanded to collect "unrecyclable" plastics for energy recovery. The system (currently only available in two medium sized cities in the US) collects multi-layer packaging and EPS. ➢ Several technologies for EPS recycling are starting up in the US and Canada. Examples include Agilyx (pyrolysis to recover styrene monomer), Green Mantra (conversion to modified styrenic polymers), Polystyvert (green solvent to concentrate EPS for shipping, followed by recycling of the PS)

Use phase	Size/ weight of items	Industrial sector and examples	Lifecycle phase current practices and aspirations					
			Production		Use		Waste management / secondary markets	
			Current practice	Aspirational practice	Current practice	Aspirational practice	Current practice	Aspirational practice
3: Short: >2 days <2 years	Medium format - small size / weight	Packaging, agriculture, household/ leisure: Food and drink containers, cosmetics, agricultural film, bags for life, personal protective equipment	➢ Design guidelines for recyclability are voluntary and largely followed by the big brand owners ➢ Examples of best practice include: The European Plastics Bottle Platform; Association Plastics Recyclers (US); European Association of Plastics Recycling (EPRO); Plastics Recyclers Europe (RecyClass software tool) ➢ PET trays (not pots) are made by extrusion and forming in a triple layer process; two of these layers are typically 80% recycled content from PET bottles. however, the trays themselves are problematic to recycle because of the PE sealing layer on the top and therefore require downcycling to textiles or long-term products such as pipe or shipping pallets ➢ On-pack labelling fairly common in UK supermarkets but not practiced widely outside the big brands and is not always completely clear	➢ Extend lifetime of products intended for reuse by making products durable/resilient - could be the type of plastic or composites may be appropriate ➢ Products such as food packaging should be designed for recyclability (see RECOUP guidelines for designers) and/or reuseability ➢ Design products to reduce leakage of components such as caps, cap rings and inserts (e.g. can ring-pull redesign) ➢ Expand on pack labelling ➢ Use single material films with barrier properties (e.g. Dow) for packaging to avoid multilayer issues.	➢ Most products, especially packaging, protect something else, including food, medicines, cosmetics from being wasted. In particular, products from outside the UK which we rely upon for 40% of our food, are more susceptible to wastage without plastic packaging. The contents are almost always more valuable than the surrounding packaging in terms of resource use and emissions ➢ Exceptions exist where packaging is used purely for marketing purposes and could therefore (in strict functional terms) be avoided	➢ Whilst reuse may appear to be a clear option, items intended for reuse which displace disposable products may contribute more CO2eq than the single use items they displace ➢ Refillables may be possible for some types of products e.g. washing up liquid, but impracticable for others e.g. pressurised cosmetics ➢ Examples of items which could be sold loose are: washing up liquid, fruit and vegetables, flour, herbs, rice, nuts and seeds. However, there are challenges with contamination of food by pathogens, cross contamination, stock control, theft and food wastage. Some research indicates that the lifecycle impacts are worse for some loose products. ➢ Packaging should be optimised for safe and effective storage of the product inside; protecting from ballistic damage; biological, physical and chemical contamination; and UV, thermal and visible light degradation - consideration should be given to optimum storage in the distribution, retail and domestic environments ➢ Alternatives to plastics such as paper glass, aluminium may add to transport or production burdens	➢ Household collection systems are comprehensive for rigids but limited for film ➢ On-the-go recycling is (proportionally) almost non-existent and implemented poorly ➢ Process losses experienced by reprocessors and sorter due to some sleeves, labels, caps, and additives that are incompatible with current practice ➢ Chemical recycling into monomers is technically proven and is at commercial venture level (for PET, Nylon, PMMA and EPS, but not yet for PE)	➢ Items can and should be easily separated and recycled with minimum thermal recovery and disposal ➢ Domestic processing capability and capacity need to be incentivised

Use phase	Size/ weight of items	Industrial sector and examples	Lifecycle phase current practices and aspirations: Production – Current practice	Production – Aspirational practice	Use – Current practice	Use – Aspirational practice	Waste management / secondary markets – Current practice	Waste management / secondary markets – Aspirational practice
4: Medium: <2 >12 years	Larger format	Automotive, household/ leisure, packaging, agricultural, Electrical and electronic other (furniture, mechanical engineering), fishing gear	➢ Consumer safety is a strong driver in this product group which often focuses on functionality but limits recyclability and the use of recycled content especially where mixtures of polymers are used on one vehicle; parts are not designed to be easily dismantled ➢ Composites often used for lightness and durability; however, this also reduces recyclability at end-of-life ➢ The use of plastics in car bodywork and interiors is expected to increase with the introduction of electric powered vehicles ➢ Previous use of PVC on dashboards for instance has been phased out in favour of EPR (ethylene propylene rubber) which is miscible with PP ➢ Fishing gear is often discarded in the sea as 'ghost nets' which ensnare and maim wildlife ➢ Many EEE products require flame retardant materials (and these are less straightforward to recycle) ➢ Most, but not all, EEE brand owners are driven to avoid BFRs and other substances of concern due to the RoHS Directive (Restriction on Hazardous Substances) and other similar regulations around the world. ➢ EEE brand owners have trouble finding sufficient volumes of PCR materials. Most manufacturing is in China, so disruptions in waste plastics trade will further complicate this. ➢ Automotive manufacturers have trouble broadly using PCR plastics due to their rigid standards and aversion to risk.	➢ Reduce/identify PVC or other problematic materials and additives with chemical markers/electronic tags/physical labelling ➢ Standardise polymers used in electrical and electronic, and especially in automotive bodywork and interior where recovery for recycling is currently uncommon ➢ Considerable scope for an industry case study for automotive manufacturers selecting products for multi-cycle recyclability back to the same application. For instance, additional stabilisers could extend the life of a plastic beyond the life of the vehicle. ➢ Polymers could be selected for potential future chemical recycling. This means using PET or PA rather than PP LDPE, PE, HDPE ➢ Design for dismantling and separation (especially automotive) and electrical and electronic ➢ Modular design (upgrades) of products to enable parts replacement and long-lived use ➢ Design fishing gear to optimise durability/reuse - mark it to trace polluters ➢ Broader use of PCR plastics in EEE and automobiles will drive recycling industry.	➢ The use phase is dominant and increased plastics use is improving this through light-weighting; particularly in automotive ➢ Reusable packaging prevents the use of disposables but may increase the impact of transport ➢ Fishing gear provides food for people, as well as nutrients for agriculture, animal production and pets	➢ Light-weighting vehicles by replacing heavier steel components with plastics/composites reduces fuel consumption ➢ Reduce consumption across the product group by making things more durable and thus extending life ➢ Improved care of products and repair to increase longevity and thus reduce replacement - could be part of a servitised offering (see next point) ➢ Servitisation/ extended product stewardship/ product service system models retain ownership of product by producers and hence encourage longevity - could be applied to electrical and electronic, packaging and automotive	➢ Bumpers are often removed pre-shredding, but other plastics remain with the car during shredding operations that are part of the process to recover metals. The plastics are often thermally treated as are they too contaminated to easily separate. The result of this practice is that recycling targets of the ELV Directive are not typically met. ➢ Companies such as MBA Polymers UK and several companies in Europe (e.g. Galloo) are using-float sink separation and other proprietary separation processes to recover PP, HDPE, ABS-and HIPS from shredded ELVs. ➢ MGG Polymers in Austria (previous MBA Polymers) has been recovering high quality plastics ABS, HIPS, PC/ABS and PP from shredded WEEE for 12+ years. ➢ Sink float and electrostatic separation are common practice in WEEE recycling ➢ Some WEEE plastics may contain brominated flame retardants and other banned substances (e.g. Cd) which inhibit recyclability, but these can be removed to below current limits using sink-float and other separation processes. Proposed regulations in the EU may result in lower limits on certain BFRs in waste streams that could make recycling economically unfeasible. ➢ BFRs are typically found in flame retardant grades of ABS and HIPS. Lesser amounts in some very old flame-retardant grades of PC and PC/ABS, though PC/ABS currently often contain phosphate ester-based flame retardants, ➢ Many Polyamides and PP in WEEE and ELVs don't contain flame retardants ➢ Mixed rigid plastic from toys, buckets, etc. end up in "Civic Amenities" stream. These plastics can be separated and recovered using existing technologies including sink float and NIR sorting. ➢ Agricultural packaging is often heavily contaminated with chemicals and biological material; take-back schemes more common ('Drum Muster' in Australia - triple washed and taken back by producer) ➢ Fishing products are discarded / cut and set adrift as 'ghost nets', trapping fauna. ➢ Demonstration projects in Central America and SE Asia have focused on paying fisherman for EoL nets, but this is not yet widely implemented.	➢ Resale, remanufacture of whole products or components considered first, followed by shredding and recovery of base materials ➢ To meet ELV directive, plastic parts will need to be easily dismantlable and separable ➢ Agricultural packaging could be made compostable in environment - as arises in great quantity and could be on-farm composted ➢ Improved recycling processes and process efficiencies to improve recycling rates. Possible role of chemical recycling to recover PA and other grades that are difficult to recycle mechanically while retaining properties. ➢ Chemical recycling of fabrics (often PET) and foam (PUR) if determined to be economically feasible ➢ Expansion of PA chemical recycling process for fishing nets ➢ New optical sorting technologies that can sort black plastics are beginning to emerge. These could potentially simplify the process for recycling shredded ELV and WEEE plastics, though further R&D is required to demonstrate utility of these processes.

Use phase	Size/ weight of items	Industrial sector and examples	Lifecycle phase current practices and aspirations: Production – Current practice	Production – Aspirational practice	Use – Current practice	Use – Aspirational practice	Waste management / secondary markets – Current practice	Waste management / secondary markets – Aspirational practice
5: Long: >12 years	Larger format	Window frames, electrical, plumbing, insulating board, wall panels, roof tiles, carpet, soffits	➢ Products are designed for cost effective functionality during use with limited consideration for end-of-life treatment or disposal (in airplanes, exemptions have been allowed for substances such as PBDEs that are otherwise restricted by RoHS and REACH) ➢ Increasingly, plastics replace wood and metal as they are often more cost effective and less prone to environmental degradation over time	➢ Modularisation (upgradability) of buildings to enable component replacement and aid dismantlement ➢ Design and manufacture for future reuse, recovery and recycling ➢ Labelling of products physically, electronically, chemical markers for end-of-life classification and reprocessing ➢ Identify technology that can renew materials completely such as chemical recycling and ease of identification (currently no labelling) ➢ Use recycled material when possible, especially in less demanding applications with little danger of long-term failures. ➢ Careful review of potential Substances of concern (SOCs) in materials. Potential SOCs could be banned by the time the product reaches end-of-life, prohibiting recycling	➢ Resilience to degradation offers increased longevity ➢ Thermal insulation properties (e.g. foams) and draught reduction further increase functional benefits ➢ Plastic pipes reduce leakage and hence repairs in comparison and last longer than concrete or metal (easier to install) ➢ Where concrete and iron is replaced, the weight of plastic used is considerably less; reducing net impact	➢ Construction practices optimised for disassembly and recovery ➢ Resilience to degradation offers increased longevity ➢ Increased use of plastic as a replacement for other products such as concrete or ferrous metals	➢ Recycling and separation during replacement/ refurbishment is uncommon but increasing and there is an existing strong value chain for these materials ➢ The PVC is highly recyclable and are used for the inner core of new windows - existing but not widely publicised - existing recycling supply chain for PVC pipe ➢ PP (supports, sinks, pipework and Acrylic (glazing) ➢ High PVC content can make materials undesirable in all thermal treatment ➢ Legacy materials like cadmium and lead (stabilisers) ➢ Unrecycled material is therefore landfilled ➢ End markets for PU insulation foam are scant ➢ EPS building foam (The Polystyrene Loop Foundation is using the CreaSolve process to recover EPS building foam that typically contains BFRs including pentaBDE) ➢ Separation on construction sites is increasing but still the exception ➢ Separation on demolition sites is almost non-existent. It is time-consuming due to the common methods employed which focus on aggregates and metals	➢ Improve separation on construction sites ➢ Optimise demolition practices to recover plastics ➢ Identify reuse opportunities and dismantle accordingly ➢ Modular building components can be reused directly ➢ Develop technological processes for deconstruction and create a market for recovered construction plastics in general ➢ Chemical recycling for PET and PA fibres in carpet (also for clothing) if economically feasible and superior to mechanical recycling.

Appendix H. Interventions long-list

Table 26: Long-list of potential interventions which could be applied to improve resource efficiency of plastics

Command and control	Economic	Corporate/Industry	Communicative
➢ Ban products ➢ Mandate durability with standards ➢ Ban single use items where supported by lifecycle thinking ➢ Legislate for provision of mains drinking water in public places ➢ Enhance and enforce the waste regulations which mandate recycling ➢ Mandatory durability declaration ➢ Ban materials for very small format items that frequently leak into the environment, do not biodegrade in the natural environment and will not be realistically captured ➢ New standards for compostability in natural environment for very small format items that frequently leak into the environment and will not be realistically captured ➢ Strengthen Urban Waste Water Treatment Directive (or Brexit version) by reducing de minimis population and mandating better filtering of treated wastewater discharge ➢ Mandate marking (chemical, physical) of products to identify source polluters ➢ Mandate the use of post-consumer recycled content ➢ Enhanced capital allowances to fund capital equipment which improves technical ability to use post-consumer recycled content ➢ Increase landfill tax and introduce incineration tax ➢ Ban avoidable plastics to landfill/incineration ➢ Increase weight-based targets for the amount of material which undergoes recycling ➢ Mandate/ improve recycling targets in specific sectors such as building and demolition ➢ Mandate recyclability by banning combinations of materials/substances in the same product ➢ Standardisation of household collection schemes	➢ Tax specified single use products ➢ Fund research and development for modular design ➢ Enhanced capital allowances (ECA) for equipment to make products more durable ➢ Introduce pay-as-you-throw for residual waste ➢ Product buy-back incentives, deposit return etc. ➢ Incentivise production of very short cycle, small format products which compost in natural environment ➢ Charge producers for items found in the marine or terrestrial environment by item count ➢ Strengthen producer responsibility regime to improve economics of post-consumer recycled plastics ➢ Tax virgin plastics (or possibly just fossil fuels at source) ➢ Use public sector procurement policies to create demand for post-consumer recycled content ➢ Fund built infrastructure for plastics separation and recycling ➢ Fund recycling on-the-go infrastructure ➢ Tax packaging that does not include recyclability by design best practice and is classed as detrimental to recycling	➢ Voluntary withdrawal of harmful products from sale or replacing with non-harmful products ➢ Voluntary product durability standards ➢ Cooperation between brands for modularity and compatibility to extend life of products ➢ Expand voluntary premises owner schemes to refill water containers (e.g. 'Refill') ➢ Servitisation extended product stewardship/ product service system model and after-care services ➢ Extended warranties ➢ Adoption of compostability standards for very small format items that frequently leak into the environment and will not be realistically captured ➢ Voluntary litter reduction interventions for polluting businesses such as fast-food outlets ➢ Voluntary commitment to a programme of increasing targets for recycled content in packaging and products ➢ Voluntary weight-based targets for recycling ➢ Voluntary adoption of design parameters for recyclability (e.g. RECOUP guidelines)	➢ Inform/support for less/alternative use by public and businesses (funded by extended producer responsibility) ➢ Inform civil society to understand the functional benefits of plastics ➢ Lifecycle product declarations ➢ Inform/support civil society on the need to separate materials ➢ Inform/support civil society on the need to care for products to extend longevity ➢ Do not label products which do not break up in sewers as 'flushable' ➢ Inform/support civil society about littering and the impact of improper disposal to sewers ➢ Label products to allow consumers to choose those which contain post-consumer recycled content ➢ Improve information on additives, polymer types ➢ Share best practice on collection, sorting and reprocessing ➢ Share information on the secondary plastics sector to reduce uncertainty for new market entrants ➢ Ensure manufacturers and designers are aware of how to design for recyclability ➢ Introduce material flow data dashboard to help sector co-ordinate actions