Fixing the system

Why a circular economy for all materials is the only way to solve the plastic problem

green alliance…

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Green Alliance
Green Alliance is a charity and independent think tank, focused on ambitious leadership for the environment. With a track record of over 40 years, Green Alliance has worked with the most influential leaders from the NGO and business communities. Green Alliance's work generates new thinking and dialogue, and has increased political action and support for environmental solutions in the UK.

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The analysis and recommendations in this report are solely those of Green Alliance and do not necessarily reflect the views of the experts consulted or the members of the task force.

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Summary

The meteoric rise of plastic, from 1.7 million tonnes produced in 1950 to more than 350 million tonnes a year today, was enabled by its versatility, its durability and, perhaps most crucially, its cheapness.[1] This rise coincided with people embracing 'throwaway living'. In 1955, *Life* magazine was lauding disposable items that "cut down household chores", which were mainly, but not exclusively, made from plastic. These included a set of six dog feeding bowls ($1 for the lot) and a set of 'disposa-pans' that "eliminates scouring of pots after cooking" ($2.98 for eight).[2]

We are beginning to realise the short sightedness of this approach which is now embedded across society, in modern times aiding our increasingly on the go lifestyles. Material that is not valued is too often discarded after brief use, and the impacts of mismanaged plastics have been devastating to the marine environment. Heightened public awareness means businesses and governments are scrambling to address plastic pollution.

But plastic is not the only material that is currently undervalued. We demonstrate the risks of simply removing it from an already dysfunctional system and replacing it with other materials that essentially perform the same functions. Our analysis shows that doing so will damage the environment in other ways. What is needed now is an approach that tackles the impacts of all resources, rather than considering plastic alone.

These are our recommendations:

Plastic-only strategies won't work
Piecemeal policies that only tackle certain uses of plastics or encourage simple substitution for other materials could lead to environmental impacts down the line that could be avoided if foresight is used. We show how the government can help to improve the sustainability of many common materials in use, including increasing the amount of steel reused, improving the recyclability of glass, paper and aluminium, and tackling non-packaging plastic.

We highlight the steps that should be taken at every stage of the lifecycle of bio-based and compostable materials, to prevent unintended consequences of their use and make sure they really do lead to environmental improvements. These range from assurances on raw material sourcing through to better standards that match real life treatment options.

New guiding principles are needed
A systemic approach, as part of a circular economy for resources, should ensure that material use meets three overarching requirements: safety, sustainability and efficiency. That means, for instance, that unnecessary

applications and certain types of material use should be eliminated, that all environmental harms should be considered and that exposure to hazardous substances should be prevented.

There is justified public concern about the presence of harmful chemicals, like phthalates and bisphenol A, in plastics. We show that there are concerns about other materials, too, including the use of the 'forever chemicals' PFAS to improve water resistance in paper, card and compostable material. An urgent review of regulations for food contact materials is required.

Better infrastructure and systems should be developed
Our leading message is the overall need to use less material. But creating a more circular economy for the materials we have to use will require the right infrastructure and carefully considered systems. To improve performance and ensure customer buy-in to reusables, for instance, we recommend a set of guiding principles as companies explore options for reuse. These include getting the delivery system right for each type of product; making it easy and attractive for consumers; and ensuring material use does not increase, as is a risk with repeat purchases of 'bags for life'.

In the case of plastics, new chemical recycling technologies are being touted as offering endless possibilities for creating new products. But, to keep material circulating at the highest value, we propose a recycling hierarchy that prioritises mechanical recycling ahead of these novel technologies, as it uses the least energy. This should be followed by chemical depolymerisation and, finally, thermal cracking, only used where material is too degraded for other recycling processes and it reduces energy use.

Fiscal incentives should be used to their full potential
The proposed tax on plastic packaging with less than 30 per cent recycled content has already helped to increase investment in plastic recycling facilities. But the tax has flaws. We show how it could be improved and how other effective fiscal measures could lead to better resource use. We argue that the Treasury should increase the tax's ambition and efficacy by introducing an escalator. We also argue that the government should be using fiscal measures to encourage lower material use across the economy, helping to meet the net zero goal. This should include further use of virgin materials taxes.

The plastic pollution crisis has highlighted major failings in how society uses and values all its resources. As the UK implements its resources and waste strategy and prepares to host the UN climate conference in Glasgow in November 2020, now is the time to re-evaluate and make sure we end throwaway culture for good.

Introduction

> "With plastics, and resource use more widely, it is not too late to change tack and ensure a sustainable solution."

Historically, developments in science, technology and policy have often had unintended consequences. A case in point is chlorofluorocarbons (CFCs), initially introduced as safer refrigerants than substances like ammonia but later found to destroy the ozone layer.

We can learn from these missteps. With careful research, such unintended consequences can often be predicted and prevented. Even unforeseen outcomes can be addressed, which is what happened after the impact of CFCs became clear and the international community reacted swiftly to phase out the offending substances through the 1987 Montreal Protocol.

An effective environmental policy, therefore, should apply foresight to prevent unintended consequences and react to the unforeseen. However, in the quickly emerging technology and policy landscape aiming to address plastic pollution, this approach is not yet evident. Some changes are already being introduced that will not be sustainable. These include the replacement of unnecessary single use plastic items with equally unnecessary single use items made from other substances, and the introduction of novel materials before their impacts are fully understood and the systems are in place to handle them properly.

Fortunately, with plastics, and resource use more widely, it is not too late to change tack and ensure a sustainable solution. In this report, we outline what is required for a more holistic approach to solving the plastics problem, one that will prevent known negative consequences and be able to respond quickly when problems occur in future.

Lessons from the story of plastic

The most relevant example of the unintended consequences of material use comes from the invention of plastic. Plastic was created in direct response to an impending environmental crisis: to prevent the extinction of elephants. At the end of the 19th century, the world's demand for ivory, particularly for billiard balls, made it increasingly difficult and expensive to source. Celluloid, the first industrialised plastic, was invented in response to a $10,000 reward offered for a new material to make billiard balls.[3]

Though its volatility made it unsuitable for use in billiards, celluloid turned out to be versatile, durable and low cost. This made it quickly indispensable, most famously for cinema, but also as a replacement for other substances obtained from nature, including tortoiseshell in combs and furniture and coral in jewellery. An early sales pamphlet boasted: "[C]elluloid [has] given the elephant, the tortoise and the coral insect a respite in their native haunts; and it will no longer be necessary to ransack the earth in pursuit of substances which are constantly growing scarcer."[4]

The single use plastic bag – the poster child of throwaway living – has a similarly telling origin. It was invented in Sweden in 1959 to prevent so many trees from being cut down to make paper bags. However, its inventor, Sten Gustaf Thulin, intended his thin bag "of wealdable plastic" to be used multiple times.[5] With the frequent mismanagement of this material, and its well documented impact on the environment, these early good intentions are ironic.

We can draw two lessons from these stories:

Simple substitution is not the answer

Aiming to find a direct substitute for plastic would repeat the mistakes of the past. Global plastics production was reported to be 359 million tonnes in 2018, and some estimates put it above 400 million tonnes.[6] This is expected to rise to 1.124 billion tonnes by 2050.[7] Efforts to address this will only succeed if the first focus is to reduce the need to use so much material in the first place, in line with the waste hierarchy legally enshrined in the UK, which prioritises prevention.[8]

A systemic approach is needed to curb throwaway living

Plastic enabled a throwaway culture to develop, meaning materials are used only briefly, are often undervalued and their impacts are often not considered or accounted for. The future system of resource stewardship should ensure that all materials – including but not limited to plastic – are properly valued throughout their lifecycle.

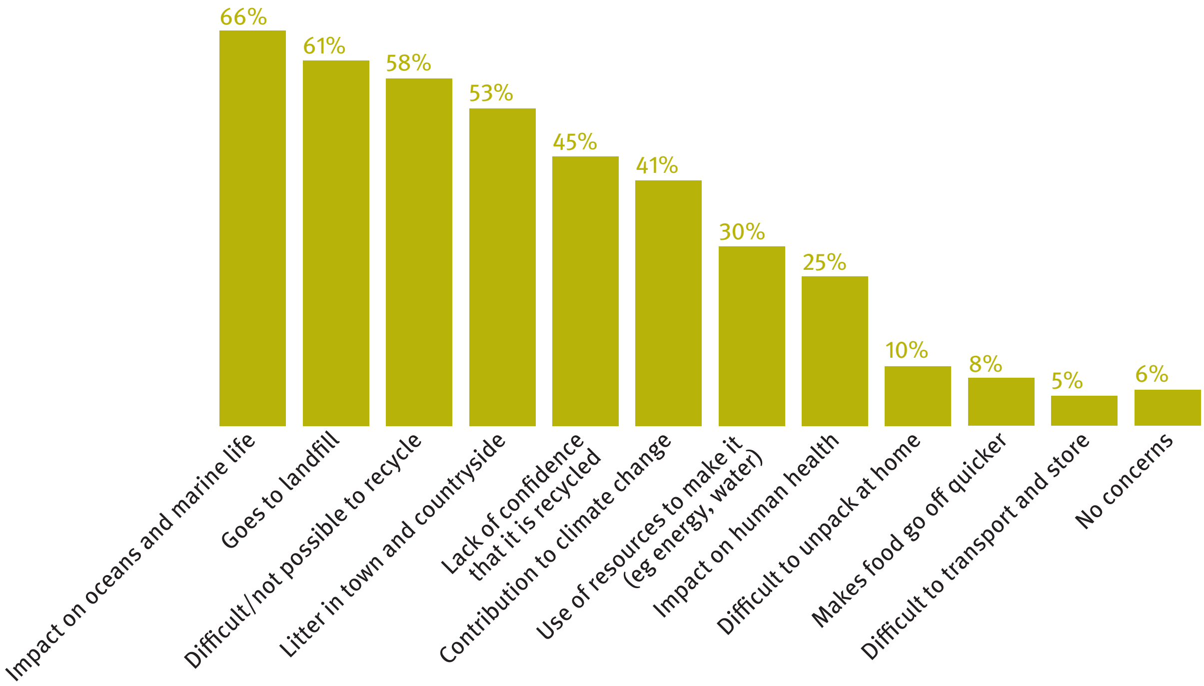
In this report, we present solutions and a more holistic approach that will avoid unintended consequences.

Shortcomings of current approaches to plastic pollution

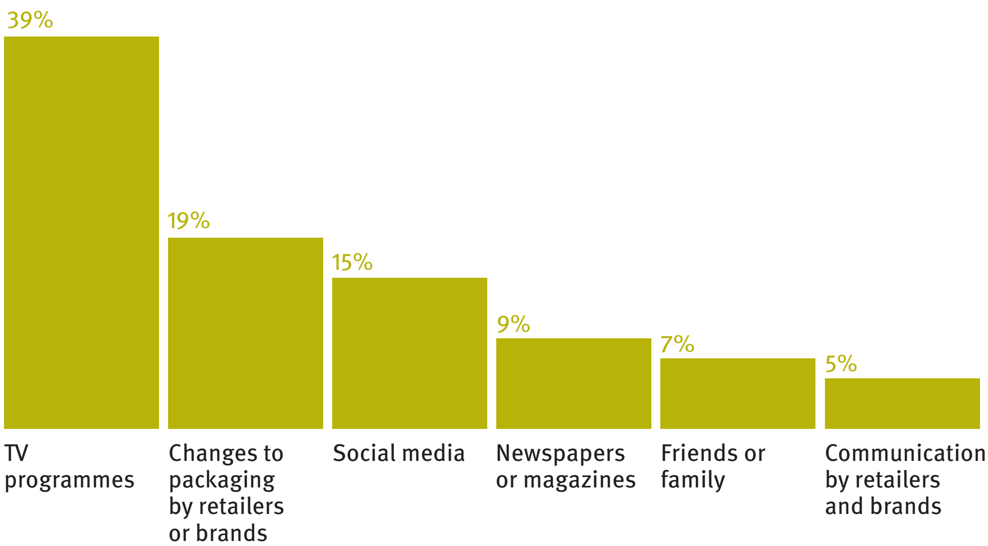
Public awareness of plastic pollution

Following decades of research and campaigning on ocean plastics, the issue finally broke through into the wider public consciousness with the airing of David Attenborough's Blue Planet II in 2017. It has remained high on the agenda ever since, helped by consistent media attention, other documentaries like the BBC's War on Plastic and extensive campaigning from environmental NGOs. This awareness is making people want to change their behaviour.

What worries people about food packaging?[9]



What influences public opinion about food and drink packaging?[10]



"Actions announced so far by governments are expected to have very limited effect. Despite efforts to reduce it, plastic production across the world is still growing."

Limited action so far

In response to this public outcry, businesses have launched a raft of new initiatives, predominantly around packaging. These include individual commitments and joint efforts like the UK Plastics Pact, replicated at the international level in the New Plastics Economy Forum, representing 20 per cent of global plastic packaging use.[11]

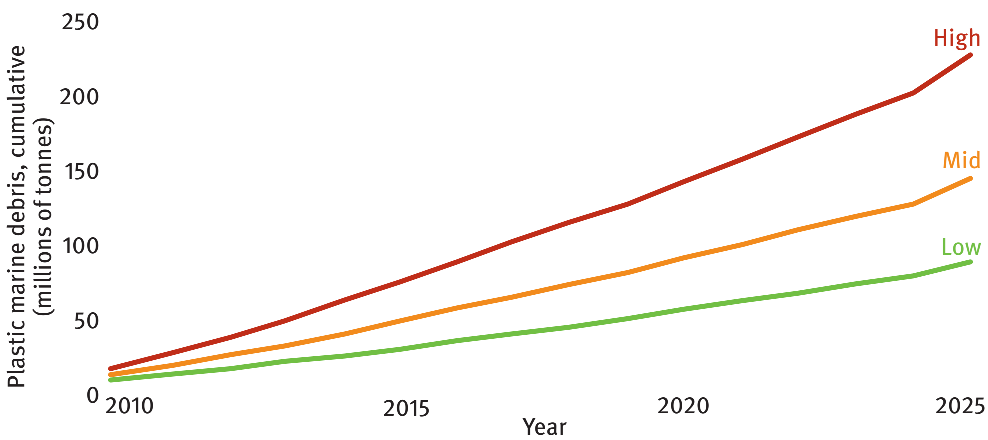
Despite this, 2019 data from WRAP suggests that the amount of plastic packaging placed on the UK market has been stable since 2006, with material lightweighting countering a rise in consumption.[12]

Similarly, more than 60 governments have proposed actions to tackle plastic and plastic pollution.[13] Actions are also being taken by sub-national governments, hundreds of which have introduced bans on plastic bags or expanded polystyrene, for instance.

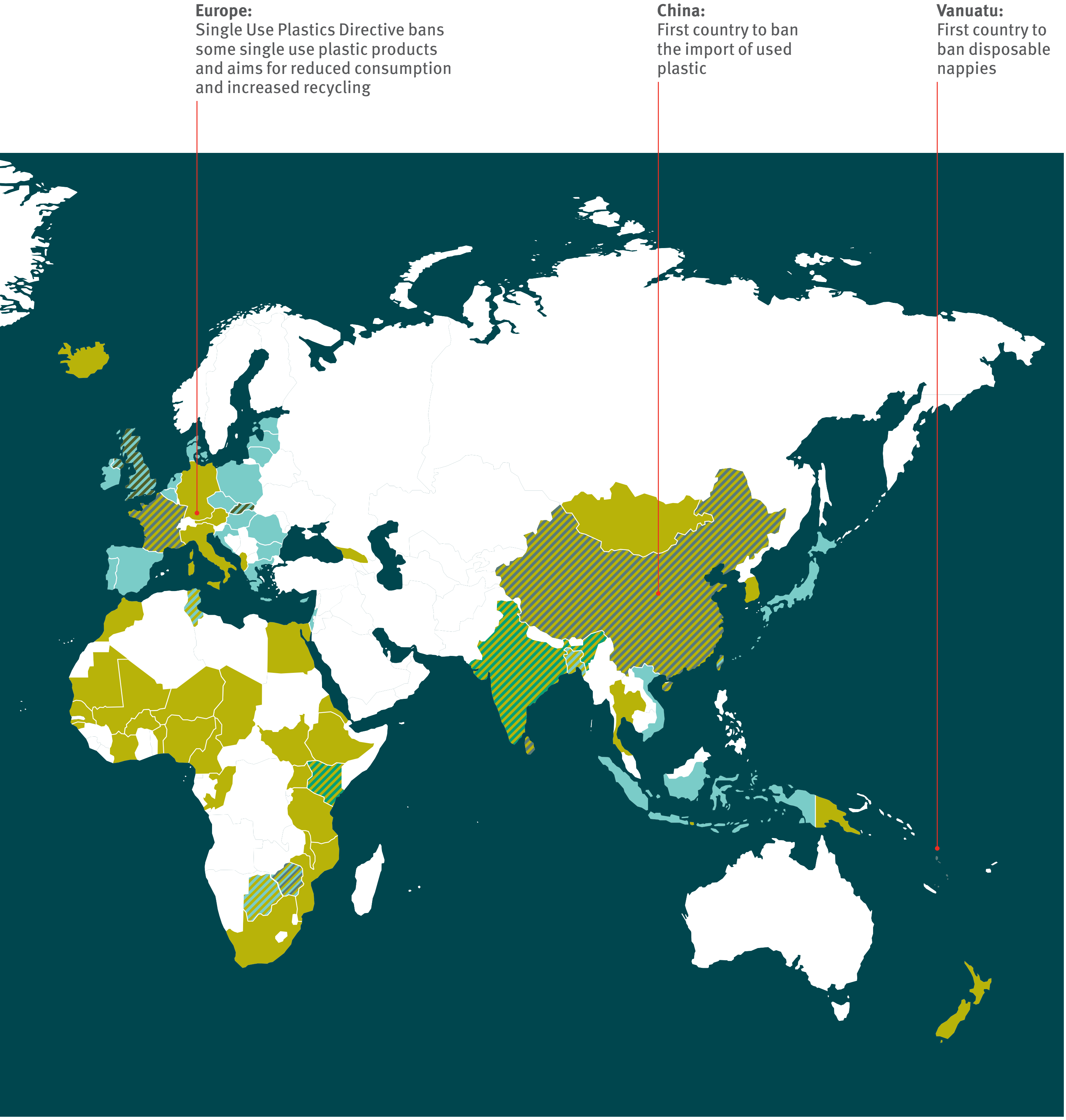
However, as with businesses, the actions announced so far by governments are expected to have very limited effect. The root cause of this is that only particular polymers and individual uses of plastic are being considered, rather than taking a more fundamental approach to how materials are used and managed.

In fact, despite efforts to reduce it, plastic production across the world is still growing. As of 2016, global production was expected to triple by 2050, having increased more than 20-fold since the 1960s, enabling a high consumption, throwaway culture to develop.[14,15] Despite global concern, this expansion could continue: as the world phases out fossil fuels, many petrochemical companies are investing in new facilities to manufacture plastics instead. In the US alone, where fracking has provided a cheap feedstock to make plastic, investment in such facilities has topped $200 billion over the past decade.[16] Ineos, meanwhile, is building a new plant in Belgium to create ethylene, a building block for plastic.[17] It is the first such facility to be built in Europe in 20 years.[18] These investments could be short lived or could become stranded assets in a few years' time. Avoiding further unnecessary investments will only be possible with a whole system approach to reduction.

In the worst case scenario, plastics in the world's oceans are projected to increase tenfold between 2015 and 2025[19]



Worldwide attempts to tackle plastic pollution are piecemeal


Europe:
Single Use Plastics Directive bans some single use plastic products and aims for reduced consumption and increased recycling
China:
First country to ban the import of used plastic
Vanuatu:
First country to ban disposable nappies

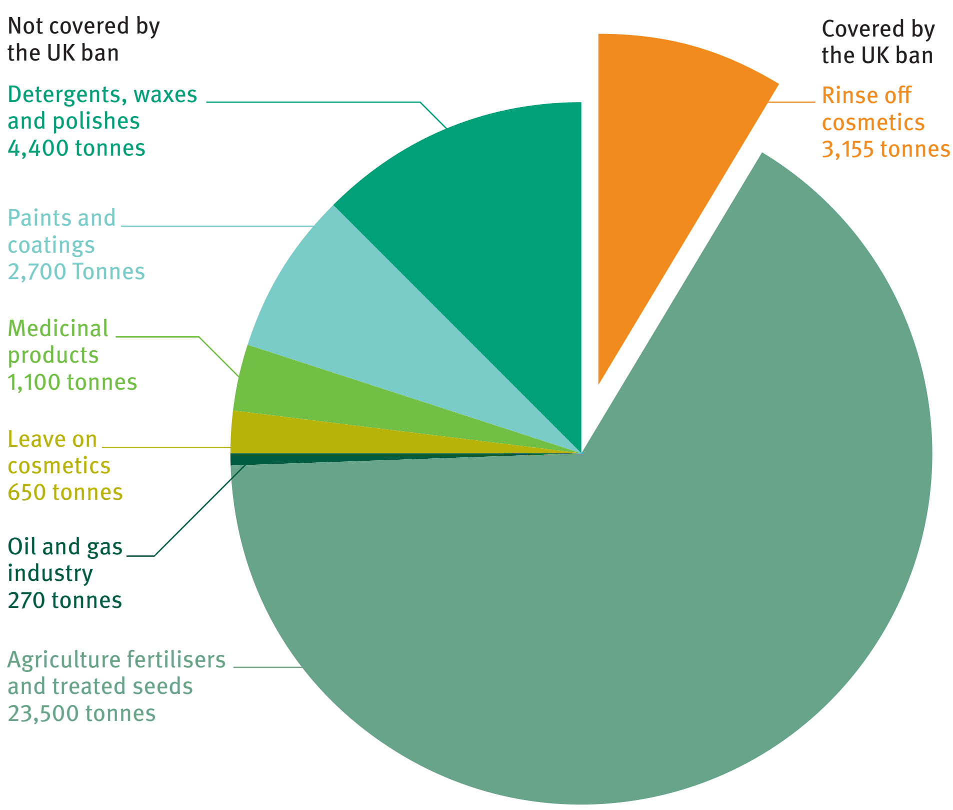
"In line with the rest of the world, the government's approach has so far been piecemeal."

Why England's current approach isn't working

England's 2018 resources and waste strategy has placed the issue of plastic pollution front and centre, promising greater action. Of the five milestones set in the document, two relate to plastic: one is to "work towards" ensuring all plastic packaging placed on the market is recyclable, reusable or compostable by 2025 and the other is to eliminate "avoidable" plastic waste by 2042.[21]

However, in line with the rest of the world, the government's approach has so far been piecemeal, restricting certain applications of plastic, starting with a partial ban on microbeads in wash off cosmetics in June 2018.[22] Although the government described the ban as "world leading", it barely covers any of the sources of intentionally added microplastics released into the environment. The EU estimates that total intentionally added microplastic pollution from Europe is around 36,000 tonnes a year. Microbeads in wash off cosmetics make up just 8.8 per cent of this.[23] The EU has proposed a much more wide ranging restriction, but it is not clear yet if the UK will adopt it.[24]

Sources of intentionally added microplastics released to the environment in the EU each year[25]



“While specific plastic bans may be laudable in some cases, they risk unintended consequences.”

Following the microbeads ban, the government has announced a ban on plastic straws, drink stirrers and cotton buds from 2020 and has indicated it is considering a ban on expanded polystyrene for food and beverage containers.[26,27] This is a similar approach to that being taken by the EU, which has banned plastic from a longer list of applications, including cutlery, plates and balloon sticks, through the Single Use Plastics Directive, which the UK has not yet committed to adopting.[28]

While specific plastic bans may be laudable in some cases, they risk unintended consequences. This can already be seen in advance of the bans coming in. Many companies are now making their single use products from other materials, like paper straws and wooden drink stirrers and cutlery. The global market for paper straws, for instance, is growing by 13.8 per cent a year.[29] McDonald’s in the UK, which uses 1.8 million straws a day (675 million a year) began switching to paper straws in 2018. These cannot be recycled, are not needed by most adults and there are reusable options for those that want them.[30,31] Similarly, supermarkets and many on the go food outlets are switching away from plastic to takeaway wooden or compostable cutlery, including M&S and Pret A Manger.[32]

This trend, to tackle plastic in isolation, looks set to continue, with the Environment Bill including a section describing powers to set charges only for single use plastic items and not for any other alternatives that would also be “likely to be used only once, or used only for a short period of time, before being disposed of”.[33]

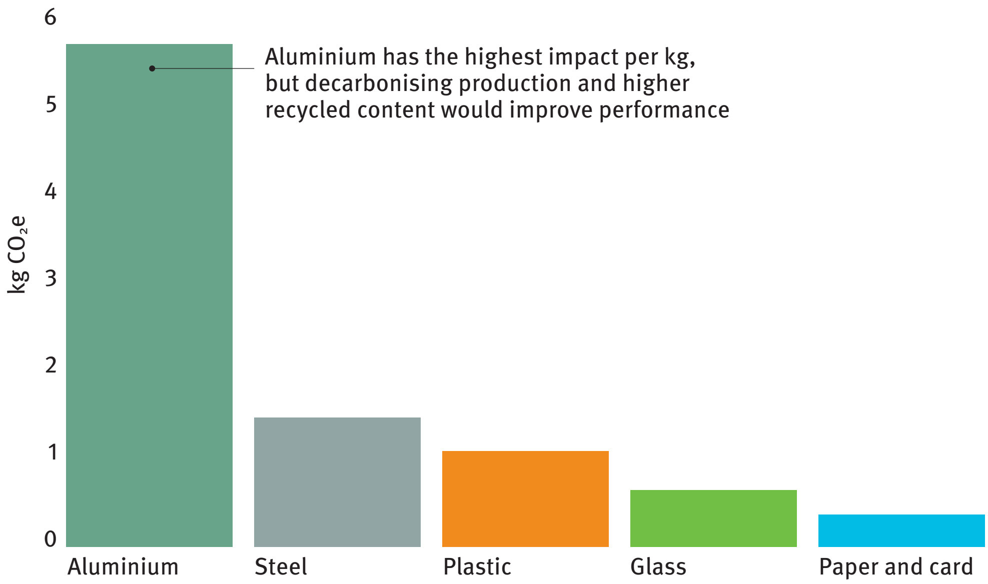
Plastic-only strategies are not working

Maintaining current systems and simply encouraging shifts away from plastic and towards other materials is problematic.

To understand the current impact of different materials, and assess wider impacts in a way that lifecycle assessments cannot, PwC examined the greenhouse gas impacts of packaging types currently used in the UK on behalf of the Circular Economy Task Force. The analysis used economic input-output modelling to estimate total greenhouse gas impacts throughout the packaging supply chain, not only within the UK.[34]

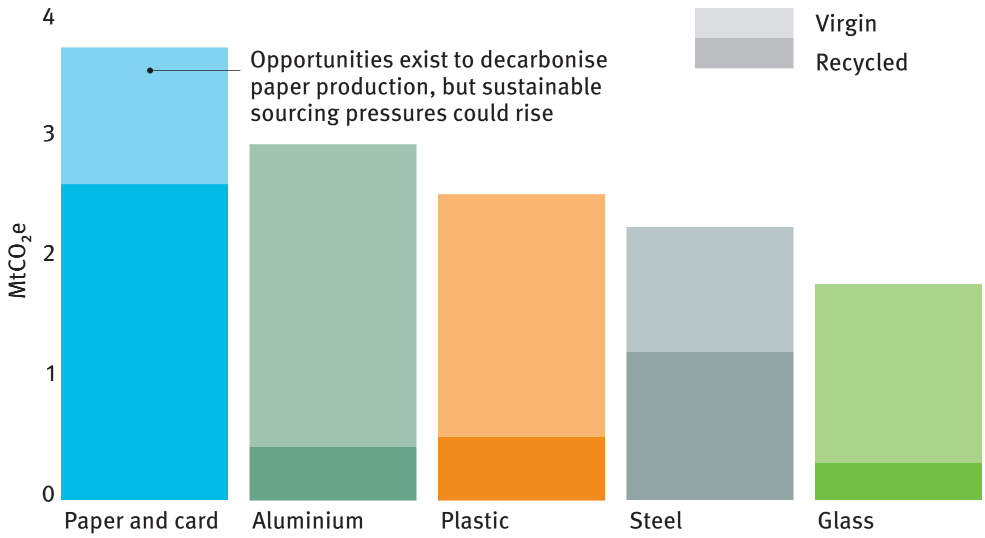
All materials used for packaging consumed in the UK account for 13.4 megatonnes of CO_2 equivalent in total, which is 1.7 per cent of the country's consumption emissions.[35] The scale of emissions arising from each common packaging material, revealed by this study, makes it clear that all materials should be addressed, not just plastic. As all materials have impacts, resource strategy should prioritise reduction in use first.

Greenhouse gas impacts per kilogram of packaging consumed in the UK (kg CO_2e)



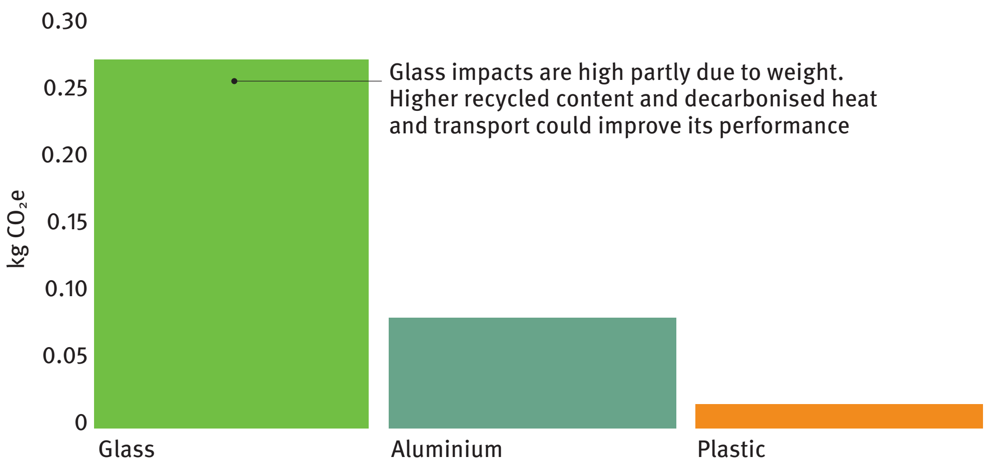
By weight, and based on current levels of recycled content, aluminium production is the most carbon intensive, followed by steel and plastic.

Greenhouse gas impacts of packaging consumed in the UK in 2018



Although aluminium is the most carbon intensive material to produce, in 2018, paper and card was responsible for more UK emissions than other materials, partly because it is 45 per cent of the packaging market.

Representative greenhouse gas impact of material used to make a 500ml drinks container



Carbon impacts are also influenced by a container's weight which can vary significantly, depending on the material used, eg a 500ml container made of glass, based on current recycled content rates for packaging in the UK, would generate significantly higher emissions than typical alternatives.

This analysis only considers the impacts associated with the single use of a packaging material; reusing items will reduce overall environmental impact in most instances. Additionally, it is possible to recycle both glass and aluminium easily with little loss of quality, meaning their impact could be less if recycled content increases from current levels.

Simply switching to other single use materials could increase carbon emissions

Plastic has many negative impacts on the environment, so how it is used must change, but just switching to another material for the same use, without addressing issues in the whole system could increase the UK's carbon emissions.

PwC estimates that switching all current consumption of plastic packaging (1.6 million tonnes) on a like for like basis, to the other materials currently used for packaging in the UK could almost triple associated carbon emissions from 1.7 billion tonnes CO_2e to 4.8 billion tonnes CO_2e.[36,37]

Other impacts must also be considered

Greenhouse gases are not the only consequence. Other environmental impacts should also be considered, like water use and pollution, including to land, water and air. Currently, aluminium production uses more water on a per kilogram basis, for instance, but paper produced for the UK market uses the most water overall, due to its greater market share.

This study shows that the multiple impacts and consequences of all material production need to be considered in developing a better approach. This is not to say we should be continuing to use plastic as we have done, especially given the risk that plastic production will increase. As has been well documented, and is widely accepted, the current system has resulted in considerable damage from plastic use, not least to the marine environment, which are not accounted for in these metrics.

Addressing the root problems of our throwaway culture should be the starting point, not only to prevent marine plastic pollution but to reduce material use and waste across the economy. This means changing the system so that it addresses all the environmental impacts of materials, rather than attempting to solve the problem of plastic pollution in isolation.

Compostable plastic: a policy problem

Novel materials, like compostable plastics, highlight a major shortcoming of the current system of resource management: materials need to be introduced into a system that can deal with them properly and that allows them to deliver benefits.

For example, the Houses of Parliament switched to compostable packaging in October 2018. Even though it provided dedicated composting bins, all of the material collected in the first six months was sent to incineration because of contamination.[38] After this was exposed, a bespoke supply chain that allowed composting was established.

This approach missed out on an opportunity to eliminate single use material entirely and also highlights a wider challenge. Parliament is a relatively closed estate, with control over what is sold and how it is collected. Ordinary cafes and other managed facilities, which are also increasingly introducing single use compostables, have little influence over infrastructure and supply chains to ensure proper treatment.[39] Only effective policy can make sure the right system is in place.

A first step towards this would be to deliver on the promise of England's resources and waste strategy to have a separate food waste collection service by 2023. For this to work, policy should ensure that only material that degrades in real life treatment conditions is allowed onto the market, and a composting stage should be added after anaerobic digestion (AD). AD is the default treatment for food waste in the UK, but the process is too fast to handle material like compostable plastic. Other European countries like Italy have made AD followed by composting mandatory. The UK should follow suit.[40]

Cross contamination of waste streams

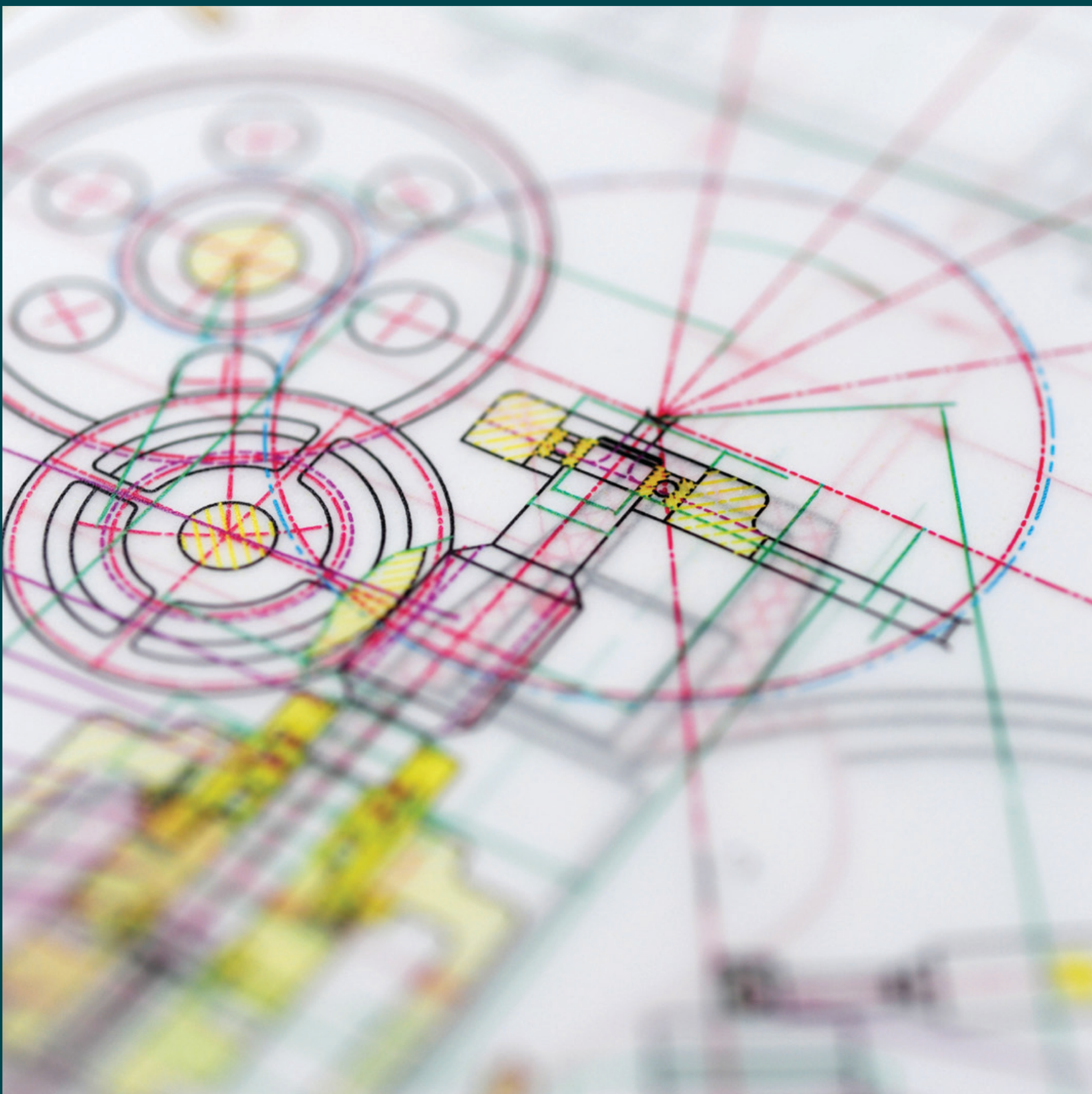
Contamination of conventional plastic with compostable plastic, and vice versa, is very problematic. PLA, the most common compostable plastic, and PET, a common polymer for drinks bottles, can be used for many of the same applications. But, at concentrations of just 0.1 per cent, contamination with PLA can cause cosmetic and structural problems to PET, rendering recycled material unusable for many applications.[41]

Likewise, PET and other non-compostable plastics are equally problematic for composters and AD operators. Compost that is contaminated with conventional plastic risks chemicals leaching into soil, microplastics being flushed into waterways and a devaluing of compost's use in agriculture. The Environment Agency has suggested the level of plastic acceptable in compost needs to be lowered considerably, from five per cent to just 0.5 per cent, after finding elevated levels of chemicals in compost, which it believes come from plastic contaminants.[42]

Composters and AD operators are currently unable to distinguish between PET and PLA and so, to avoid contaminating compost with PET, most plastics, compostable or not, are currently removed from organic waste and sent to landfill or incineration facilities.[43] Similarly, the Department for Environment, Food and Rural Affairs (Defra) has admitted that the growth in compostable materials is problematic without the proper treatment infrastructure in place and better understanding of its use, cautioning that it "may be necessary for consumers to be advised to put this type of packaging in the residual waste bin."[44]

See page 34 for our recommendations for a better system for novel materials like compostable plastic.

Guiding principles for a sustainable system



> "A systemic approach, as part of a circular economy for resources, should ensure that all material use is safe, sustainable and efficient."

While promised action by government and business could result in less ocean plastic pollution and higher recycling rates, both of which are vital, they could also increase other environmental harms if they are not complemented by policies that tackle resource use more generally.

Policy makers and political, environmental and business leaders should seek to translate the heightened awareness around plastics into a more systemic approach to resources overall.

Defra has recognised the importance of good data to inform policy, and has supported the development of a National Materials Datahub to track resources throughout the economy.[45] It also recognises the need to map entire systems, including for resources and waste, launching a Systems Research Programme "to identify how a policy change in one area might affect another, and to make sure the connections between environmental issues are properly considered".[46]

The information emerging from these initiatives should provide the basis of a new, systemic approach to resources, one that is cross government, not solely confined to Defra.

A systemic approach, as part of a circular economy for resources, should ensure that all material use is safe, sustainable and efficient. To meet these goals, we recommend the following guiding principles as a minimum.

Safety

Minimise harm from extraction and production
Apply measures at the beginning of the material cycle to address full lifecycle impacts.

Minimise exposure to hazardous substances
Use the 12 principles of green chemistry to ensure more resource efficient and safer design of molecules, materials, products and processes.[47]

Eliminate litter and leakage
Handle materials and products appropriately at the end of their useful lives, to minimise litter and the considerable harm that can be caused to the environment and health by mismanaged waste.

Sustainability

Consider all environmental harms

Use multiple, but standardised and independently verifiable, measures to evaluate damage and risk, including carbon impacts, pollution, land degradation and water use.

Follow a hierarchy

Design products for durability and repairability, as a priority, ahead of reuse and recycling, to minimise material use and retain product value in the first instance.

Use systems thinking

Consider environmental impacts together and develop plans to address unintended consequences. Policy change in one area can affect others; for instance the food, packaging and waste management systems are all interconnected.

Efficiency

Keep it simple

Rationalise use and eliminate unnecessary applications of materials. For example, in the case of plastic packaging, polymers, additives and colours should be rationalised, sleeves should be eliminated and composite materials should be avoided, unless a treatment system is developed for more complex designs.

Build the right infrastructure

Establish logistics, systems and infrastructure to minimise resource use, maintain value and limit harm, including to other material streams, from the products and materials on the market.

Work in harmony

Connect actors at all stages of the material cycle, including extractors, designers, producers and retailers, consumers, and waste and resource managers.

In the following section, we outline the elements of a safe, efficient and sustainable system for material use.

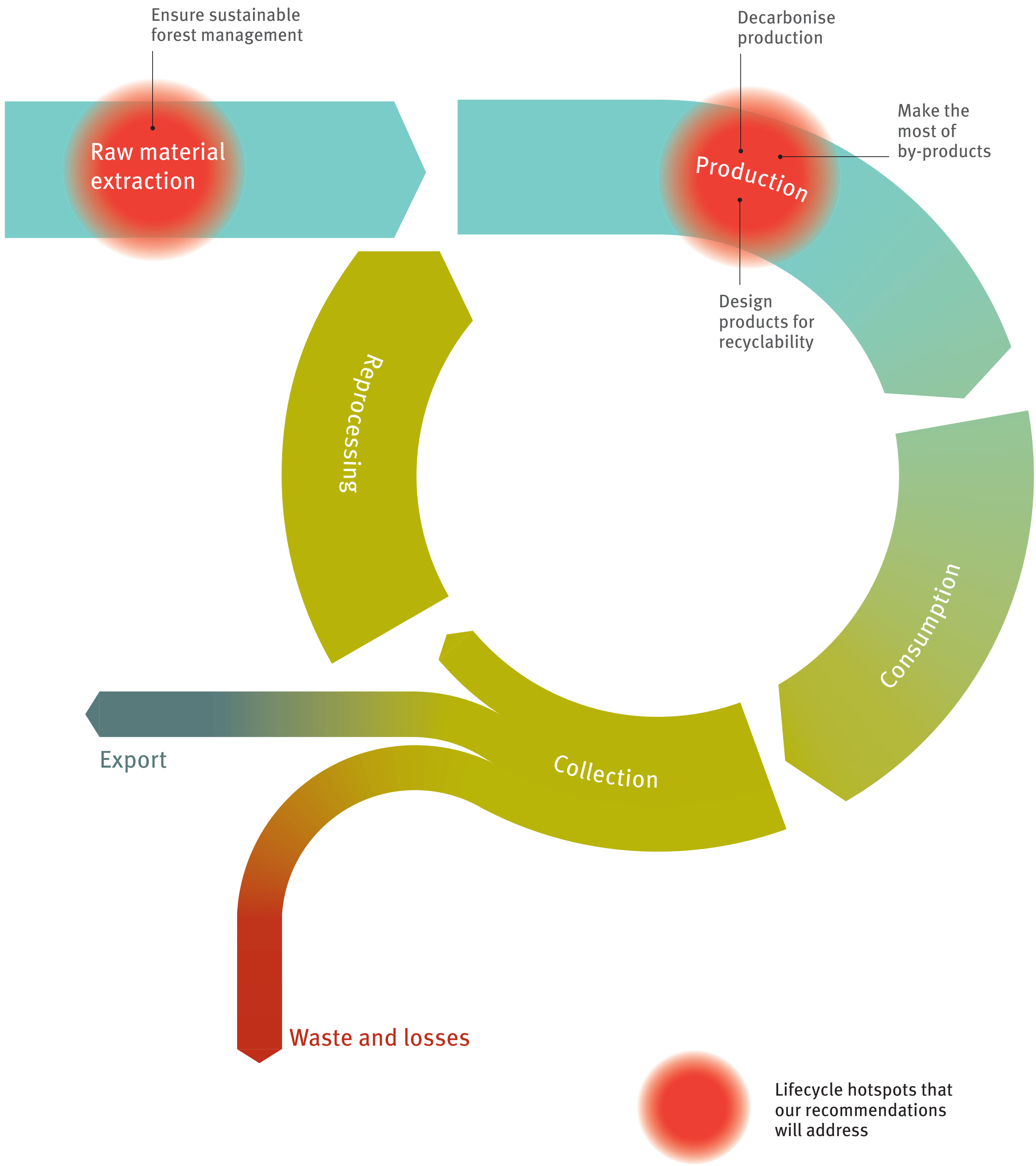
Reducing the impact of all materials

Rather than focusing exclusively on plastic, a systemic approach would help to ensure that all resources are used sustainably and that environmental harm is minimised. To achieve this, the government should assess and address the whole lifecycle impacts of all materials.

Using the examples of the materials studied by PwC on behalf of the Circular Economy Task Force as a starting point (see page 14), in this chapter we make initial recommendations to improve their environmental performance.

We also examine some novel materials in detail and offer guidance for their introduction. In line with the waste hierarchy's guidance to minimise environmental impact, the top priority should be to cut material use, so our recommendations focus on desired improvements for when minimisation or elimination of a material are impossible. As a general rule, simplifying what goes in at the start of a production process helps to increase the quality of what comes out.

Paper and card



Paper production contributes to global warming as well as air and water pollution, and it generates solid wastes. Water use by the industry is also very high, with around 16 to 17 tonnes of wastewater for each tonne of paper produced in the UK.[48] The Environment Agency describes water pollutants as "a major issue in this sector", with the potential for contaminants arising from paper making, including formaldehyde, heavy metals and cadmium.[49] Regulation in the UK and EU has driven improvements in many of these areas, apart from CO_2 emissions.[50,51]

Incremental tightening of pollution legislation, coupled with action to meet net zero targets, could continue to decrease the impact of paper production.

After finding ways to cut use, our three recommendations are:

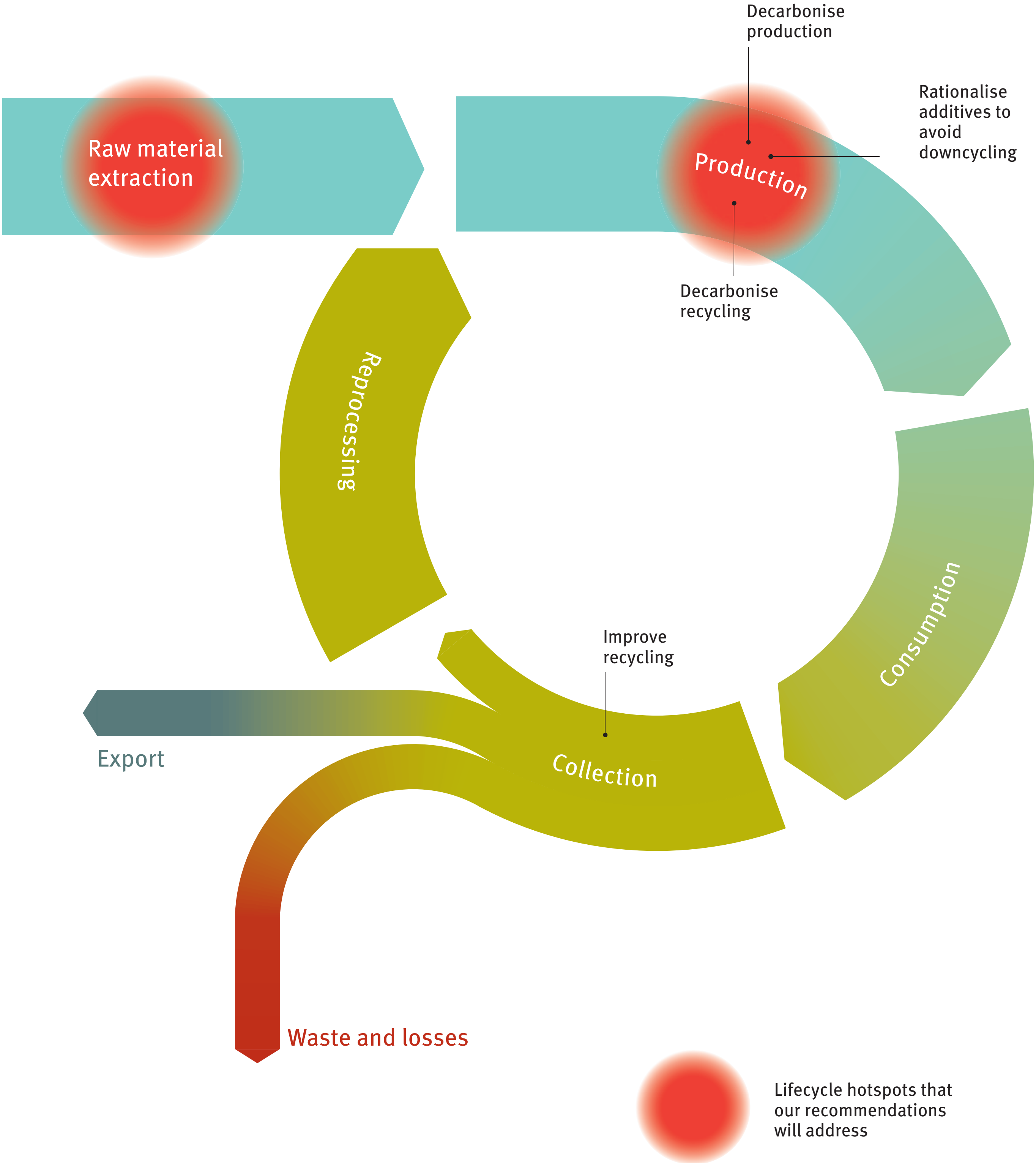
1. **Ensure sustainable forest management.** As pressures on land increase, forests must be carefully managed to ensure they deliver benefits, including removing and storing carbon, enhancing biodiversity, providing recreation opportunities and protecting livelihoods. Organisations such as the UN's Food and Agricultural Organisation (FAO) and the Forestry Stewardship Council (FSC) can help businesses with sustainable sourcing. Demand for sustainably sourced paper in some global areas, like the US and Canada, already outstrips supply, so it will be vital to avoid unsustainable expansion of single use paper products, to ensure forests can be protected and restored.[52]

2. **Decarbonise production.** Mechanical dewatering reduces the need for energy intensive thermal drying. New techniques, like compression refining, can lower emissions by around 20-30 per cent.[53] Using waste biomass to produce combined heat and power on site can lower a plant's fuel consumption by 15 per cent so should be brought in for any plants that lack it. Future pre-treatment processes with enzymes are expected to lower the energy needed for wood processing and reduce the electricity used by 40 per cent.[54]

3. **Design for recyclability.** Recycling rates for paper are already high, but 20 per cent of material in the EU is rejected due to the high concentration of dyes, adhesives and other additives.[55] Better regulation of these could reduce rejections and improve the quality of recycled paper.[56] The logic of designing material for eventual recycling should also extend to cartons which, as our previous research has highlighted, present a particular challenge, given their complex, multi-layer format.[57]

4. **Make the most of by-products.** Potential uses of paper by-products include compost for agriculture, additives in concrete production and coagulants for wastewater treatment.[58]

Aluminium


Decarbonise production
Rationalise additives to avoid downcycling
Raw material extraction
Production
Decarbonise recycling
Reprocessing
Consumption
Improve recycling
Export
Collection
Waste and losses
Lifecycle hotspots that our recommendations will address

Aluminium production is energy intensive and results in environmental degradation and hazardous waste. It is responsible for over one per cent of global greenhouse gas emissions.[59]

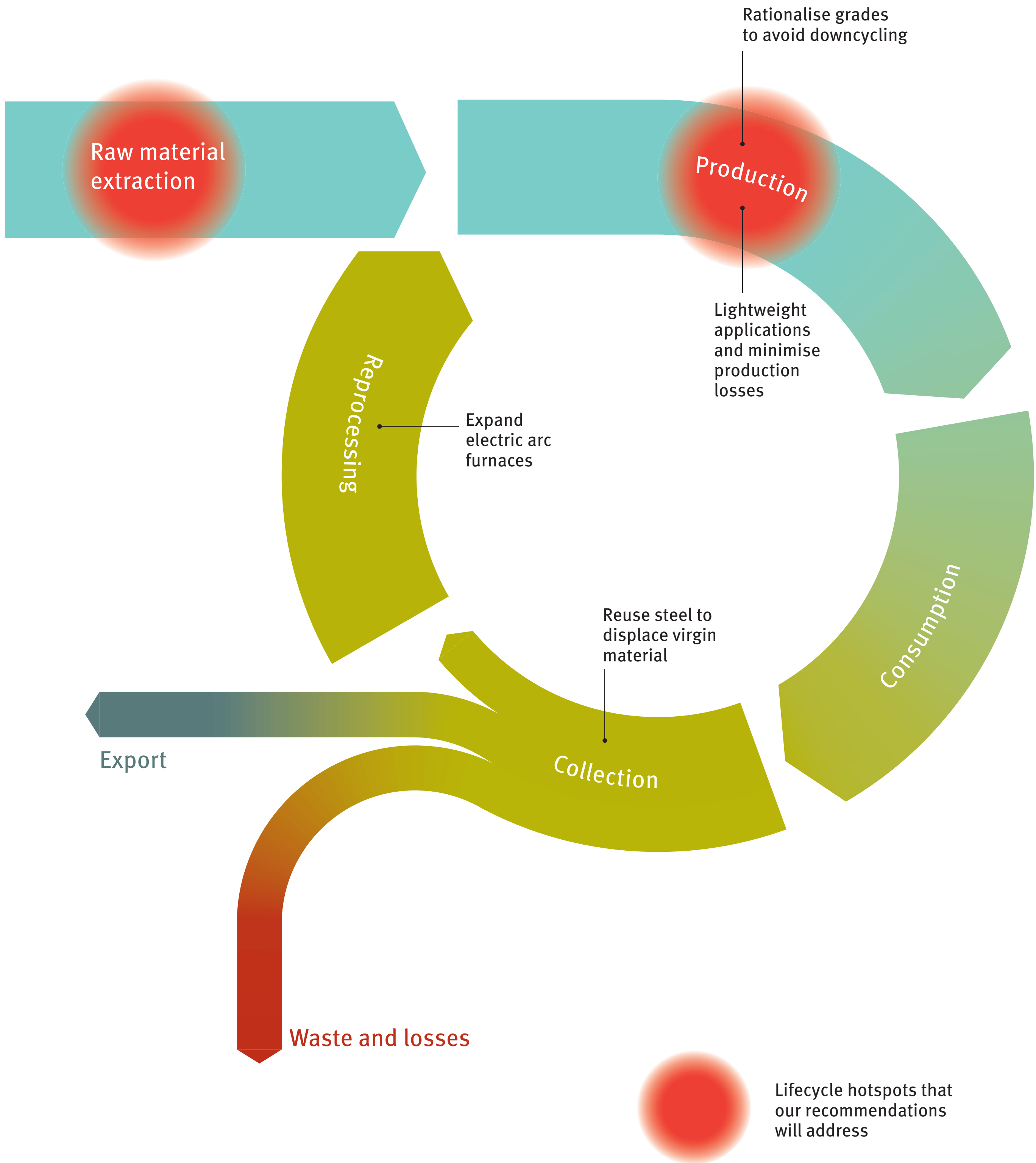
After finding ways to cut use, we recommend improving recycling to displace new primary materials, because production of new primary material requires significant environmentally damaging mining activity and waste generation:

1. **Decarbonise production.** Unlike steel manufacturing (see page 28), aluminium production still offers considerable potential to reduce its greenhouse gas impact. The EU estimates that new production methods, coupled with renewable energy resources, could lower its emissions by as much as 77 per cent, with further incremental improvements from existing facilities as the electricity grid decarbonises.[60]

2. **Avoid downcycling.** Downcycling, or the downgrading of material, happens when different aluminium alloys are processed together, resulting in a product that is not suitable for high performance applications. This can be avoided by using alloys that are more compatible with recycling processes. New sorting technologies, currently at the pilot stage (including laser induced breakdown spectroscopy), offer the potential to sort aluminium into separate streams based on alloy components.[61]

3. **Improve recycling to displace primary production.** If additives are rationalised and separation is improved, aluminium can be recycled over and over again with little loss of quality. We have previously set out a four step system to achieving 97 per cent aluminium packaging recycling in the UK. This can be achieved by creating an 'all in' deposit return scheme to capture most drink cans; improving kerbside services to recover remaining packaging; ensuring best practice at sorting plants, through the addition of robots and extra eddy current separators; and recovering the remainder from incinerator bottom ash as a last resort.[62]

Steel


Rationalise grades to avoid downcycling
Raw material extraction
Production
Lightweight applications and minimise production losses
Reprocessing
Expand electric arc furnaces
Consumption
Reuse steel to displace virgin material
Collection
Export
Waste and losses
Lifecycle hotspots that our recommendations will address

Steelmaking is energy intensive, accounting for a quarter of global industrial carbon emissions and as much as five per cent of total greenhouse gas emissions, which is twice that of aviation.[63,64] Traditional steel production using a blast furnace is now near the limit of what is technically feasible in terms of optimising efficiency.[65] Therefore, opportunities for improvement lie mainly in changing how steel is used and how it is handled at the end of its life.

Steel is becoming a less common component of packaging, so our recommendations focus on its general and industrial uses. Reductions of impact and demand can be achieved by following these steps:

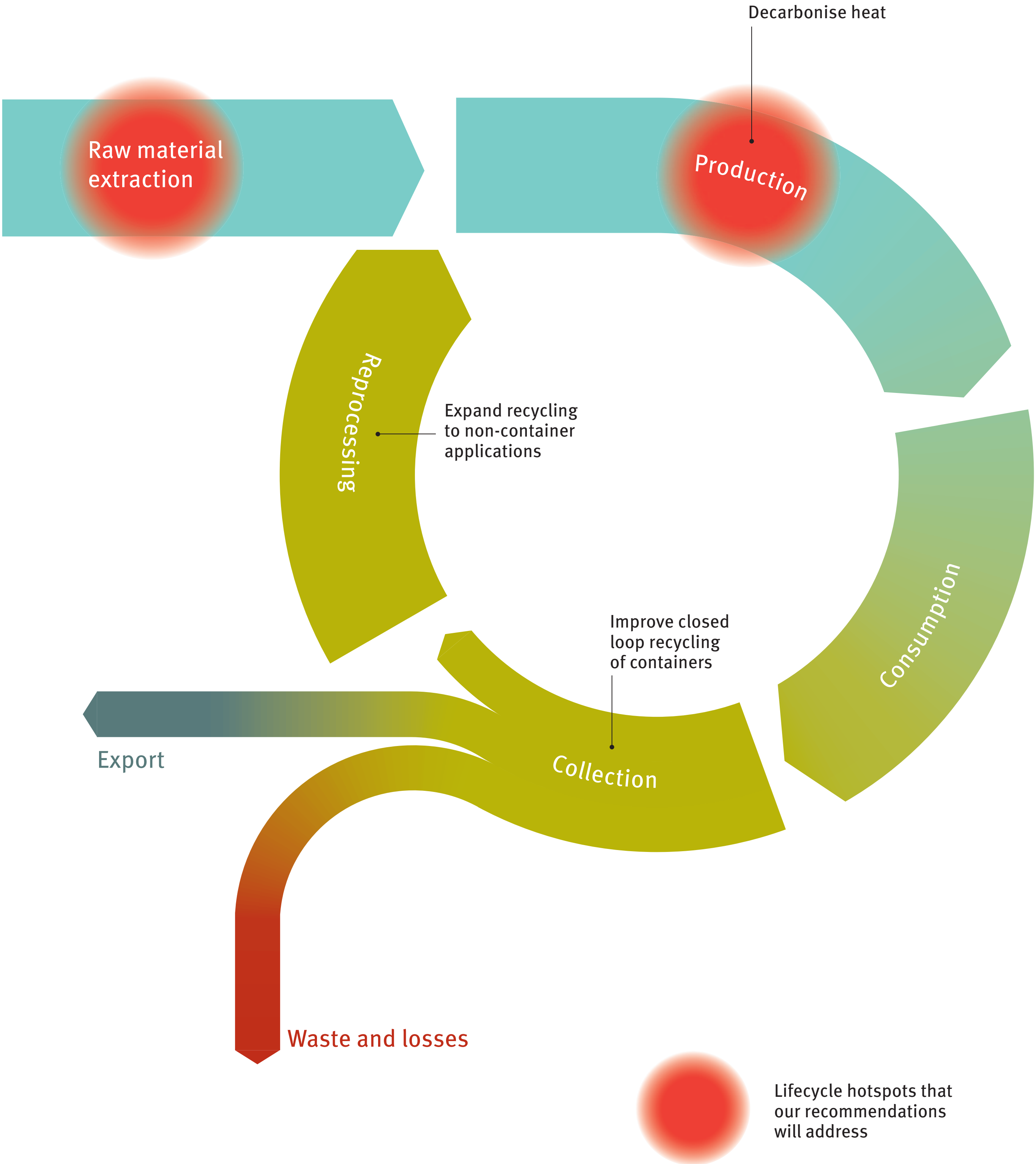
1. **Reuse existing steel.** Currently, only around five per cent of structural steel from buildings is reused, although up to 50 per cent could be.[66] This is largely down to the lack of effective supply chains, materials testing systems and design for disassembly in current applications. Standards or requirements could encourage greater reuse of steel components in construction, where scrap supply is expected to grow. Similarly, increasing refurbishment or remanufacturing in industries like aviation and vehicles would prevent steel going to waste.

2. **Minimise the need to downcycle.** As with aluminium, the number of different types of steel can result in unnecessary downcycling when grades become mixed. According to the World Steel Association, there are over 3,500 grades of steel in use and the small quantities of many of these means it is more likely they will end up as low quality 'rebar' following their first life.[67] Effort is needed to rationalise types as far as possible, and better mark and sort grades to maintain value and limit energy use.

3. **Make products lighter and minimise production losses.** Over engineering during production processes can result in considerably more high carbon material being used than is actually required. The weight of steel in vehicles, where a third of the world's steel is used, could easily be reduced by 45 per cent and manufacturing losses could be cut by ten per cent, for instance.[68]

4. **Expand the use of electric arc furnaces.** Previous Green Alliance research has demonstrated opportunities for the UK to focus on high value secondary steel applications, rather than low value steel, which can be produced much more cheaply elsewhere.[69] The use of secondary steel as an input for electric arc furnaces is limited by the quality and availability of collected scrap. New technologies, such as laser induced breakdown spectroscopy and robotic sorting, could improve this, as could better 'pull' measures to encourage high recycled content.[70,71]

Glass


Decarbonise heat
Raw material extraction
Production
Reprocessing
Expand recycling to non-container applications
Consumption
Improve closed loop recycling of containers
Collection
Export
Waste and losses
Lifecycle hotspots that our recommendations will address

The majority of energy use in the production of glass is at the smelting stage, in which the raw materials (mainly sand) are heated to 1,500°C.

Glass containers are well suited to some reuse systems but, due to their weight, this is only viable if it does not involve long journeys or if transport is powered by renewable energy. Additional research should be carried out into improving glass containers' suitability for reuse, including by decreasing their weight and improving stackability to minimise transport impacts.

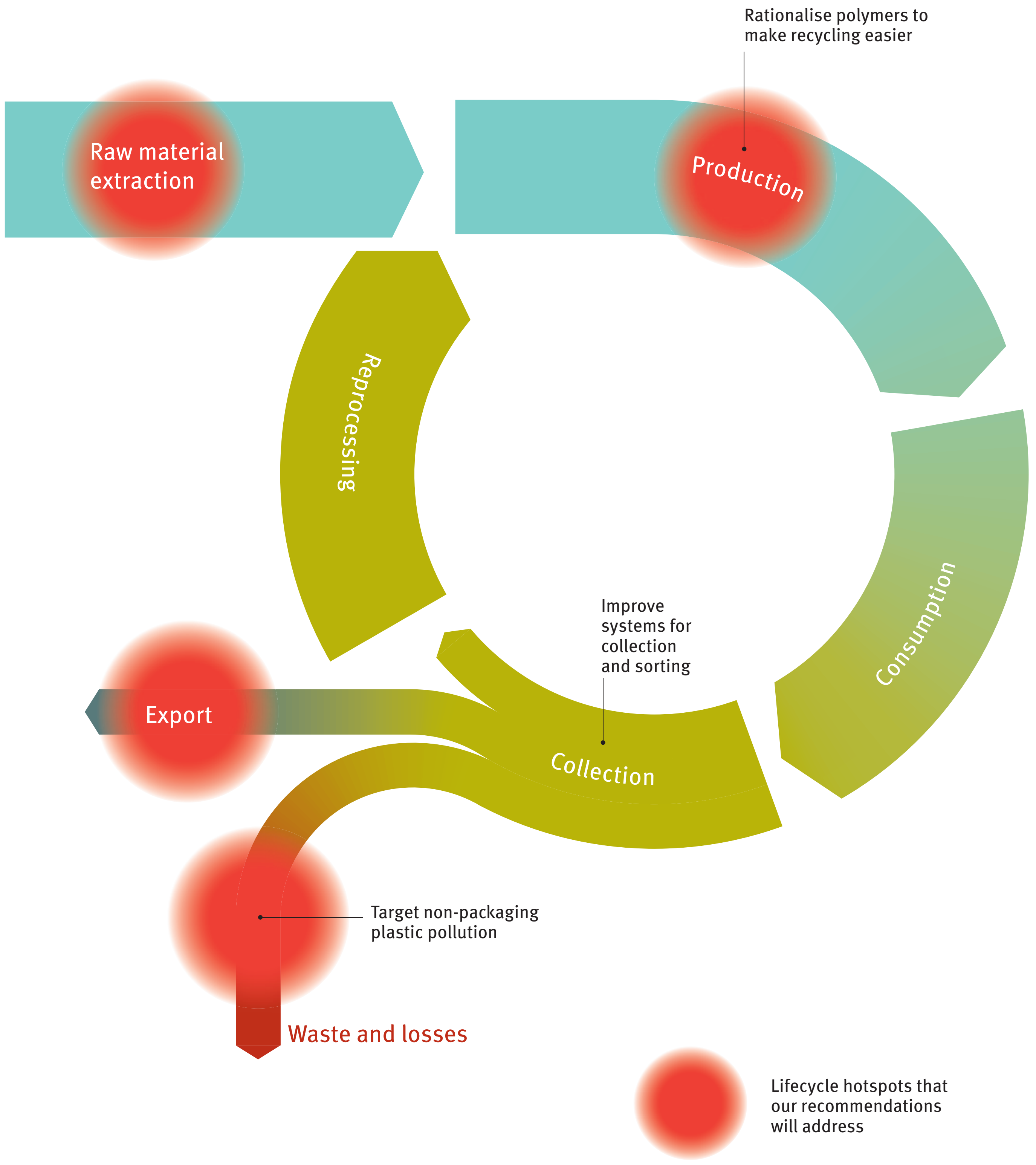
As with aluminium, after reduction in use, our recommendations focus on cutting energy and raw material use through increased recycling, which would also lower the energy demand of production by around 15 per cent:[72]

1. **Decarbonise heat.** The glass sector continues to be reliant on fossil fuels during its high temperature smelting, so heat decarbonisation will be key to ensuring future sustainability. This includes electrification, which a 2015 government roadmap identified as an important future decarbonisation technology for glass.[73]

2. **Improve closed loop recycling of glass packaging.** In the UK, 73 per cent of the packaging glass collected for recycling was made back into glass between 1 January and 1 December 2019, down from 82 per cent the year before.[74] Ensuring that more material is made back into glass should be a priority. Glass collected separately provides the highest quality feedstock, so the government should mandate this and include glass beverage containers in an all-in deposit scheme. Colour separation at source also allows for the best quality without the need for further separation technology, so should be prioritised. If this is not possible, technology can also be used to separate colours for recycling back into glass.

3. **Expand recycling for other glass applications.** Collection and recycling rates for other uses of glass, particularly flat glass used in windows, doors and walls, are relatively low, and have not received the same policy attention as packaging.[75] Where it is recycled, glass recovered from buildings is typically downcycled to be used as aggregate, but the UK Green Buildings Council estimates that closed loop recycling of glass waste from buildings in the EU would avoid 925,000 tonnes of landfill waste and the need for 1.23 million tonnes of primary materials each year.[76]

Plastic



Rationalise polymers to make recycling easier
Raw material extraction
Production
Reprocessing
Consumption
Improve systems for collection and sorting
Export
Collection
Target non-packaging plastic pollution
Waste and losses
Lifecycle hotspots that our recommendations will address

Plastic production processes in Europe are already mature, but greater electrification and renewable energy still has the potential to cut the material's carbon impact by 50-75 per cent.[77]

Rather than focusing on the production process, our recommendations focus on limiting pollution and improving circularity, once usage has been reduced:

1. **Target non-packaging plastic as well:** Most policy attention has gone to single use plastic items and, often, packaging. As this is responsible for two thirds of plastic waste and the largest share of marine pollution, it is a sensible place to focus on reduction.[78] Other notable sources of marine pollution, requiring different policies, include synthetic fibres, tyre dust, fishing gear and pre-production pellets of plastic, known as nurdles. Several of these could be dealt with through extended producer responsibility schemes, combined with resource efficiency standards. For maritime waste, bans on dumping require greater monitoring and enforcement, and the best practice Operation Clean Sweep, aimed at preventing nurdle pollution, should be made mandatory.[79] Other major users of plastic, such as the electronics industry, also require attention. For this, designing for longevity, repair and upgradability will reduce the amount of electronics becoming waste and, therefore, the amount of plastic needed for production.[80]

2. **Rationalise polymer types and uses:** The government has indicated it may ban expanded polystyrene on the grounds that it cannot be easily recycled, but this is not the only type of plastic that poses problems for recycling. Starting with household packaging, where research into recyclability is extensive, the government should consider banning or setting targets for the phase out of non-recyclable uses of problematic materials. According to research by the UK Plastics Pact, these include PVC, styrenes and some multi-layer materials.[81]

3. **Improve collection and sorting:** High quality, source separated material is needed for high quality recycled content. At the moment, downcycling to lower grade applications is common. Several government proposals could improve this in the UK, including standardising recycling systems across the country and the all-in deposit scheme.[82] To prevent contaminated and poorly sorted waste, the origin of much plastic pollution abroad, the Environment Agency needs adequate resources to regulate waste shipments.[83]

Making a success of bio-based and compostable plastic

As novel materials, like bio-based and compostable plastic, are being speedily developed and introduced in the UK, consideration of their full lifecycle impacts should be an inherent part of the process.[84] Here, we set out some important considerations and guidelines to avoid problems at each stage of the material cycle.

Raw material extraction Evaluate material availability and impacts

Bio-based plastics currently require little of the world's agricultural harvest, but this could change if their use expands to the extent some have predicted and virgin crops are used.[85] Agricultural waste and food by-products offer alternative feedstocks, which could be cheaper and require less land and fertiliser. However, seasonal variations could require multiple sources for year round supply and alternatives like forestry residues have much lower yields than dedicated energy crops and can require energy intensive pre-treatment.[86] And while using bio-based feedstocks to make plastic may offer greater CO_2 savings than using it as fuel, this must be balanced against competing claims on land for food, fibre, afforestation and biomass for energy.[87]

Success criteria

Do not displace food production. Biomass feedstock should come from land which does not compete with food production. Wastes and by-products should be preferred as feedstock.

Use local feedstocks wherever possible. Local material will avoid transport emissions, and environmental and socioeconomic harm in developing countries, including from deforestation.

Production Understand and prevent impacts

Bio-based alternatives can have lower carbon impacts than conventional plastic, but this is not guaranteed. Variations can occur because of farming practices, technologies used, energy and raw material differences. Before new materials are introduced, impacts beyond global warming potential, like the impact of increased fertiliser use, need to be understood to ensure sustainability and the safety of chemicals used in all material needs to be ensured. At present, there is limited research into novel plastics beyond the most common, like bio-PET and PLA.[88]

Success criteria

Prioritise and verify greenhouse gas emissions reductions and environmental improvement. Any claims made should be verifiable, through a lifecycle analysis conducted to ISO standards.

Prevent persistent organic pollutants entering the food chain. Compostable material should not be allowed to contain harmful chemicals that can enter the human food chain or the wider environment through contamination of compost.

Consumption Simplify uses

Compostable plastics could offer a solution in situations where reduction and reuse cannot be achieved and recycling is unlikely, such as for plastic films, or food contact materials likely to become contaminated. But this is unlikely to work if conventional and compostable materials are used simultaneously for the same applications and are difficult to distinguish from each other. Evidence suggests there is also public confusion about definitions like 'compostable', 'bio-based' and 'biodegradable'.[89]

Success criteria:
Limit or mandate some applications. Greater government control over the use of novel materials can reduce consumer confusion and lower contamination rates for recycling businesses and composters. The system would work better, for instance, if all rigid plastics were mechanically recyclable and all films, especially those likely to come into contact with food, were compostable. The government should also consider colour coding types of materials to facilitate sorting by both households and treatment facilities.

Collection Ensure separate infrastructure

At present, many compostable materials are incinerated or landfilled due to a lack of collection and treatment infrastructure.[90] Materials should only be introduced where separate collection infrastructure will allow them to be properly and easily handled at end of life.

Success criteria
Only use materials where appropriate collection and treatment infrastructure exists. This would prevent contamination that harms both conventional recycling and composting streams.

Make sure materials can be recycled cost effectively. The government should align product guidelines and producer responsibility regimes with EU targets which require all plastics placed on the market to be recyclable in a cost effective manner.[93]

Reprocessing Evaluate against real life conditions

Even certified compostable plastics, especially rigid materials, do not necessarily degrade in the UK's composting infrastructure, as standards allow for longer treatment times than are actually practiced.[91] Standards for compostability should be reviewed following testing in real life conditions.

Success criteria
Develop and enforce better compostability standards. Only certified materials should be allowed on the market, and these must be tested against real life conditions.

Waste and losses Avoid pollution

Bio-based plastics that mimic the chemistry of conventional plastics pose exactly the same problems when littered. And, while some bio-based plastics will have shorter lifespans in the marine environment, some that are compostable under certain circumstances, like PLA "will behave like conventional plastics and fail to degrade", according to the UN.[92]

Success criteria
Bio-based and compostable plastics should not be promoted as solutions to plastic pollution. The aim should be to eliminate leakage and loss of all materials.

These success criteria are explored in more detail in annex two (page 53).

The health risks of food packaging

One aspect of material use that has not received the attention it deserves is exposure to potentially harmful chemicals from packaging. Along with the impacts of pollution, there is justified growing public concern about the presence of harmful chemicals in plastic. These can include intentionally added substances, like phthalates and bisphenols, which have known risks including endocrine disruption and cancer.[93] Contamination can also come from compounds created by the production process and legacy chemicals in recycling. Although many companies have voluntarily removed some harmful substances, many have not.

And this is not just a concern in plastic. Bisphenol-A (BPA) is used in the internal coatings on aluminium and steel cans and tins to prevent corrosion. While many manufacturers are voluntarily removing it, some are not, and there are concerns that it is being replaced by other bisphenols, which may carry the same health risks.[94]

Likewise, over 250 chemicals with potential health concerns, including phthalates and bisphenols (used in adhesives, inks and thermal paper) have been detected in recycled cardboard used for food packaging and can migrate into food.[95,96,97] Cardboard and other compostable materials are also sometimes lined with per- and poly-fluoroalkyl substances (PFAS). Research in December 2019 showed that PFAS is found in food packaging on sale in each of the nine major UK supermarkets sampled, as well as many takeaway outlets.[98] This group of toxic chemicals is used to improve water resistance, but it is linked to health problems, including high cholesterol, lowered fertility and testicular cancer. Its presence in compost is especially worrying as PFAS can migrate into food and accumulate in humans.[99,100]

Regulation in this area has been led by the EU. On the one hand, substances in many plastics are regulated, but the regulations have become outdated with the development of materials. On the other, many alternatives to plastics, including paper, card and linings, are not covered by harmonised regulations, beyond a general requirement that they do not endanger health.[101] This is concerning given the danger of human exposure to hazardous chemicals in food packaging and the potential that recycled material and compost could be contaminated by legacy chemicals.

Our recommendation is that the shortcomings in the current regulations for food contact materials should be addressed as a matter of extreme urgency. To employ risk-based standards, the government should mandate the disclosure of the chemical identity and concentration of the different additives used. Substances of very high concern should be banned from food contact materials, and the government should follow the example of the Danish ministry of the environment, which has banned PFAS in all food packaging.[102] It should also introduce enhanced testing regimes to ensure contaminated recyclate is removed from circulation.

In annex one (page 52), we summarise the potentially harmful compounds in common food contact materials, and suggest steps to remove these compounds or mitigate their associated risks.

Infrastructure and incentives for reuse

“Systems for reusing packaging offer opportunities to reduce the quantity of materials used and their environmental impacts, but only if they are designed well.”

Creating a more circular economy will require careful consideration and planning of the right infrastructure.[103] In this section, we examine the requirements for reuse systems for packaging. Such systems are already being promoted by many campaigners and investigated by many businesses. Along with government, they should consider the following principles to ensure success.

Making a success of reusables

According to the Ellen MacArthur Foundation, converting the need for 20 per cent of global disposable plastic packaging to reuse models instead is a $10 billion (£7.5 billion) business opportunity.[104] Small changes are occurring in some UK supermarkets, including Waitrose’s ‘Unpacked’ trials and other small scale initiatives allowing shoppers to reuse containers for fresh produce and at deli counters.[105] As they are rolled out more widely, systems for reusing packaging offer opportunities to reduce the quantity of materials used and their environmental impacts, but only if they are designed well and used as intended.

To avoid unintended consequences and ensure customer buy-in, we recommend the following factors are considered as new reuse systems are developed:

Get the delivery system right for each product
In-store refill may work for products like dry, long lasting foods, but it is not suitable for everything. For short-lived products, like fresh fruit juices, either different delivery systems should be developed or refill should happen at the factory to ensure shelf life can be maintained and to avoid a rise in food waste and food safety issues. (Different systems for reuse and refillable packaging are described in annex three (page 54)).

Make it easy and attractive for consumers
Previous studies have shown that shoppers are more likely to use refill options where the product is good value and creates less waste, and where dispensers are clean and easy to use.[106] Cost can play a role in making them more attractive, which is something being addressed by the supermarket chain Morrisons, where loose and refillable options are ten per cent cheaper than the packaged equivalent.[107]

Prevent increases in material use
The introduction of the UK’s single use carrier bag charge, has resulted in a perverse trend towards repeat purchasing of thicker ‘bags for life’.[108] Reusables could follow a similar path if, for example, consumers forget to bring their high quality reusable containers and end up buying multiple replacements.[109] Getting the container and product price right, and embedding the right incentives and behaviours, will be crucial. Systems should be carefully tested before widespread introduction.

Develop new information systems
Some delivery models, like in-store refill, will require new ways of providing information on use by dates, cooking instructions or allergens. Legally required information might need to be included on labels attached to weighed containers, but digital technology could also play a role, eg using QR codes that can be scanned for more information.

Design all containers for recycling
Guides on designing for recycling are common in the packaging sector, but these are so far focused on single use. If we are to move to reusable systems, end of life considerations should be factored in from the start. This means containers would ideally be designed for durability as well as eventual recycling. Silicone, for instance, is not currently recyclable, so its more widespread use could cause problems down the line.

Standardise across brands wherever possible
To aid logistics and smooth operations around collection and sorting, reusable packaging designs should be standardised across brands and value chains, which could require an adjustment to relevant competition laws. Research indicates consumer frustration at incompatibility between refill systems.[110] Standardisation would facilitate shared logistics and cleaning facilities across brands, sectors or wider networks. These could theoretically be provided by third party packaging and service companies.[111]

Developments in plastic recycling technology

> "Contamination and mixing of polymers results in recycled plastics of lower technical and economic value than virgin materials."

As with their compostable counterparts, conventional plastics also require the right collection and treatment infrastructure for when use cannot be avoided through redesign or new product delivery models.

With the shortcomings of the current approach well understood, different forms of chemical recycling are being touted by some as vital to the future, even offering "endless…possibilities for creating new products".[112] In the following section, we examine what is meant by chemical recycling and propose a hierarchy of recycling technologies that should guide infrastructure development.

Today, nearly all plastic recycling is mechanical. This means waste plastics are treated through processes like shredding, grinding and melting to form new plastic products with the same chemical composition. This sort of recycling requires separation by polymer type (eg HDPE, commonly used for milk bottles, or PET, used for fizzy drinks bottles).

Currently, contamination and mixing of polymers results in recycled plastics of lower technical and economic value than virgin materials.[113] Currently, plastics can also only be recycled a few times because mechanical processes degrade their properties, for instance by shortening polymer chains, which weakens them.

Novel recycling processes

Novel recycling technologies are being touted as part of the solution to plastic pollution. Some have the potential to enhance mechanical recycling, while others offer new forms of 'chemical recycling'. We have categorised them below into four main forms, although the terminology to describe each sometimes varies:

Chain lengthening: The physical process of rebuilding polymer chains is technically possible at various stages of the mechanical recycling process: when the polymer is molten after extrusion, before the polymer is extruded or after extrusion.[114]

Solvent based purification or dissolution: Polymers are dissolved in solvent to remove contaminants like additives or dyes.[115] The technique could theoretically treat plastics such as PS and PVC better than typical mechanical recycling, although it should be noted that momentum is building to stop using such polymers entirely for some applications.[116]

Chemical depolymerisation or decomposition: This form of recycling involves chemically breaking down plastic into monomers or intermediary units. These can be purified to remove unwanted compounds and then repolymerised into plastics with the same properties as virgin material.[117]

Thermal cracking or conversion, often called 'feedstock recycling': This process, most commonly done through pyrolysis, sees plastics converted at high temperature into shorter chain hydrocarbons split into different fractions which can either be used as a feedstock for polymer production or as a fuel, similar to light sweet crude oil.[118] However, it cannot be classed as recycling if the output is used as fuel. As a recycling technology, it is potentially more resilient to low oil prices than other forms of recycling, but the final yield of useable polymers from this process could be as little as ten per cent.[119,120]

A hierarchy for plastics recycling

Chemical recycling technologies are relatively new and, as such, have not had the considerable development and deployment at scale of mechanical recycling. Given their energy and chemical requirements, simple mechanical recycling is preferable in most cases, where it is possible.

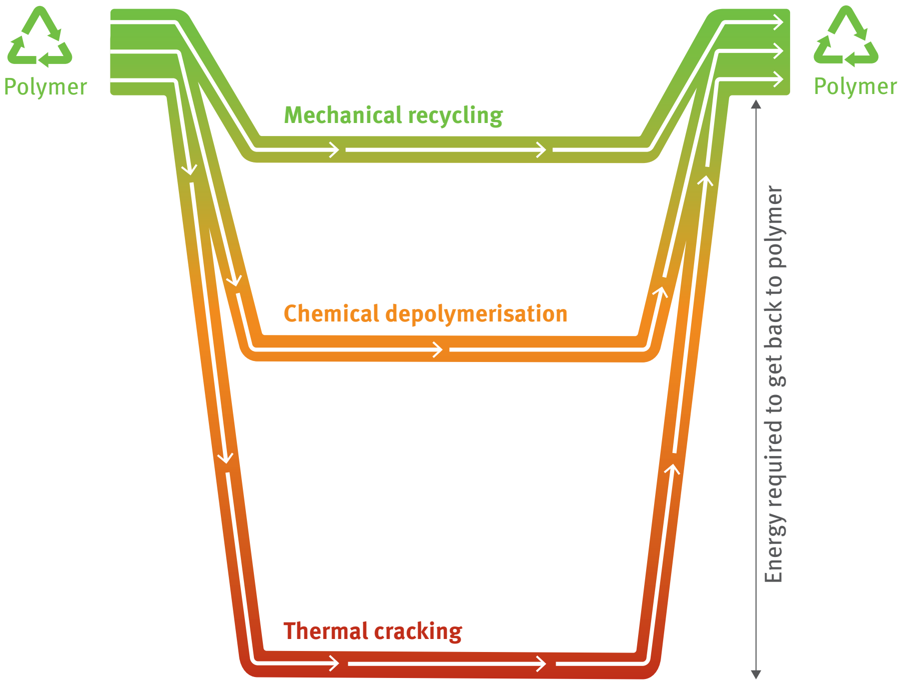
As the image below shows, a general hierarchy for plastic recycling would keep material circulating at the highest value, using the least energy for the longest time, while also countering degradation.

Mechanical recycling
This process is preferred because of its lower energy requirements, its mature technologies and existing infrastructure.

It could be enhanced by the addition of chain lengthening and solvent based purification processes, to maintain mechanical properties for multiple recycling loops and expand the range of plastics that can be recycled.

Chemical depolymerisation
This offers the most potential for polymers which cannot be mechanically recycled due to contamination. Until its energy and chemical requirements are fully understood, it should not compete with existing mechanical recycling streams.

Thermal cracking
This should be approached with caution and only used in limited circumstances where material is too degraded for other recycling processes.



These three technologies are potentially suitable for different polymer types, and could help to keep material in circulation for as long as possible.[121] As a principle, material should always undergo the least energy intensive and most appropriate processes possible, and only recycling processes that ultimately save energy and conserve resources, compared to primary production, should be used.

"To get the infrastructure right, the government first needs to understand material flows."

Infrastructure requirements

Investment in better recycling technologies should not detract from the primary aim of reducing use of materials overall in the first place and improving design early on in the material cycle. To get the infrastructure right, the government first needs to understand material flows and judge likely future developments, to evaluate need and avoid the negative consequences of technology lock-in and path dependency.[122]

Technologies that enhance current practices should be prioritised, including those that can demonstrate the best carbon savings.[123] Careful consideration should be given to the location of plants. Pilot solvent-based recycling plants, for instance, have been co-located with mechanical recycling facilities to limit transportation and ensure the technologies do not compete.[124] Similarly, pyrolysis products are only likely to be used to make virgin plastics if they are located close to a plastic facility. This type of synergy should be encouraged so that new technologies can work within, rather than against, existing infrastructure.

Building on the plastics tax

In the 2018 budget, the chancellor promised to introduce a "world leading" tax on plastic packaging.[125] In combination with other measures on plastics set out in the resources and waste strategy, and various voluntary agreements from businesses, this has led to an increase in investment in plastic recycling facilities in the UK.[126]

This shows how fiscal measures can influence developments. In this section, we examine how the plastics tax should be adjusted to align better with the government's ambitions, and what other financial incentives could be employed to improve wider resource use.

Essential fixes

The government's proposed tax on packaging that has less than 30 per cent recycled content seeks to redress market balances that have disadvantaged recycled content. Draft legislation is expected this year, and it is likely to come into force by 2022.

Before it does, it needs two essential fixes:

Include imported filled packaging. An exclusion for filled packaging would encourage multinationals with access to global supply chains to shift production of both packaging and products abroad. This could damage the UK economy.

Introduce differentiated obligations. Recycled content is easier to achieve for some polymers than others. A single obligation will encourage gaming and switching between polymers. For example, manufacturers could reduce recycled content in packaging already exceeding the threshold so they can increase it elsewhere, resulting in no overall increase.

Increasing ambition

The following actions would encourage innovation in the plastic recycling sector and improve the effectiveness of the tax in driving recycled content:

Introduce an escalator: The 30 per cent recycled content target is unlikely to drastically increase ambition, as the UK Plastics Pact is already targeting an average of 30 per cent recycled content across all plastic packaging by 2025.[127]

Ramping up ambition could be achieved through an escalator, like that used effectively for landfill. The escalation could be on the rate of tax, the percentage of recycled content needed to avoid the tax, or both. UK businesses would benefit from a long term trajectory to help domestic supply chains increase recycled content and avoid being locked in to foreign supply chains. This would also encourage technology developers to overcome barriers to higher recycled content use.

Introduce a stabilisation fund: The relative effectiveness of a flat tax is likely to change according to market conditions. These include seasonal variations for plastic prices and fluctuations in oil prices.[128,129]

Analysis by McKinsey suggests that below $65 per barrel of oil "the economics of mechanical recycling become more challenging" and chemical recycling might become unprofitable below $50 a barrel.[130] It is difficult to predict what future prices will be. The central assumption made by the Department of Business, Energy and Industrial Strategy (BEIS) for the years 2030-35 is $78 a barrel. But its stress test of $35 a barrel could be more realistic, given global moves to stop burning fossil fuels, combined with a glut of cheap shale gas.[131]

A price stabilising mechanism could derisk investments in reprocessing and ensure that recycled content, as the more sustainable option, is always cheaper than virgin material. The fund would absorb money when recyclate prices exceed an upper threshold and release money when prices fall. Potential sources of funding for this idea include reprocessors, producers, the extended producer responsibility (EPR) system, unclaimed DRS deposits or revenue from the plastics tax. Ensuring that income closely matches outlay will be essential.

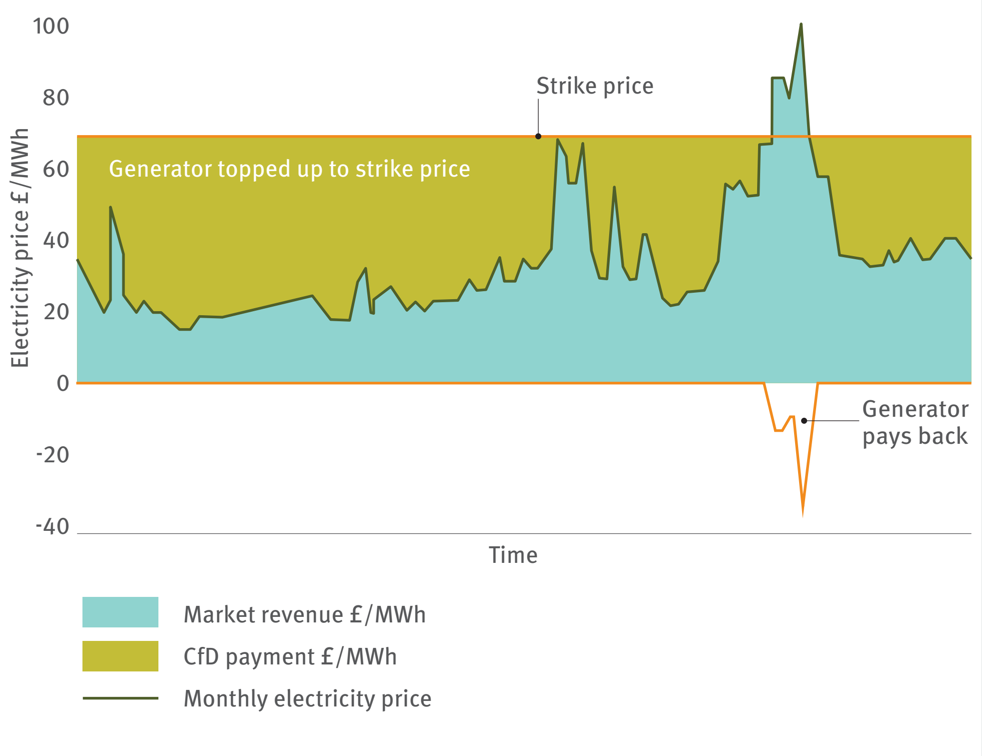
Introduce contracts for difference: A more interventionist approach would be to introduce contracts for difference (CfDs) for recycled content, modelled on the system used in the renewable energy sector.

Translating this to plastics could increase the speed at which new recycling technologies come online, while also enabling supply chain investment that would reduce the final cost of reprocessed material. Reprocessors would be awarded contracts based on an auction. They would be paid the difference between the 'strike price', which would reflect the cost of investing in a recycling technology and generating recycled material, and the 'reference price', a measure of the average market price for plastic in the UK, which would vary by polymer type. Funding could come from the same sources as the stabiliser described above.

How contracts for difference have helped the renewable energy market

Contracts for difference (CfDs) for renewable energy are funded by a compulsory levy on all licensed energy suppliers in the UK, based on their market share. Renewable energy generators are awarded 15 contracts at auction with the Low Carbon Contracts Company (LCCC), an independent, government owned company.[132] Renewable energy generators are paid the difference between the 'strike price', a price for electricity reflecting the cost of investing in a particular technology, and the 'reference price', a measure of the average market price for electricity in the UK.[133] When the market price exceeds the strike price, generators pay back the difference. This competitive approach has encouraged innovation and has reduced the cost of clean energy. Renewables are now the cheapest form of new energy in the UK.[134]

How the CfD system works for renewable generators[135]



"Virgin material taxes should be on the government's net zero agenda."

Radical option: virgin material taxes

Regardless of any adjustments, the plastics tax, as currently envisaged, will only drive recycled content in plastic packaging, which is a small proportion of material use in the economy.

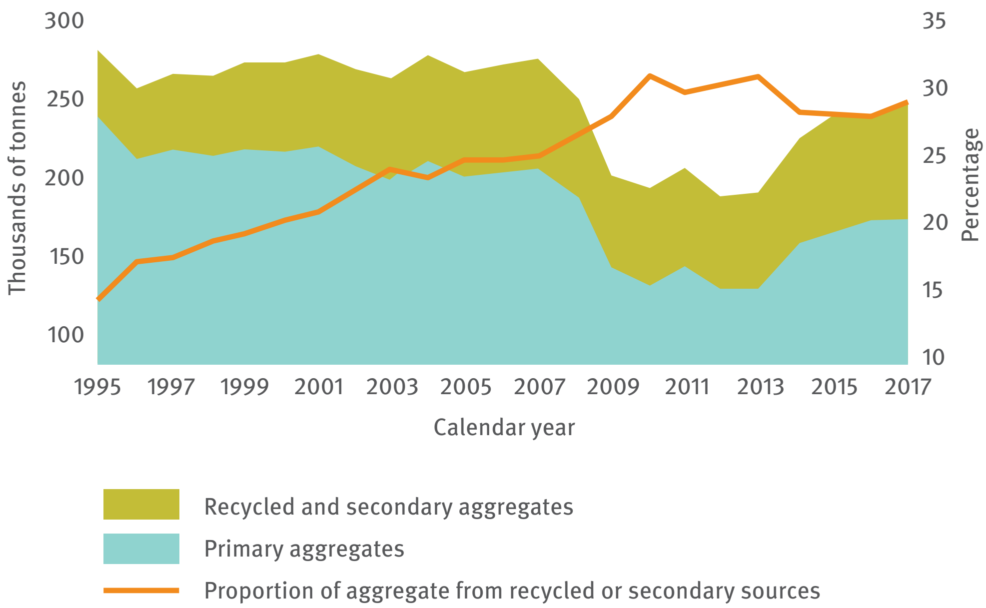
Fiscal measures could be used much more ambitiously to drive the better use of resources, moving beyond plastic, beyond packaging and beyond recycling to target lower material use.

Virgin material taxes should be on the government's net zero agenda. These have already been used widely across Europe, though predominantly for sand, gravel and rock extraction. And there is already a precedent in the UK. Introduced in 2002, the aggregates levy is one of the most effective material taxes in Europe. It involves a tax of £2 per tonne on domestic and imported aggregate and has driven recycled content above 30 per cent in the UK, compared to around ten per cent in countries in the EU.

This type of national taxation is most suited for metals and minerals extracted and traded at the local level, but is more complicated for global trading.[136] An approach is needed that taxes virgin materials to reflect their global impacts. Given the strong link between resource use and climate change, it might make sense to use carbon as the proxy. In the UK, for instance, the 30 economic sectors (out of 106 categories) that account for 80 per cent of the total carbon footprint, also account for 80 per cent of the total material footprint.[137]

With the UK due to host the next UN climate talks in November 2020, it has the perfect opportunity to lead global discussions on introducing this approach to encourage greater resource efficiency across the world.

The aggregates levy has increased recycled content[138]



Innovation in private financing: Casella Waste Systems[139]

Innovative fiscal arrangements can be used by private companies as well, in the absence of government action or to complement regulation.

Casella Waste Systems, for instance, operates in the north east United States, in a market where many refuse collectors operate recycling services as a loss leader for other services.

The company wanted to develop a business model to make recycling more financially sustainable. Initially, it attempted to broker long term contracts for recycling collections to fix future income in the face of volatile markets. However, this arrangement only proved successful for high value aluminium, meaning further investment in paper and plastics recycling was difficult to justify.

Instead, the company developed a variable pricing mechanism whereby its customers are charged a 'sustainability recycling adjustment fee' based on the monthly market prices for recycled commodities and fixed costs, including transportation. Through this mechanism, the company passes on 90-93 per cent of risk to the consumer, though the fee only varies between four and 15 per cent of the customers' bills. (The 15 per cent peak was reached when commodity prices crashed at the time China, which had previously accepted much of the world's recycling, stopped accepting shipments in 2018.)

Initially, the added charge made the company less competitive than its rivals when bidding for contracts, but it has since become standard for larger recycling companies in the area. Customers have been receptive, as similar approaches have been adopted by airlines, via fuel surcharges on tickets, contributing to a growing awareness of the need to share out risks to deliver sustainable services.

Conclusion

“Heightened public awareness provides policy makers with a unique mandate to change the direction of travel and reduce the environmental burden of our resource use.”

Unsustainable resource use, high consumption levels and a ‘throwaway’ society have become entrenched in the UK over decades. The toll on the environment was reflected in the joint climate and environment emergency declared by the UK parliament in May 2019.

The public is increasingly demanding solutions. Concerns include the wider issue of climate change as well as the specific issue of plastic pollution. This heightened public awareness provides policy makers with a unique mandate to change the direction of travel and reduce the environmental burden of our resource use.

This requires fundamental system change to decrease the emissions, health impacts and degradation of the natural environment caused when resources are extracted, processed, transported and used. It means avoiding materials becoming discarded waste wherever possible and repurposing them for continual use in a truly circular economy.

Above all, as we have shown, we must learn the lessons of the past and avoid simply replacing our current environmental problems with different harms down the line. Rather than piecemeal substitution, that requires an overarching focus on reduction: reduction in the overall levels of material use, in lifecycle impacts and in the damage that different materials can cause.

This year, 2020, has been hailed a ‘super year’ for the environment, providing plenty of opportunities for the UK to make significant progress in its efforts to tackle climate change and improve outcomes for the natural environment. This chance for a step change in the way we manage resources should not be missed.

Annex one
Compounds present in common food contact materials and actions to limit risk[140]

Material type	Type of contaminant/ substance of concern	Likely origin	Risk	Recommendations
Plastics	Additives, such as antioxidants, UV absorbers, plasticisers and their degradation products	Intentionally added, though products of degradation are also likely to be present	Hard to quantify risk due to lack of available information, but many known additives are endocrine disrupters	Require producers to disclose the identity and concentrations of additives Focus on removing compounds harmful to health so they do not enter recycling loops
	Production process contaminants such as monomers, oligomers and catalysts	Incomplete purification processes during production	The catalyst antimony has been found in recycled and virgin PET, and other heavy metals have been detected	Further research on migration and health risks Better cleaning processes during recycling
	Contaminants from non-food grade materials, such as flame retardants	Mixing of food grade material with non-food grade plastics, coupled with poor sorting	Very high risk, as these compounds have been specifically banned for food grade applications	Ban use in products which may end in recycling Clear labelling More rigorous separation at the collection and sorting stages, potentially enabled through tracers
	Food compounds	Carry over of adsorbed food compounds during the recycling process	Can interfere with recycling processes	Improved cleaning processes Limit the use of some plastics for applications that are likely to be contaminated by food
Paper and cardboard	Mineral oils	Inks, particularly from newspapers	Potential carcinogens and liver toxicity	Switch to vegetable inks Enhance deinking processes in recycling
	Bisphenols	Thermal paper, inks and adhesives	Endocrine disrupter	Restrict use Seek benign substitutions
	Phthalates	Inks and adhesives	Endocrine disrupter	Restrict use Seek benign substitutions
Compostable materials	PFAS	Intentionally added as a barrier to liquid	Endocrine disrupter Potential carcinogen	Restrict use Seek benign substitutions
Bio-based materials	Allergens*	May be present in some initial animal or plant based feedstock or generated through processing. Particular concerns include proteins like casein and gluten	Very limited information is available on the presence or impacts of allergens in bio-based FCMs or the potential for these to transfer to food	Urgent assessment of the impact of potential allergens, as well as heavy metals, persistent organic pollutants and natural toxins Restrict market access until material is proven safe
Aluminium and steel	Bisphenols	Intentionally added as a barrier to reduce corrosion	Endocrine disrupter	Restrict use Seek benign substitutions

* This is not strictly a contaminant, but a particular concern that emerges from making packaging out of natural substances or agri-food by-products that some people may be allergic to, like gluten.

Annex two
Guiding principles for bio-based and compostable plastic

Criteria	Comment	What is needed?
Food production should not be displaced	There are large and competing demands on land suitable for growing crops in the UK, including food provision and afforestation to meet climate and biodiversity targets. Any biomass to create bio-based plastic should therefore come from land that does not compete with food production, ideally wastes and by-products. Further research and development is needed into lignocellulosic feedstocks that can lower the energy requirement of producing bioplastics from lower quality feedstocks. An assessment of the potential for grass crops to be grown on marginal land is also needed and could provide a new source of income for farms in less favoured areas.	Research into lignocellulosic feedstock A survey to determine UK grass resources and competing uses
Local feedstocks should be prioritised	Transport emissions and costs will be disproportionally high if low energy-density biomass is shipped around the world, meaning emissions savings are unlikely to be achieved. There is also the risk of deforestation or other land use impacts if production occurs in developing countries.	Account for transport in lifecycle analyses (LCAs) Certification of feedstock Ban on using some materials
Greenhouse gas emissions reductions should be targeted and verifiable	Bio-based plastics can offer lower greenhouse gas emissions than fossil-based plastics, however the data on the full lifecycle are sparse. It is therefore necessary to review these claims as more data becomes available on, for example, end of life scenarios, and as the domestic industry for biomass and bio-based plastics grows. At the same time, other impacts, including those from increased fertiliser use must be quantified and monitored.	Standardised and verifiable LCAs, in the first instance to ISO standards
Persistent organic pollutants (POPs) should not be allowed to enter the food chain	Where plastics are biodegradable or compostable, it is essential that they do not include chemicals which may pose a risk in the human food chain or in the wider environment. This has already been demonstrated for the PFAS family of chemicals, which are used as waterproof coatings for food containers made from materials including paper and card. These have been found in high concentrations in composting facilities that accept compostable food containers. Strong regulation will be required to ensure that compost remains free of POPs.	Regulation and enforcement to prohibit use in food contact materials
Better standards should be developed and enforced	The EN13432 standard for industrial compostability allows six months for near complete degradation of compostable material (90 per cent conversion to CO_2). Such lengthy treatment times are not realistic for operators of industrial composting facilities, and we have spoken to many who have problems with current materials marketed as compostable that do not break down. Standards that meet realistic conditions are required for both industrial composting facilities and, increasingly, home composting.	Standards for degradation in real life conditions Restriction of materials that do not meet the standards
Material should only be used where infrastructure exists	Adoption of compostable containers before the necessary collection and treatment infrastructure is in place is already leading to the material simply going to incineration or landfill, meaning the intended benefits of composting at the end of life stage are not being realised. As well as ensuring infrastructure development, current research and development into tagging systems to aid sorting by material at materials recovery facilities (MRFs) looks promising and should be pursued as a priority as more materials are placed on the market.	Clarity on the use of terms Development of new sorting mechanisms Strategic investment in required infrastructure
Material should be recyclable in cost effective manner	At present, many products placed on the market are not recyclable in a cost effective manner, in some cases even where collection is provided, including multilayer materials and films. The government should align product guidelines and extended producer responsibility practices with the EU plastics strategy that includes a target for all plastic being placed on the market to be recyclable in a cost effective manner. This should guide the market towards materials which fit into existing recycling streams (eg bio-based versions of existing plastics) or to materials for which high value recyclate is feasible, if collection and separation infrastructure is available.	A focus on drop in bio-based plastics, which can lower carbon of conventional plastic if it cannot be eliminated Development of separate collection and treatment streams
The government should explore the limiting of applications	Greater government control over the applications that novel – and other – materials are used for is the fastest way to achieve a systemic approach. This has been demonstrated to an extent in Italy, for instance, where all carrier bags are now made from compostable material which can facilitate household food waste collections. This limits confusion for consumers and lowers contamination for recyclers. Another option is to colour code types of materials to facilitate sorting at both the household and treatment facilities. If all compostable plastics were a standard colour, such as green or bright pink, and that colour could not be used for non-compostable plastic, material would be easily identifiable and contamination would be lower.	Command and control, including standardised applications and colours

Annex three
Types of refill systems

Reuse System	How does it work?	Strengths	Weaknesses	Example
Store refill	Customers refill their reusable containers at in-store dispensing machines. Product types, including food and drink, home and personal care products, are especially suitable for this model.	Elimination of single use customer facing packaging. Buying small quantities of products at affordable prices can reduce food waste and also benefit customers on low incomes. Businesses' tertiary packaging costs can be cut, as can related emissions and material use.	User behaviour will need to change, and some find cleaning and remembering containers a hassle. Retailers are concerned about contamination and quality control, if containers are not properly cleaned, though this concern may be overstated. Storing large quantities of fresh product runs the risk of spoilage, if demand is not high enough.	Waitrose's 'Unpacked' trial was regarded as a major success, and the scheme has subsequently expanded. More than 160 loose fruit and vegetable products and 48 other products, such as pasta, coffee, wine and cleaning products, were available to buy packaging-free in the trial stores.
Home refill	Customers refill reusable containers at home, potentially using refills delivered through subscriptions, or with concentrated products bought in store. Drink, home and personal care products are particularly suited to this model.	Reduction of single use, customer facing packaging. Transport emissions and material use could be cut. Businesses can increase brand loyalty through direct delivery of refills to users' homes. Can be cheaper for consumers.	Businesses could face higher costs if two separate manufacturing lines are needed for the parent pack and refills. Transport emissions or secondary packaging could increase if companies individually develop their own delivery systems. Small and independent businesses could find it difficult to participate.	Several companies, such as Splosh and Cif, offer refills for their full-sized cleaning products. Splosh also runs a home subscription service, as well as offering a free recycling facility for empty refill pouches.
Home return	Products are delivered to customers' homes and empty packaging collected at the same time by a courier service. This allows products to be delivered in high quality, durable packaging which is then cleaned and refilled for further use. This model suits urban environments where the distance between deliveries is relatively short.	Elimination of single use, customer facing packaging. Potentially easier for customers, as they do not have to remember to clean containers. Businesses can increase brand loyalty through deposit and reward schemes which incentivise the return of packaging. Suitable for perishable items that may go off too quickly if dispensed in stores, as packaging sealing and functionality can be better controlled.	In rural areas, transport emissions could outweigh the benefits of reuse, especially at low take-up levels. Potential to standardise packaging types across businesses. Hoarding or theft of high value packaging is a risk, and breakages or losses of durable containers could tip the carbon and material balance in favour of single way packaging. Potentially difficult for small and independent companies to participate.	TerraCycle's 'Loop' model is currently being trialled in US cities and Paris, with plans to expand to the UK. Major brands such as P&G, Nestlé and Unilever participate, with packaging products only allowed on the platform if they are reusable and can be recycled into the same products at the end of their life. A deposit incentivises the return of packaging to prevent an increase in overall packaging produced.

Reuse System	How does it work?	Strengths	Weaknesses	Example
Store return	In this model, users return packaging at a store or a designated drop-off point, from where it is returned to producers to refill.	Elimination of single use customer focused packaging. Businesses can improve brand loyalty through deposit and reward schemes and could save on logistics and cleaning if facilities are shared across businesses or sectors. Suitable for perishable items that may go off too quickly if dispensed in stores as packaging sealing and functionality can be better controlled.	Customers could either forget or hoard packaging if the initial deposit is not high enough to incentivise return, or if there are not enough drop-off points in the right locations. Frequent breakages or losses of durable containers could tip the environmental balance in favour of single way packaging. Establishing efficient reverse logistics could be a challenge, including potentially persuading retailers to take back and store empty containers and handle deposit returns.	There are many examples of successful deposit return schemes across Europe, including in Norway, Germany, Croatia, Denmark and Finland. Much of the packaging collected in these systems currently goes for recycling, but systems could be adapted to return packaging to manufacturers for cleaning, refilling and reuse.
On the go return	This model is especially suitable for takeaway food containers and cups. Through it, local businesses like cafes or restaurants can group together to offer refillable containers, in which customers can take away food or drink from different establishments before returning through shared infrastructure, either in store or on street.	Elimination of single use takeaway containers, a particularly challenging packaging stream to tackle. This model comes closest to maintaining 'on the go' consumption culture and means that there is limited obligation for consumers to modify their behaviour or remember to bring refillable containers with them, or make special trips to return empty containers.	Customers could hoard packaging if the initial deposit is not high enough or there are not enough drop-off points in the right locations. Customers may leave the local area or closed venue before finishing the contents of the packaging and so take it beyond where collection infrastructure exists. Establishing or agreeing shared infrastructure and logistics could be a challenge.	CupClub is a returnable packaging service for hot and cold takeaway drinks. The service is most suitable for closed loop venues and 'campus environments', like government departments, universities or serviced office environments, where multiple vendors can share a network of drop-off points.

Endnotes

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2. *Life,* 1 August 1955, 'Throwaway living: disposable items cut down on household chores'
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4. J L Meikle, 1995, *American plastic: a cultural history*
5. BBC, October 2019, 'Plastic pollution: how plastic bags could help save the planet'
6. Plastics Europe, 2019, op cit; Heinrich Böll Foundation, 2019, *The plastic atlas 2019*
7. Ellen MacArthur Foundation, 2016, *The new plastics economy: rethinking the future of plastics*
8. Defra, June 2011, *Guidance on applying the waste hierarchy*
9. The chart is based on the response of 6,214 UK adults who were presented with a range of options about food packaging and plastic packaging for food. In an unprompted question, four key concerns were raised: the amount of packaging; the packaging material; the environmental impact; and difficulties with recycling packaging. See: INCPEN & WRAP, 2019, *UK survey 2019 on citizens' attitudes & behaviours relating to food waste, packaging and plastic packaging*
10. *The Grocer Vision*, June 2019, 'Beyond plastics: grocery packaging in a sustainable future'
11. New Plastics Economy, 2019, *The New Plastics Economy global commitment: 2019 progress report*
12. WRAP, 2019, *Plastics market situation report 2019*
13. United Nations Environment Programme (UNEP), 2018, *Single-use plastics: a roadmap for sustainability*
14. World Economic Forum, January 2016, *The New Plastics Economy: rethinking the future of plastics*
15. *Life*, 1 August 1955, op cit
16. American Chemistry Council, December 2019, *U.S. Chemical investment linked to shale gas: $204 billion and counting*
17. INEOS previously indicated that shale gas fracked in the US would form its feedstock. See: INEOS, July 2018, 'INEOS announces €2.7 billion investment in new European chemical complex'
18. Ibid
19. Government Office for Science, 2017, Foresight future of the sea: plastic pollution evidence review
20. These include bans and charges that have either already been implemented or for which the legislation is passed or in some cases drafted by the government. Throughout, we have only analysed actions taken at the country level, although there are many bans and charges at subnational and regional level, including in US and Australian states. All Australian states, for instance, have implemented bag bans apart from New South Wales. This list of bans includes partial bans, such as on small bags in Colombia and only polyethylene bags in Bangladesh. The information is correct to the best of our knowledge as of February 2020.
21. HM Government, 2018, *Our waste, our resources: a strategy for England*
22. Defra, press release, June 2018, 'World leading microbeads ban comes into force'
23. The range of estimations for release is often quite large, and covers the whole of the EU. It is not clear if the proportion of uses in the UK matches exactly the rest of the EU. The EU has also studied the release into the environment of microplastics that have not been intentionally added and found that such sources account for 176,300 tonnes of releases each year, nearly five times as many as intentionally added microplastics. See: European Chemicals Agency (ECHA), August 2019, *Annex XV restriction report: microplastics*
24. EHCA, 2018, *Registry of restricted intentions until outcome: microplastics*
25. ECHA, 2019, op cit
26. Defra, press release, May 2019, 'Gove takes action to ban plastic straws, stirrers, and cotton buds'
27. *The Times*, 30 May 2019, 'Ban on polystyrene food boxes will force takeaway outlets to go green'
28. The government has indicated that it will meet or exceed the EU's ambitions in this and other areas of environmental regulation, potentially through alternative approaches. In instances where the EU is banning certain plastics, though, it is difficult to see what the UK could do apart from a similar outright ban if it intends to match EU results. See: European Union, 2019, *Directive (EU) 2019/904 of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment*
29. Transparency Market Research, 2019, *Paper straws market: global industry analysis 2013-2018 and forecast 2019-2027*
30. WIRED, August 2019, 'Why the hell can't McDonald's recycle its paper straws? It's complicated'
31. BBC, August 2019, 'McDonald's paper straws cannot be recycled'
32. *Telegraph,* July 2018, 'Consumer backlash over wooden cutlery'
33. House of Commons, 2020, *Environment Bill*
34. Given the modelling process, which relies on multiregional input-output data, this information tracks material input up until consumption and does not include the end of life phase, although the use of recycled content is accounted for in the figures. The full methodology can be found

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[36] Defra, 2019, compliance scheme data

[37] These results are based on the percentage split of existing virgin and recycled material used in the UK market. The results have been proxied based upon the weights required to make a 500ml bottle for each of the materials, with carton board being used as a proxy for paper. These cannot be extrapolated to the entire sector, but are meant to give an indication of the scale of increased carbon that would be possible from simple switches. More information on the methodology can be found at: www.green-alliance.org.uk/fixing_the_system_methodology.php

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[39] Footprint Intelligence, 2019, *The future of foodservice packaging*

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[41] P Morone, 2018, *Sustainability transition towards a bio-based economy: new technologies, new products, new policies*

[42] Environment Agency, October 2019, *Standard rules consultation no 20: revision of standard rules sets for biowaste treatment*

[43] Sustainable Restaurant Association, 2018, *Unwrapping plastics: understanding disposables in hospitality*

[44] Defra, February 2019, *Consultation on consistency in household and business recycling collections in England*

[45] HM Government, 2018, op cit

[46] Defra, press release, May 2019, 'Science research programme launched to inform Defra policy making'

[47] As first set out by Paul Anastas and John Warner in 1998 in *Green chemistry: theory and practice*

[48] Defra, 2012, *Project WR1210 – how can paper be made more sustainable?*

[49] Environment Agency, 2012, *Pollution inventory reporting – paper and pulp guidance note*

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[51] Ibid

[52] Greenpeace International, 2019, *Throwing away the future: how companies still have it wrong on plastic pollution 'solutions'*

[53] ICF Consulting Services Limited and Fraunhofer ISI report to the European Commission, 2019, *Industrial innovation: pathways to deep decarbonisation of industry*

[54] Ibid

[55] Ibid

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[58] L Simão et al, 2018, 'Wastes from pulp and paper mills: a review of generation and recycling alternatives', in *Ceramica*

[59] M Niero and S Irving Olsen, 2016, 'Circular economy: to be or not to be in a closed product loop? A life cycle assessment of aluminium cans with inclusion of alloying elements', in *Resources, conservation and recycling*

[60] ICF Consulting Services Limited and Fraunhofer ISI report to the European Commission, 2019, op cit

[61] P Stotz et al, 2017, 'Environmental screening of novel technologies to increase material circularity: a case study on aluminium cans', in *Resources, conservation & recycling*

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[63] CIEMAP, 2016, *Understanding consumption: why and how do we use products?*

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[65] CIEMAP, 2016, *A whole system analysis of how industrial energy and material demand reduction can contribute to a low carbon future for the UK.* The use of hydrogen in a blast furnace could reduce CO_2 emissions from traditional steelmaking in future, although nearly all hydrogen is still made from fossil fuels.

[66] Green Alliance, 2018a, *Completing the circle: creating effective UK markets for recovered resources*

[67] www.worldsteel.org, accessed 2020, 'About steel'

[68] Green Alliance, 2018b, *Less in, more out: using resource efficiency to cut carbon and benefit the economy*

[69] Green Alliance, 2018a, op cit

[70] ICF Consulting Services Limited and Fraunhofer ISI report to the European Commission, 2019, op cit

[71] Green Alliance, 2018a, op cit

[72] ICF Consulting Services Limited and Fraunhofer ISI report to the European Commission, 2019, op cit

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partly be down to the fact that high PRN prices at the end of 2018 brought more material into the system.

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[76] UK Green Buildings Council, 2018, *Building glass into the circular economy*

[77] Report to the European Commission, 2019, *Industrial innovation: pathways to deep decarbonisation of industry*

[78] Valpak & WRAP, 2016, *Plastics spatial flow;* Green Alliance, 2017, 'What happens to plastic in the sea?'

[79] Green Alliance, 2017, 'How to stop nearly two thirds of plastic waste getting into the sea'

[80] Green Alliance, 2015, *A circular economy for smart devices: opportunities in the US, UK and India*

[81] WRAP, 2019, *Defining what's recyclable and best in class polymer choices for packaging*

[82] Defra, February 2019, *Consultation on consistency in household and business recycling collections in England*

[83] The Environment Agency has been very under resourced to carry out inspections in recent years, which needs addressing. In 2016-17, for instance, it only conducted a total of 124 compliance visits to recyclers and exporters, against a target of 346, and only carried out three unannounced site visits in 2017-18. (See: National Audit Office, 2018, *The packaging recycling obligations*) The government has promised to end the practice of sending polluting plastics abroad.

[84] Green Alliance, 2017, *Getting it right from the start: developing a circular economy for novel materials*

[85] One estimate suggests, for instance, that around 40 per cent of the total corn harvest in the USA would be needed to meet the country's plastic demand from this source. Alternatives such as switchgrass, which can be grown on more marginal land, are potentially a better option, although this crop could still require as much as 15 per cent of US agricultural land. See: D Posen et al, 2017, 'Greenhouse gas mitigation for US plastics production: energy first, feedstocks later', in *Environmental research letters*

[86] C Reeb, et al, 2015, 'Environmental LCA and financial analysis to evaluate the feasibility of bio-based sugar feedstock biomass supply globally: part 1. supply chain analysis', in *Bioresources*

[87] One of the main reasons making bio-based materials is potentially more beneficial than using the feedstock as fuel is because the material can act as a carbon sink if it is long lasting and recyclable, rather than releasing its emissions if it is used as fuel. See: H Bos, et al, 2012, 'Accounting for the constrained availability of land: a comparison of bio-based ethanol, polyethylene, and PLA with regard to non-renewable energy use and land use', in *Biofuels, bioproduction and biorefining*

[88] S Spierling, 2018, 'Bio-based plastics – a review of environmental, social and economic impact assessments', in *Journal of cleaner production*

[89] Green Alliance, 2019c, *Plastic promises: what the grocery sector is really doing about packaging*

[90] Footprint Intelligence and BaxterStorey, 2019, *The future of foodservice packaging*

[91] The EN13432 standard for industrial compostability mandates that 90 per cent of material must have biodegraded after six months of treatment. Such lengthy treatment times are not practiced in the UK, and this is unlikely to change if facilities are to remain financially viable. In our research, we spoke to several industrial composting facilities that reported problems handling even certified compostable material in existing infrastructure, with several suggesting that materials like compostable cutlery and plates are still easily identifiable as such after treatment. Similarly, we have spoken to industry insiders who suggest that the degradation for certified home compostable material takes significantly longer than allowed by the standards, when practiced in real life conditions.

[92] UNEP, 2018, *Exploring the potential for adopting alternative materials to reduce marine plastic litter*

[93] See, for example, UNEP, 2017, *Exploring the potential for adopting alternative materials to reduce marine plastic litter*

[94] See, for example, *The Guardian*, June 2019, 'Ask the experts: do the plastic linings of tin food cans contain BPA?'; Healthline, July 2019, 'Food industry's switch to non-BPA linings still poses health risks'

[95] B Geueke, et al, 2018, 'Food packaging in the circular economy: overview of chemical safety aspects for commonly used materials', in *Journal of cleaner production*

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[97] M Biedermann and K Grob, 2013, 'Assurance of safety of recycled paperboard for food packaging through comprehensive analysis of potential migrants is unrealistic', in *Journal of chromatography A*

[98] Fidra, 2020, *Forever chemicals in the food aisle: PFAS content of UK supermarket and takeaway food packaging*

[99] Y Choi et al, 2019, 'Perfluoroalkyl acid characterization in US municipal organic solid waste composts', in *Environmental science & technology letters*

[100] R Ghisi et al, 2019, 'Accumulation of perfluorinated alkyl substances (PFAS) in agricultural plants: a review', in *Environmental research*

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[102] Food Packaging Forum, 2019, 'Denmark to ban PFAS in paper & board in 2020'

[103] Green Alliance, 2019d, *Building a circular economy: how a new approach to infrastructure can put an end to waste*

[104] Ellen MacArthur Foundation, 2019, *Reuse: rethinking packaging*

[105] Food and Drink Federation, 2019, *Plastics & packaging: avoiding the unintended consequences of food waste & food safety in food & drink manufacturing;* Greenpeace and EIA, 2019, *Checking out on plastics II: breakthroughs and backtracking from supermarkets*

[106] V Lofthouse et al, 2006, *An investigation into consumer perceptions of refills and refillable packaging*

[107] Greenpeace and EIA, 2019, op cit

[108] Ibid

[109] V Lofthouse, et al, 2006, op cit

[110] Ibid

[111] Ellen MacArthur Foundation, 2019, op cit

[112] This quote refers specifically to conversion processes (eg pyrolysis and gasification), which can crack plastics back into simpler molecules, including oils or gas that can be used either as fuel or as building blocks for new plastics. See: Closed Loop Partners, 2019, *Accelerating circular supply chains for plastics: a landscape of transformational technologies that stop plastic waste, keep materials in play and grow markets*

[113] R Geyer, et al, 2017, 'Production, use, and fate of all plastics ever made', in *Science advances*

[114] Examples in development include: the Gneuss Processing Unit, which takes place when the polymer is molten; the Erema Vacurema technology, which takes place before the polymer is extruded; and the Starlinger Solid State Polycondensation (SSP) technology after extrusion. See: Green Alliance, 2018, www.green-alliance.org.uk/completing_the_circle_methodology for more.

[115] As with mechanical recycling, this technology does not address degradation problems like polymer shortening.

[116] Zero Waste Europe, 2019, *El Dorado of chemical recycling: state of play and policy challenges*

[117] It must be noted that not all chemical depolymerisation technologies can achieve this, though the ones which can offer a way of overcoming the reduction in material properties brought about by multiple iterations of mechanical recycling. As not all polymers can be mechanically recycled, chemical recycling can help pull these more challenging materials into the circular economy, although development of the technology should be balanced against the increasing trend to remove challenging polymers from circulation altogether.

[118] In fact, around a quarter of the fuel produced through pyrolysis, for instance, is needed to power the process itself. See: A Rollinson and J Oladejo, 2019, '"Patented blunderings": efficiency awareness, and self-sustainability claims in the pyrolysis energy from waste sector', in *Resources, conservation & recycling*

[119] McKinsey & Company, 2018, *How plastics waste recycling could transform the chemical industry*

[120] WRAP, 2019, *Non-mechanical recycling of plastics*

[121] The best feedstocks for mechanical recycling, for instance, are PE, PET, PP, and PS; solvent purification is most useful for PVC, PE, PP and PS; chemical depolymerisation is suitable for PET in addition to PU, PA, PLA, PC, PHA, PEF, and cracking for PP and PE, although it can theoretically handle more of a material mix. See: Zero Waste Europe, 2019, op cit

[122] Green Alliance, 2019d, op cit

[123] A Rahimi and J Garciá, 2017, 'Chemical recycling of waste plastics for new materials production', in *Nature reviews chemistry*

[124] Zero Waste Scotland, 2013, *Plastics to oil products*

[125] HM Treasury, 2018, *Single-use plastics: budget 2018 brief*

[126] Green Alliance, 2019d, op cit

[127] WRAP, 2019, *Eliminating problem plastics, version 2*

[128] In 2018, for instance, there was a 23 per cent increase in the market price of PET between February and June. See: *Plastics News Europe*, July 2018, 'PET demand continues to boom with the hot summer weather'.

[129] Drops in oil prices have been implicated in the closure of several UK plastic reprocessors already. See, for instance, *The Manufacturer*, 2019, 'The price of plastic: taking control of raw material costs' and *Resource Magazine*, May 2016, 'Euro closed loop placed into administration'.

[130] McKinsey & Company, 2018, op cit

[131] As facilities for fossil fuels are already looking likely that they will be stranded assets, many traditional petrochemical companies are looking to shift to plastic production, which would also have an impact on recycled plastic prices. By the end of 2017, the boom in US shale gas had already seen £180 billion invested in plastic production facilities by ExxonMobil Chemical and Shell Chemical, and in January 2019, INEOS announced a €3 billion investment in the first new hydrocracking facility in Europe in 20 years. See, for example: Department for Business, Energy and Industrial Strategy (BEIS), 2018, *Fossil fuel price assumptions: 2018,* and *The Guardian*, December 2017, '$180bn investment in plastic factories feeds global packaging binge'; INEOS, 2019, 'INEOS, Europe's largest petrochemicals company, announces Antwerp as the location for it new ground breaking 3 billion Euro petrochemical investment'.

[132] National Grid Delivery Body, 2014, *Contracts for difference user guide – issue 2*

[133] BEIS, 2018, *Contracts for difference: methodology used to set administrative strike prices for CfD allocation round 3*

[134] BEIS, press release, September 2019, 'Clean energy to power over seven million homes by 2025 at record low prices'

[135] Adapted from UK government, 2011, *Planning our electric future: a white paper for secure, affordable and low-carbon electricity*

[136] Government Office for Science, 2017, *From waste to resource productivity*

[137] CIEMAP, 2018, *Developing a carbon based metric of resource efficiency*

[138] Adapted from HM Treasury, 2019, Review of the aggregates levy: discussion paper

[139] Personal conversation with Ned Coletta, Casella Waste Systems, 4 October 2019

[140] This list is partly based on research into contaminants in FCMs. See: B Geueke et al, 2018, op cit. It also builds on a recent study for the Food Standards Agency in the UK: Fera, June 2019, *Bio-based materials for use in food contact publications*

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