Report

Phasing out plastics

The packaging sector

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Cover photo: Plastic bottles. © Jonathan Chng/Unsplash

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Acronyms and abbreviations

3D	three-dimensional
BAU	business as usual
CIS	Commonwealth of Independent States
CO_2e	carbon dioxide equivalent
EPS	expanded polystyrene foam
EU	European Union
GAIA	Global Alliance for Incinerator Alternatives
GHG	greenhouse gas
HDPE	high-density polyethylene
LDPE	low-density polyethylene
LED	low energy demand
Mt	million tonnes
NGO	non-governmental organisation
OECD	Organisation for Economic Co-operation and Development
PaaS	product as a service
PE	polyethylene
PET	polyethylene terephthalate
PP	polypropylene
PS	polystyrene
PUR	polyurethane
PVC	polyvinyl chloride
PVOH	polyvinyl alcohol
RIC	Resin Identification Code

Executive summary

Background

Plastics today are almost always made from fossil fuels and use fossil-fuel energy in their manufacture. In 2015, about 4% of greenhouse gas (GHG) emissions globally could be attributed to the manufacture and use of plastics (Zheng and Suh, 2019). In the same year, more than a third (36%) of all plastics were produced for packaging, which also accounted for a disproportionate share of total emissions from plastic (Geyer et al., 2017). Because GHG emissions need to be reduced to net zero by 2050 to avert catastrophic climate change, plastic packaging made from new fossil fuels needs to be phased out.

This report explores the technical feasibility of phasing out packaging made from fossil plastic by 2050. It is part of a broader research project investigating the technical potential for the phase-out of virgin (new) plastics made from fossil fuels. The study compares a business-as-usual (BAU) scenario for plastic packaging in 2050 with a low-plastic-consumption vision that is compatible with containing the rise in average global temperature to 1.5°C. The feasibility of phasing out the production of new fossil plastics for packaging considers two main strategies to reduce plastic packaging: dematerialisation and reuse, and materials substitution.

Four plastic types dominate the packaging sector: polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE) and polypropylene (PP). In 2015, packaging consumed 94% of global PET production, 65% of LDPE and 55% of HDPE (Geyer et al., 2017).

The unique properties of plastic make it a highly convenient and cost-effective material for a wide variety of packaging – to protect solid and liquid goods during transport and storage, to reduce waste, to ensure safety and hygiene, and to inform and attract consumers. It is, therefore, omnipresent in retailing. In the United Kingdom, for example, about two-thirds of plastic packaging is used for consumer goods and 40% is used in grocery retailing (WRAP, 2016).

Most plastic packaging is used only once, within six months of its manufacture, making packaging in 2015 the source of 47% of the world's plastic waste (Geyer et al., 2017). The environmental damage of this waste is largely determined by how it is handled. Globally, only 26% of this waste was recycled in 2018 (Conversio, 2018).

Plastic packaging in 2050

Our analysis compares a BAU scenario for 2050 with a low-plastic-consumption vision. The former assumes that plastic packaging production and consumption grow by 3% a year to 2050. The latter is based on Grubler et al.'s (2018) low energy demand (LED) scenario, which provides a framework for investigating changes in plastic consumption and is compatible with the aim of a global temperature rise of no more than 1.5°C.

In our 2050 vision, the main purpose of packaging becomes the safe delivery of goods to consumers. Packaging would no longer be required to display goods and influence consumer choices, as retail purchases would be largely made online. Durable packaging that makes efficient use of space and protects from damage would be used to deliver goods, supported by digital technologies to maximise the efficiency of materials. This packaging would be reusable and recyclable. Single-use plastics would be discouraged or banned by regulation.

The need for plastic packaging would be reduced by changes in business models and consumer behaviour. Supermarkets, for example, would use bulk containers to dispense goods into reusable packaging brought by consumers. Single-use plastic water bottles would be replaced by reusable bottles filled at water fountains. Products would be designed to facilitate reuse and recycling, while rental and product-as-a-service (PaaS) business models would reduce overall materials consumption and the need for single-use packaging.

The vision scenario for plastic packaging in 2050 would lead to an 80% reduction in the consumption of single-use packaging compared with BAU and a 44% reduction compared with production in 2015. Rather than 411 million tonnes (Mt) of plastic single-use packaging produced on current trends, the 2050 vision sees just 82 Mt. This reduction would be the result of dematerialisation and reuse (60%) and substitution by non-plastic materials in packaging (40%). However, there would be a 10 Mt increase in the production of durable plastic packaging to replace some single-use packaging.

A greater share of plastic packaging would be recycled in our vision for 2050, either mechanically or chemically, facilitated by a higher proportion of PET and HDPE (Resin Identification Codes 1 and 2) in the packaging mix. In our vision, around 45% of the plastic packaging produced in 2050 would be made from recycled plastic packaging.

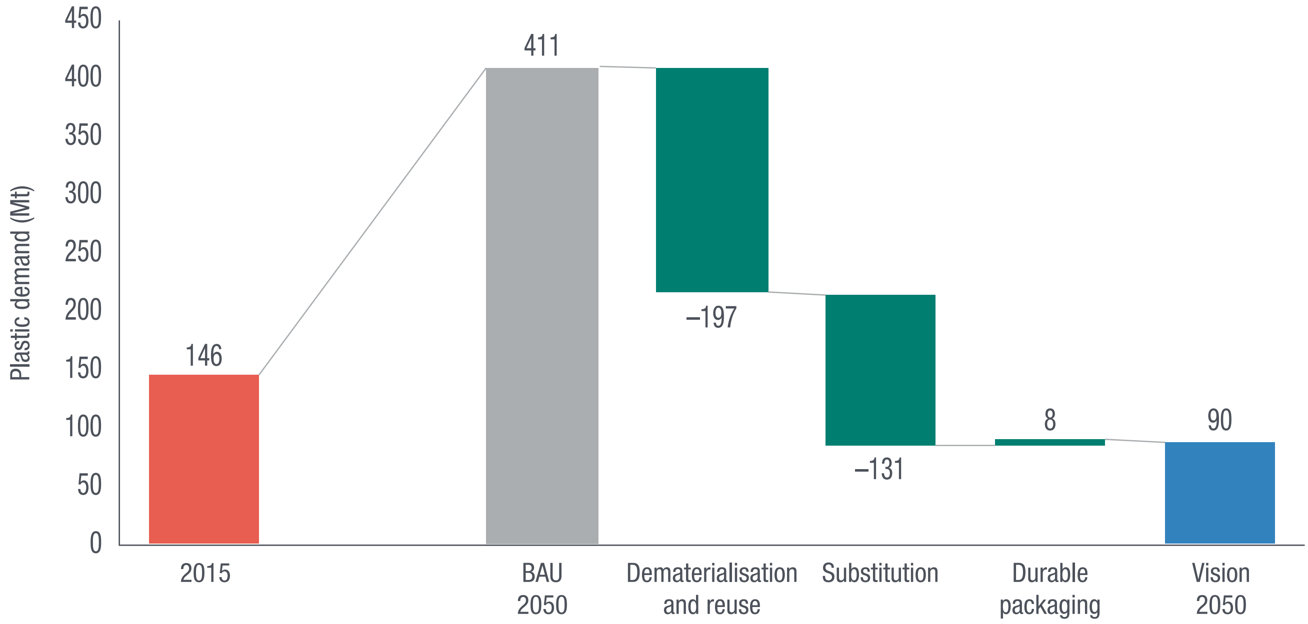
Pathways to 2050

To achieve this 2050 vision, the packaging sector and consumers of packaging would need to take various actions between now and 2050. Most of the components that together create the 2050 vision for packaging are already present on a smaller scale today, including:

- **Regulation of single-use packaging:** A critical step towards curbing growth in single-use packaging is to ban the most problematic single-use packaging items, including those that are known to be frequently littered, contain hazardous substances or are very difficult to recycle. Many countries have already introduced such bans. A tax on the use of new plastics in the manufacture of single-use packaging would encourage recycling.
- **Deposit schemes:** Deposit schemes for plastic bottles exist in some countries to encourage recycling. In Norway, 97% of plastic bottles are collected for recycling as a result of a combination of a deposit scheme and a tax on plastic bottles. In low-income countries, the recycling of plastic waste could be incentivised by providing income for those who collect it.
- **Non-plastic packaging materials:** Other materials are already used as substitutes for plastics in packaging, such as glass for bottles and metal boxes for food. New, organic packaging materials that can be composted or are biodegradable are also already in use, while other new materials are water soluble.
- **Enhanced recycling:** Goods can be designed to make recycling parts or whole products easier. Avoiding certain plastic additives and colourings increases recyclability. Greater use of readily recycled plastic, such as PET, in packaging and changes in the way multi-material packaging items are made would also enhance plastics recycling.
- **New business models:** Reduced use of single-use plastic packaging and greater use of reusable, durable packaging is made possible by new business models, such as PaaS and the trend to rent assets (such as cars and tools) and infrequently used goods, rather than owning them. This reduces the single-use packaging required for products and replacement parts.
- **Changes in retailing:** A variety of innovations in retail operations, such as self-dispensing products from bulk containers, reusable containers in distribution, the sale of condensed or concentrated products (such as detergent), offering frozen and loose grocery products, local manufacture by 3D printing and the expansion of online retailing, would reduce the quantity of single-use packaging required to sell and distribute goods to consumers.

The pathway towards the 2050 vision is likely to build on existing public concern about plastic waste and the policy momentum to address it. Catalysts for action to regulate plastic waste have been context-specific, but broader narratives about ocean plastic pollution and microplastics in the food chain have also captured public attention. Achieving the vision will require

Figure 1 Potential to reduce the quantity of plastics used for packaging



Sources: Author's analysis; Geyer et al. (2017)

developing the narrative beyond plastic packaging waste and recycling, however, to reducing and reusing packaging.

The plastics industry, which is closely linked to the oil and gas industry, can be expected to oppose movement towards our 2050 vision. The industry has resisted regulations proposed by the European Commission and has advocated the prohibition of bans on plastics in the United States (Lerner, 2019). The effectiveness of bans on single-use plastics depends on the ability to enforce them. The plastics industry and businesses using plastic packaging may be more supportive of recycling in response to public concerns about waste, but also to divert attention from any moves to reduce plastics use.

A coalition for change towards our 2050 vision would probably first involve working with national policy-makers already tackling single-use plastics, to encourage them to increase the ambition of their policies. Such a coalition could include businesses seeking to demonstrate a commitment to environmental sustainability. International cooperation on questions such as the treatment of plastic waste may also be needed.

Outcomes in 2050

Figure 1 shows how dematerialisation, reuse and substitution contribute to a reduction in plastic consumption for packaging under our 2050 vision compared with BAU. Around 60% of the reduction would stem from dematerialisation and reuse, and 40% from substitution.

Such a decrease in plastics use could reduce GHG emissions from plastic packaging to 178 Mt CO_2e from the 715 Mt CO_2e emitted in 2015. Compared with the 2050 BAU scenario, the reduction in emissions would be almost 2,000 Mt CO_2e.

In our vision for 2050, the quantity of plastic packaging waste generated would still be about the same as the quantity produced, at 90 Mt. However, recycling rates would be higher than today and about 60 Mt of recycled plastic would be made from packaging waste. In 2050, therefore, about 44% of single-use plastic packaging and 66% of durable plastic packaging could be produced from recycled plastic packaging.

1 Introduction

1.1 Background

Plastics today are almost always made from fossil-fuel raw materials (oil, gas and coal) and use fossil-fuel energy in their manufacture. They account for 9% of total demand for oil and 3% of demand for gas, and by 2050 they could account for as much as 20% of oil demand (World Economic Forum et al., 2016). Plastics were the source of about 4% of global GHG emissions in 2015 (Zheng and Suh, 2019). By 2050, when the global economy needs to generate net zero emissions, on current trends plastics emissions would be three times greater.

Recently, plastic waste and pollution have dominated the narrative on the negative side of plastics. As well as the effects of plastic pollution on sea life, there are concerns about toxicity and health from plastic microfibres found in the air, water and food. These are challenges that cannot be completely addressed by better materials handling or waste management. Nor would they be resolved by the substitution of plastics derived from fossil fuels with those derived from biomass – the latter would also lead to waste and pollution. It is imperative from a climate and broader environmental perspective that the demand for new plastic materials is curtailed.

1.2 Context

This technical analysis serves as an input to a broader research project investigating the technical potential for the phase-out of virgin plastic materials produced from fossil fuels by 2050. Our focus complements existing forecasting and circular economy work, but our method is different. We take a bottom-up approach to assessing the use of plastics in four sectors (packaging, construction, automotive, and electrical and electronic appliances), which together account for approximately 60% of total plastics consumption (Geyer et al., 2017).

We consider the upstream and downstream aspects of the plastic value chain to operate outside the individual sectors, as the production of plastic resin and the collection of plastic waste are largely separate to – and cut across – the sectors in which plastic products are used. We, therefore, discuss opportunities to reduce the environmental impacts of plastics demand through changes to the production, recycling and disposal processes in the accompanying synthesis report.[1] The technical reports in this study series focus on minimising the demand for plastic materials because any reductions in aggregate demand facilitate easier management of the associated processes.

The point of these detailed sector studies is to illustrate the technical feasibility and high-level political feasibility of phasing out fossil plastics production and use within these sectors. The target audience for the synthesis report is broad, including policy-makers, advocacy groups, the private sector and other researchers. The audience for the technical reports is narrower: mainly researchers and those working directly in the sector.

1.3 Methodology

Our analysis begins by identifying the amount of plastic used in each sector currently and using recent trends to project BAU demand for plastics in the sector in 2050. We investigate the different uses of each bulk plastic type in the sector today to provide a basis for reducing future demand. We then assess the technical potential to reduce the demand for new plastic materials compared

1 See the accompanying synthesis report, entitled ‘Phasing out plastics’.

with BAU in 2050 by considering the following opportunities in cascading fashion:

1. dematerialisation and reuse (avoiding the demand for new plastics)
2. substitution for non-plastics (shifting the demand for new plastics to demand for other materials)
3. plastics recycling (optimising the waste-management schemes associated with plastics)
4. non-fossil feedstocks (for residual demand that cannot be reduced by the above approaches).

This report focuses on the first two steps of this analysis, namely how to reduce demand. Steps 3 and 4 (how to accommodate residual demand) are addressed holistically in the companion synthesis report. Figure 2 illustrates the process across the technical and synthesis reports.

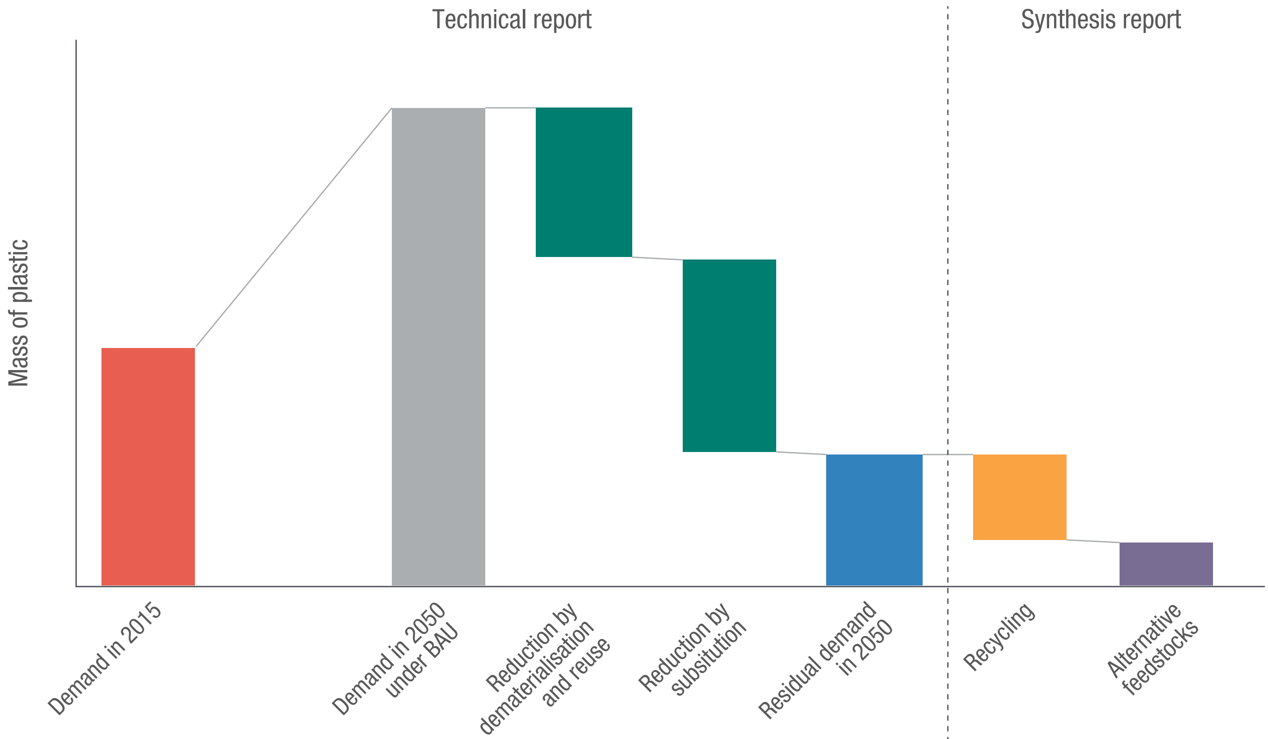
We round out our focus on the technological feasibility of making changes by 2050 with some high-level insights into things to consider if such changes are to be brought about. However, this work is not an assessment of likelihood and we do not explore in detail the economic, political or behavioural dimensions of these changes. We aim to provide one possible outcome and illustrate how it may come about, rather than to predict the future.

1.4 Structure of the report

The remainder of the report is structured as follows:

- Chapter 2 provides an overview of plastic consumption by the sector, the main uses of plastics and the fate of the sector's plastic waste.
- Chapter 3 illustrates our 2050 vision for reducing the demand for virgin fossil plastics.
- Chapter 4 provides a high-level analysis of the steps on a path to achieving that vision.
- Chapter 5 illustrates the potential outcomes in 2050, illustrating total demand for plastics in the sector under the low-plastics-demand scenario, the associated impact on GHG emissions and the amount of waste generated.
- Chapter 6 provides an overall conclusion to our analysis of the sector.

Figure 2 How to cut demand for fossil-fuel plastics by 2050



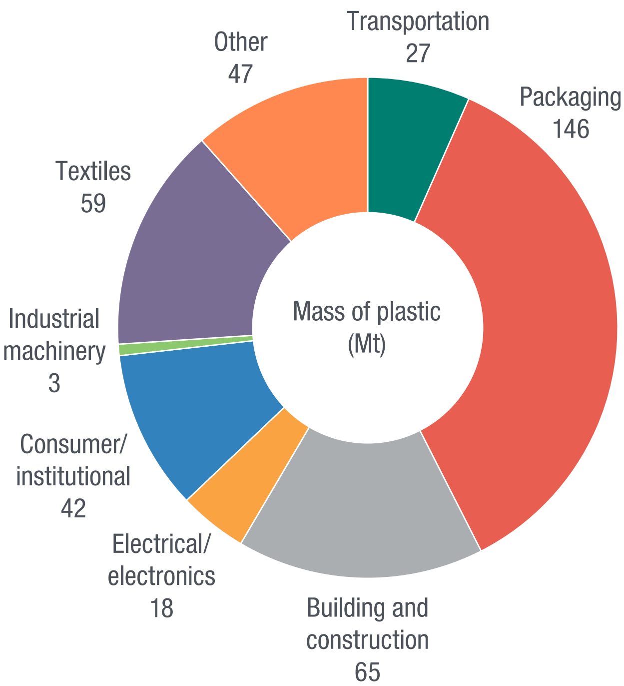
Source: Authors

2 Plastics in the packaging sector

2.1 Overview

Packaging consumes the largest quantity of plastics of any sector (see Figure 3). In 2015, the baseline year for this study, 36% of all plastics produced globally were used for packaging, an estimated total of 146 Mt (Geyer et al., 2017). The scale of worldwide production and consumption of plastic packaging is evident from statistics such as the purchase of 1 million plastic drinks bottles every day, the use of 5 trillion single-use plastic bags every year and the production of 500 million disposable cups a year (UN Environment, 2018a; 2018b). However, the short life of single-use plastic packaging also means that packaging accounts for a large proportion of plastic waste – about 47% globally in 2015 (Geyer et al., 2017) – and is a major source of plastic pollution.

Figure 3 Annual primary plastic production by industrial sector in 2015



Source: Geyer et al. (2017)

Plastic's unique properties make it a highly convenient and cost-effective material for a wide variety of packaging purposes. Packaging of all kinds is used to protect goods from damage during transport and storage, to reduce waste, ensure safety and hygiene, and to inform and attract consumers. Plastic accounts for about a fifth of all packaging by weight, according to European Plastics Converters (2017), citing Eurostat data,[2] and is mostly used in the form of bottles, jars, food containers, flexible packaging, bags, film, tubes, tapes and straps, caps, baskets, trays, boxes, pallets, shipping crates, buckets and bubble wrap. Most plastic packaging items are single-use (typically disposed of after one use), for example grocery bags, food packaging, beverage bottles, detergent bottles, wrappers, foils and food containers. Other common single-use plastic items include plastic cups, plates and cutlery, plastic-lined paper cups, straws and stirrers (UN Environment, 2018c).

In the UK, which is probably fairly typical of Organisation for Economic Co-operation and Development (OECD) economies, about two-thirds of plastic packaging is used for consumer

2 In Europe, 19% of the total packaging tonnage used in 2016 was plastic. The shares of other packaging materials were glass (40%), paper and board (20%), wood (15%) and metal (6%), according to Eurostat data cited in European Plastics Converters (2017).

goods and one-third for goods supplied to commercial, industrial, construction and agricultural buyers. Around one-third of plastic packaging is flexible film and two-thirds is rigid packaging (WRAP, 2016; Environment Canada, 2019).[3] More than 40% of plastic packaging is used in the grocery retail sector (WRAP, 2016).

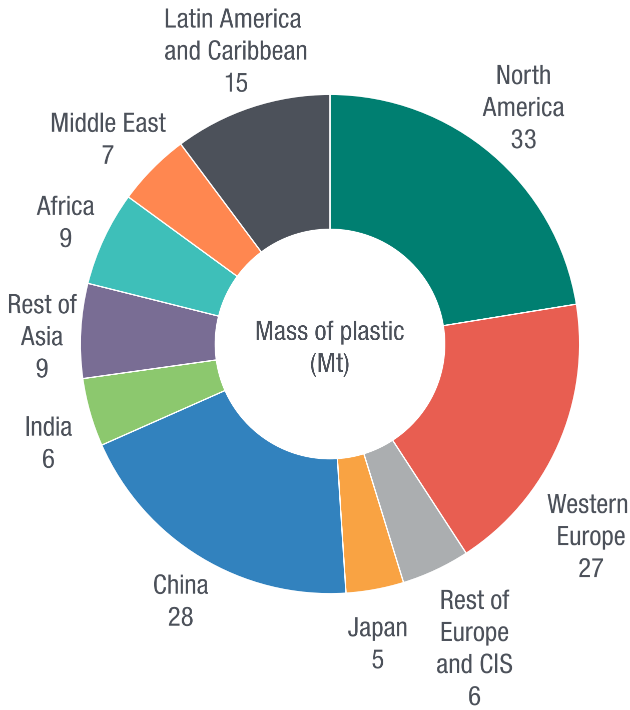
There is growing demand for flexible and complex packaging materials, including moisture absorbers, active data labels and antimicrobial coatings. These types of packaging combine different plastics, or mix plastics and other materials, such as thin metal foils, coatings and layers of paper or cardboard, and amalgamate the functional properties of the different materials. However, multi-material laminated films, such as those used in snack bags, foil pouches and toothpaste tubes, are very difficult to separate into their various material substrates, so the recycling of such packaging is not economically feasible at present.

Three regions dominate the consumption of plastic packaging: North America, Western Europe and East Asia (Figure 4). China alone consumes 19% (28 Mt) of global plastic packaging, but produces 28% of the world's plastics. North America and Western Europe consume roughly as much plastic as they produce, with shares of around 22% and 18% respectively (Ryberg et al., 2018).

Plastic is a highly convenient and cost-effective material, making it suitable for a variety of purposes such as food and liquid packaging, preserving the contents and ensuring they are delivered to the consumer in a safe and suitable condition. Plastic packaging thus offers major benefits to society. However, with plastic packaging becoming the norm, even when feasible alternatives are available, our plastic consumption is becoming increasingly problematic (UN Environment, 2014).

Hawkins (2018) describes plastic packaging as 'the skin of commerce', ever-present in retailing, which is primarily due to its low cost and partly due to its usefulness in preserving food quality and ensuring longevity (Verghese et al., 2015). Though plastic packaging is often heralded for extension of shelf-life and preservation of food, in Europe the growth in the use of plastic packaging has occurred alongside growth in food waste. Since the use of plastic packaging for food became common in Europe in the 1950s, annual plastic packaging waste has increased to 30 kg per capita, while household food waste has risen to 70 kg per capita (Zero Waste Europe, 2018). Although there are many reasons for the increase, the rapid growth in prepared, pre-cut and convenience foods, enabled by plastic packaging, is a contributor, reflecting urban lifestyles that increasingly favour food 'on the go' and where there is less time for meal preparation (Zero Waste Europe, 2018).

Figure 4 Regional distribution of plastic packaging consumption



Note: CIS, Commonwealth of Independent States.
Source: Ryberg et al. (2018)

3 The proportions vary between packaging for food and other consumer goods. Rigid packaging for non-grocery consumer goods in the UK accounts for 80% of plastic packaging used for these goods (WRAP, 2016). In Canada, plastic film accounts for about a third of plastic packaging and rigid plastics 54%, measured by waste (Environment Canada, 2019).

2.2 Plastic types

Although there are many different types of plastic, our study focuses on six common types, which together account for about three-quarters of all plastics produced (Geyer et al., 2017). They are LDPE and HDPE, polypropylene (PP), polystyrene (PS) (including expanded polystyrene, EPS), polyvinyl chloride (PVC), PET and polyurethane (PUR). In the packaging sector, plastics are labelled with a Resin Identification Code (RIC) corresponding to the type of resin (plastic) used. Figure 5 lists the six RICs and illustrates the kind of packaging item made from each type of plastic.

Four plastic types dominate the packaging sector (see Figure 6): PET (RIC 1), HDPE (RIC 2), LDPE (RIC 4) and PP (RIC 5). The packaging sector is the principal consumer of PET, perhaps the best-known plastic type, as it is used to make plastic beverage bottles and has a higher recycling rate than other plastics. Packaging consumed 94% of the world's PET in 2015 (Geyer et al., 2017).

A fifth of all plastic packaging is made from HDPE, which is used for milk cartons, washing liquid and detergent bottles, and also has a strong recycling market. Packaging consumed 55% of total HDPE output in 2015, and 65% of LDPE. PP, used for a variety of packaging items, including bottle lids and food tubs, accounted

Figure 5 Main plastic resin types and examples of their application in packaging

Water and soft drink bottles, salad domes, biscuit trays, salad dressing and peanut butter containers

Milk bottles, freezer bags, dip tubs, shopping bags, ice cream containers, juice bottles, shampoo, chemical and detergent bottles

Cosmetics containers, commercial cling wrap

Squeeze bottles, cling wrap, shrink wrap, rubbish bags

Microwave dishes, ice cream tubs, potato chip bags, dip tubs

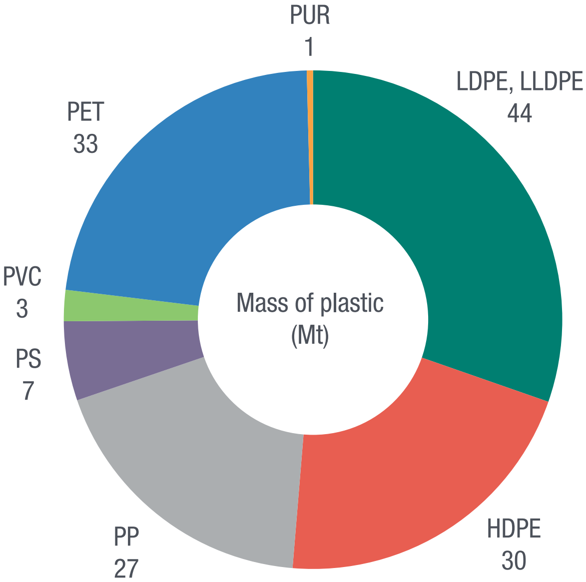
CD cases, water station cups, plastic cutlery, imitation 'crystal glassware', video cases

Foamed polystyrene hot drink cups, hamburger take-away clamshells, foamed meat trays, protective packaging for fragile items

Water cooler bottles, flexible films, multi-material packaging

Source: World Economic Forum et al. (2016)

Figure 6 Types of plastic used for packaging in 2015



Source: Geyer et al. (2017)

for 18% of all plastic packaging in 2015 (Geyer et al., 2017).

2.3 Plastic packaging waste

Packaging generally has a very short 'in-use' lifetime of six months or less and, with more than a third of global plastics output used for single-use packaging (Lerner, 2019), the sector is the main generator of plastic waste. In 2015, waste from plastic packaging was equivalent to 97% of the plastic packaging manufactured that year (Geyer et al., 2017).[4] With the packaging sector growing at a rate of 3% annually, driven mostly by emerging markets, the quantity of plastic waste from the sector has also been growing.

Plastic packaging generates significant negative externalities, conservatively valued at $40 billion globally per annum. In Asia alone, plastic litter costs the tourism, fishing and shipping industries $1.3 billion per year (UN Environment, 2018a). However, many lifecycle assessments of plastic packaging fail to consider the impact of plastics across the entire lifecycle, including its end-of-life fate (Zero Waste Europe, 2018). Instead, they focus on single measures that are relatively easy to quantify, such as carbon reduction, so may paint an overly positive picture of the net beneficial impact of plastic packaging (World Economic Forum et al., 2016).

The environmental damage of plastic packaging waste depends on how it is handled. Globally, in 2018, about 30% was either improperly disposed of or leaked into the environment, 20% was incinerated, 26% was sent to landfill and 26% was recycled (Conversio, 2019). However, practices vary from country to country. In the United States, for example, the proportion of plastic waste recycled peaked at just under 10% in 2014 and the quantity of plastic waste incinerated is six times the amount that is recycled (Lerner, 2019). Although plastic recycling rates in Europe are often claimed to be around 30%, the reality is closer to 10% of plastic consumed, as the volume of plastic waste collected for recycling is higher than the volume eventually recycled. Plastic waste collected for recycling is often contaminated and includes plastics that contain additives, limiting their recycling value (Material Economics, 2018a).

While China is the largest worldwide generator of plastic packaging waste in absolute terms, the United States is the largest generator of plastic packaging waste on a per capita basis, followed by Japan and the European Union (UN Environment, 2018a). Plastic packaging waste from Europe and North America is often exported. It was previously sent to China, for the most part, but a recent ban on waste imports has displaced much of it to other Southeast Asian countries (GAIA, 2019).

To tackle the most problematic packaging items, more countries are adopting legislation that regulates, bans or extends producer responsibility for a variety of single-use packaging items. This follows a substantial shift in consumer norms, especially with regard to single-use plastics and their impact on marine environments. The most commonly regulated items are plastic bags, with the number of public policies restricting plastic bag consumption increasing from around 20 in 2003 to 160 in 2018 (Nielsen et al., 2019a). Such regulations can include restrictions on their manufacture, distribution, use and trade, as well as taxes and levies, such as charging consumers for plastic bags, and policies on post-use disposal (UN Environment, 2018c).

4 Conversio (2019) estimates plastic packaging waste in 2018 to be 83% of global plastic packaging consumption, which may reflect recent measures to regulate the use of single-use plastics.

3 Plastic packaging in 2050

Our BAU scenario for 2050 assumes 3% growth per year in the consumption and production of plastic packaging. The low-plastic-consumption scenario is based on the LED scenario published by Grubler et al. (2018), which is compatible with restricting global heating to 1.5°C. The LED scenario provides a framework to investigate changes in plastic consumption through dematerialisation and reuse, which we apply here to the packaging sector. We further consider the potential to substitute other materials for plastics in the manufacture and use of packaging materials to arrive at a technically feasible estimate of plastic packaging under the low-plastic-consumption scenario.

3.1 The vision for 2050

By 2050, we expect the online economy and e-retail to have changed the role of packaging. While retail companies currently spend billions on packaging to seduce consumers into making a purchase, in 2050 consumer influencing and the provision of product information will happen online and in 'experience stores'.

The 'first moment of truth' in retailing, the shelf, will increasingly be replaced by the 'zero moment of truth' (online). Nifty online tools could allow consumers to more accurately assess the suitability of a product, such as clothing, which could be 3D-fitted to virtual images of prospective purchasers, thus greatly reducing the number of product returns.

With consumers able to instantly read reviews of everything they are considering buying, they would no longer need to put their faith in brands. Advertising and attractive packaging would become less important than the rating displayed online next to a product. Retailers would increasingly invest in making things people actually want, rather than enticing consumers to buy more and more things they do not need. With the majority of products no longer displayed to consumers in or with their packaging, the appearance and aesthetics of packaging would no longer matter much beyond its functionality.

Packaging, therefore, would mainly serve the purpose of delivering a product safely to the consumer. A wide range of standardised, durable and reusable packaging would be available for different types of transaction, designed to allow goods for delivery to be packed in a way that minimised package size and helped prevent damage. Electronics and appliances, for instance, could be delivered in strong cases that are immediately returned with the courier.

Reusable packaging would be mostly modular and made from a single material to ease recyclability at end of life. Some packaging would be directly compostable rather than reusable. Mushroom packaging (mycelium), for instance, could replace expanded polystyrene foam (EPS) for the safe transport of fragile products. The move away from single-use plastics would be further strengthened by governments imposing bans on all 'problematic' plastic packaging. In OECD countries, this would mainly mean a ban on plastic packaging that was not recyclable or that contained harmful substances, while in non-OECD countries, governments would ban plastic packaging items that were commonly found littering urban and natural environments. These legislative changes could create further pressure on retailers to shift to mostly durable, reusable packaging that was part of a managed product or product-service offering.

For products delivered to the home, the courier would take packaging back for reuse. To minimise empty space in delivery vehicles, consumers would be incentivised to fill standardised boxes as much as possible. Online tools could calculate the optimal amount of produce to order. For purchases collected at pick-up locations, consumers could either bring their own reusable packaging, obtained from (online) stores and delivery companies, or pay on pick-up a refundable deposit for returnable packaging.

In non-OECD countries, e-retail via smartphones could leapfrog many conventional stores altogether. Many non-OECD governments, meanwhile, would push for rapid reductions in the use of packaging as they struggled to cope with the volume of single-use plastics in the face of less well-developed waste-disposal infrastructure.

Overall, 'servitisation'[5] and the sharing economy have already significantly reduced the need for packaging. An increase in modular products designed for easy replacement and disassembly would allow faulty components to be easily swapped out, reducing the need to buy an entirely new device or appliance that previously came with extensive packaging for both the product and its components.

The availability of low-cost renewable electricity would allow many food items to be frozen immediately after production until the moment of consumption, drastically reducing the need for protective packaging. Fridges could be designed to check how long food can be preserved and, based on the items in the fridge, provide suggestions as to what needed to be consumed shortly.

With consumers ordering 80% of their products online, traditional shops would, to a large extent, be replaced by 'experience stores'. Rather than empty shopping streets, consumers would continue to visit stores in large numbers as a leisure activity. Rather than primarily stocking products for display and purchase, stores would have become delivery hubs, freeing up floor space for lifestyle experiences. At many stores, consumers could be directly in contact with producers, who would offer their products on demand, with consumers able to influence the design to meet their specifications. Same-day design and pick-up could become a reality, not least due to 3D printing.

Supermarkets would have switched to a largely 'self-dispensing' model, with a greatly increased supply of frozen products, thereby reducing or eliminating the need for packaging. Consumers would bring their own containers, boxes, tubs and bags, or pay a deposit to use a variety of reusable in-store tubs and baskets to fill with the items they wanted to purchase. A wide variety of foldable and 'flat pack' containers that minimised space when empty could be available to consumers. If desired, consumers could also order pre-filled containers for pick-up, with a small deposit paid for the reusable container.

Liquids such as shampoos and detergents would be made in hyper-concentrated form, such as solid dishwashing tablets that the consumer would put in a bottle and fill with water to dilute and create dishwashing liquid. Single-use beverage bottles would mostly cease to exist, as water filters and drinking-water fountains would be ubiquitous, while flavoured drinks would come in the form of small, concentrated packs that could be rapidly turned into a fizzy drink at home using a beverage maker.

There would also be major uptake of the use of lease, rental and product-service formats, with consumers increasingly renting or buying a service rather than a product. Apps would make it convenient to rent products at short notice and for very short or longer periods of time, either from retailers or from other citizens in the neighbourhood. With products frequently loaned and re-loaned, packaging would reflect this shift, moving to strong, durable and reusable packaging that ensured products arrived and were returned in perfect condition, day after day.

For durable products, PaaS would take over many markets, with consumers purchasing a home-appliance package suited to their needs. All products would be designed for longevity.

5 Using products to sell the provision of services rather than just one-off product sales.

The service provider would ensure appliances kept functioning as intended and would exchange components or entire products, should a product break down or the consumer wish to 'buy' something else. Packaging, therefore, would be durable and standardised and remain with the service provider for consumer delivery and pick-up.

The breakthrough of additive manufacturing, particularly as a result of the 3D printer, would also fundamentally change supply chains. The production of many products would take place on a small scale and within the vicinity of, or even in, consumers' homes. Cell phones, for instance, could consist of a core block that could be reused or replaced and a case that was printed on demand via a large and widespread network of 3D printers. Consumers could collect the phone at a nearby store or pick-up point or, for smaller products, even purchase the design and print it at home. With 3D printing only requiring the transport of raw materials, little packaging would be necessary.

Even meals could be increasingly created on demand, allowing consumers to use a wide variety of organic materials to create food and reduce food waste. For perishable foods still purchased online or in a shop, such as fresh fruit and vegetables, cheese and meat, edible coatings would be developed to help preserve them, making plastic packaging redundant.

Overall, by 2050 the change in consumer mindsets on convenience and ownership would lead to major shifts in the way we shop and purchase and fuel an increase in local and more tailored production close to home. This would create major opportunities and strong incentives for retailers, manufacturers and service providers, such as couriers, to massively reduce the volume of single-use plastic packaging and move to durable/reusable or compostable/edible packaging.

3.2 The implications for plastics

3.2.1 Overview

Our 2050 vision would lead to an overall decrease in the weight of single-use plastic packaging consumed of 80% compared with BAU. We assume 2050 BAU production for packaging to be 411 Mt, based on 146 Mt of packaging in 2015 (Geyer et al., 2017) growing at a rate of 3% a year (Gaster, 2019). The 2050 vision would result in remaining annual single-use plastic packaging consumption (from virgin or recycled feedstock) of about 82 Mt.

This reduction is the result of dematerialisation and substitution, accompanied by significant increases in the durability and utilisation of packaging, which could rapidly take off in the next decade and beyond. Substitution of single-use plastic packaging with single-use compostable or edible (non-plastic) packaging would account for about 25% of the reduction versus BAU (Material Economics, 2018b). Another 60% would come from dematerialisation, while 15% would stem from the use of durable, non-plastic substitutes in select applications. These include materials such as cardboard and thin metals.

Plastics would still be used for packaging in 2050, but mostly for applications with a long lifespan. The annual demand for durable, reusable plastic packaging would amount to 9.9 Mt, met by recyclable, bio-based, 'drop-in' substitutes. This packaging would be designed for its durability and reusability, as well as optimal recyclability at the end of its life, but would result in far lower annual replacement quantities than current single-use plastic packaging.

Remaining single-use packaging

The 82 Mt of annual single-use plastic packaging remaining in 2050 would have an average lifespan of less than six months[6] (Geyer

6 Ninety-seven percent of annual plastic packaging produced becomes waste in the same year (Geyer et al., 2017); the remaining 3% may have a slightly longer lifespan, but for purpose of this analysis, it has been assumed that the total quantity of plastic packaging currently produced (2015 data) is similar to the amount of single-use plastic packaging entering the market in one year.

et al., 2017). However, 65%[7] of the waste generated could be recycled from the 76% of waste collected[8] (Material Economics, 2018a). This would be done through a combination of mechanical (65%) and chemical recycling (35%) (Hundertmark et al., 2018). Mechanical recycling is used mainly for easy-to-recycle plastic types (mostly PET and HDPE) that can be used for applications of a similar value to or higher value than the original, such as current recycling of PET bottles. As of 2015, PET and HDPE together accounted for 44%[9] of the packaging market (Geyer et al., 2017), but careful rethinking of single-use packaging design towards greater recyclability, we estimate, could boost this to at least 50% by 2050.[10]

Major improvements in mechanical recycling could allow the single-use plastic types (PET, HDPE), which are predominantly recycled in this manner, to be recycled at a similar or higher value than the original products, resulting in six or seven lifecycles compared with the current average of just one additional lifecycle (Ellen MacArthur Foundation, 2017). For chemical recycling, the number of lifecycles is unlimited.

As a result, we estimate that, through a combination of mechanical and chemical recycling, the single-use packaging sector could supply 36 Mt of recycled feedstock of sufficiently high quality for use in new packaging applications in 2050, thus covering 44% of its annual production.[11] This means 56% of annual consumption of single-use plastic packaging, equivalent to 55.5 Mt, would have to be supplied from other feedstocks, potentially including recycled plastic feedstock from other sectors, depending on availability and suitability.[12]

Durable, reusable plastic packaging

Part of the reduction in single-use plastic packaging would be offset by an increase in plastics demand for durable packaging purposes. By 2050, we estimate consumption of durable plastic packaging at 9.9 Mt annually, which could be met by recyclable, bio-based, drop-ins of PET (50%) and HDPE (50%).

The proportion recycled would increase to 80% for durable, reusable packaging, assuming a 91% collection rate,[13] as changes in packaging's business and ownership models would allow suppliers, retailers and couriers to retain a much greater degree of control over end-of-life packaging. Consumers could be incentivised through deposit and payback schemes to bring their own end-of-life durable packaging to a collection point. Recycling could supply 6.6 Mt annually of sufficient-quality recycled feedstock for direct reuse in new durable, reusable packaging applications, covering 67% of annual consumption.

7 Global average; in some markets, a higher share of remaining single-use packaging is expected to be collected and subsequently recycled.

8 This assumes a loss rate of 11% (Hundertmark et al., 2018).

9 2015 data: PET 23%, HDPE 21% (Geyer et al., 2017).

10 Although PET and HDPE are deemed easiest to recycle using mechanical recycling, many of their current applications, such as single-use bottles, tubs and containers, are excellent candidates for single-use plastic packaging phase-out, curbing their growth in market share by 2050.

11 In reality, some of this recycled feedstock may be used in applications outside the single-use packaging sector. However, the amount of recycled single-use plastic packaging that could meet quality requirements for use in similar packaging applications covers 44% of total annual demand.

12 There are currently some limitations on the use of feedstock from other sectors for applications such as food-grade, single-use plastic packaging. Mechanically recycled feedstock from the electronics sector, for instance, contains additives that are toxic and could leach into food if recycled as food packaging.

13 We assume an 11% loss rate.

4 Pathways to 2050

To achieve our 2050 vision, both the packaging sector and consumers would need to take various actions between now and 2050. The first part of this section outlines some of the most important changes needed to achieve our vision and when these would be technically possible. The second part provides a brief analysis of current trends in the packaging sector and indicates how these could contribute to achieving the low-plastic-consumption scenario. The third part builds on these trends to provide a high-level political economy analysis exploring what might be done, and by whom, to shift the sector away from BAU towards the low-plastic-demand scenario of 2050. This includes the interests and incentives of various key stakeholders that sustain the sector status quo and how they would need to change.

4.1 Technical possibilities for change

Table 1 lists key actions required to achieve our low-plastic-consumption scenario in 2050 and, broadly speaking, when each of these actions is likely to be technically possible. This is distinct from when they are likely to be implemented, which involves political, economic and behavioural considerations. We divide the actions into three degrees of technological readiness:

- **possible now** – changes that can be made today with existing technology

Table 1 Indicated timescales for technical advances to achieve our 2050 vision

	Possible now	Possible soon (by 2035)	Possible later (by 2050)
Ban problematic single-use packaging	✓		
Introduce deposit schemes	✓		
Incentivise consumers to reduce single-use plastics	✓		
Substitute single-use packaging	✓		
Encourage self-dispensing and refill	✓		
Encourage fruit and vegetables to be sold loose	✓		
Encourage supplier-owned durable packaging	✓		
Expand leasing and servitised models	✓		
Impose a levy on single-use plastic	✓		
Move to single-material packaging or separable multi-material packaging		✓	
Move to more recyclable plastic types		✓	
Encourage enhanced sorting and recycling		✓	
Expand 3D printing facilities		✓	
Develop materials designed to facilitate multilayer reprocessing, such as reversible adhesives			✓
Develop 'superpolymers' with the functionality of today's polymers, but with superior recyclability			✓
Develop chemical marking technologies to improve recycling			✓

- **possible soon** – the technological requirements to carry out these changes are already being developed; they typically require incremental advances or repurposing of existing technologies.
- **possible later** – these changes require fundamental technological advances and may currently be at the concept stage of technological development or require a plausible but unrealised technological breakthrough.

These various actions are specific to plastics used in the packaging sector and complement those set out in the synthesis report for plastics in general (for example, to develop wide-scale chemical recycling). These plastic-focused technical actions also complement the broader societal changes that would lead to the outcomes envisaged in the LED scenario (namely clean, compact cities) and the policy and sectoral trends described in the following sub-section.

4.2 Drivers and trends

Most of the components that together create the 2050 vision for packaging are already present on a smaller scale today. This section outlines key trends and drivers of change towards lower plastic packaging consumption arising from changes in the manufacture, use and end-of-life treatment of plastic packaging.

4.2.1 Regulation of single-use packaging

A first, critical step in curbing the growth in single-use packaging is banning the most problematic single-use packaging items. Problematic packaging includes those items that are known to be frequently littered in the natural environment, contain hazardous substances or are very difficult or impossible to recycle.

Many countries have already introduced bans on single-use plastic bags (UN Environment, 2018c), including several small island developing states and countries in Africa with limited waste-management capacity. Increasingly, governments and companies are also introducing bans on a range of common plastic tableware items, such as straws and stirrers. The EU, for example, adopted a single-use plastics directive in June 2019 that bans, from 2021, a range of throwaway plastics commonly found on Europe's beaches (European Union, 2019).

Subnational governments and NGOs are also taking action. San Francisco has prohibited the sale and free distribution of drinking water in small single-use bottles on city property, requiring drinking fountains and bottle filling stations to be installed. Programmes like the Surfrider Foundation's 'Ocean Friendly Restaurant' scheme guide businesses on how to eliminate single-use packaging in restaurants and takeaways or to provide such items only on explicit request (5 Gyres Institute, 2018).

Virgin fossil-fuel-based plastics are often cheaper to make than using recycled material, particularly for types of plastic with weak recycling markets (which is currently the case for most plastics). Imposing a levy on manufacturers for using new, single-use plastic rather than recycled material would improve the competitiveness of recycled plastic, encourage innovation to enhance the recyclability of plastics and increase the volume of recycled plastic feedstock (George, 2018).

4.2.2 Deposit schemes

Several countries in Europe, such as Germany and the Netherlands, have had deposit schemes for plastic PET bottles in place for decades. Consumers pay as much as €0.25 per beverage bottle purchased and can take empty bottles back to almost any supermarket to get a refund. These deposit schemes usually have recycling collection rates in excess of kerbside recycling and could be expanded to incorporate more plastic packaging items of high recycling value.

Norway has achieved a collection rate for plastic bottles of 97%, through a combination of a deposit scheme and a per-bottle tax levied on companies manufacturing or importing plastic bottles. If companies can prove they are recycling the bottles, the tax is lowered and eventually waived at recycling rates of 95% or more (Environmental Technology, 2019). Restaurants could also encourage consumers either to bring their own containers for take-outs or to take home a reusable container, on which they would pay a deposit (5 Gyres Institute, 2018).

The Plastic Bank, a non-governmental organisation, is rolling out an initiative in low-income countries such as Haiti, allowing citizens low-income countries to exchange any plastic bottles they collect for cash or digital tokens, which can be used to buy goods or pay for a range of basic services (such as school tuition, medical insurance, wi-fi, electricity or sustainable cooking fuel). The model assigns value to used plastics that might otherwise be littered, while generating income for those who collect it (Nava, 2018).

The use of harmonised reusable packaging designs combined with deposit schemes would allow economies of scale in distribution and logistics. Universal bottles with a deposit, which are collected and cleaned and can subsequently be refilled by any beverage producer, have been around for a long time in some regions. It is a practice that could also be applied to, for example, ice-cream containers, which could be refilled by any ice-cream producer. A variety of reusable packaging solutions could be made available to consumers, in exchange for a small deposit, that matched the dimensions of products or amounts commonly purchased.

4.2.3 Substitution of packaging materials

For certain single-use packaging applications, plastic can already be substituted by alternative materials. For example, substituting EPS, which has almost no recycling value, with mushroom (mycelium) packaging – an emerging alternative that can be grown and composted afterwards. In 2018, IKEA announced that it would begin to implement this substitution across all of its products (Lempert, 2018). Another example is the return of glass beverage bottles – from milk to cola – which can be collected, cleaned and reused.

Using water-soluble films, such as polyvinyl alcohol (PVOH), helps to eliminate individual plastic dishwashing and laundry detergent tablet wrappers. Seaweed is being trialled in single-use food containers, while a fully biodegradable water bottle that can hold water for up to several days has been developed from red algae (Baker, 2018). By Humankind sells mouthwash tablets that consumers dissolve in a glass of water to use, and which are delivered in compostable packaging (Ellen MacArthur Foundation, 2019). Inroads are also being made into edible coatings to replace plastic wrappers (World Economic Forum et al., 2016).

Even if a company uses recyclable materials, however, it is no guarantee that the packaging will be recycled. A Finnish study of McDonalds' restaurants, for instance, showed that only 29% of its restaurants' packaging was recycled, even though 93% of the packaging provided was recyclable (Zero Waste Europe, 2018). An easy substitution for eat-in clients, in this case, would be to provide reusable plates and cups.

This does not address those diners using a restaurant's takeaway or delivery services, however – a segment that tends to be highly packaging-intensive. Using reusable and long-life stainless-steel boxes, for example, could help address the high packaging footprint of the convenient on-the-go food sector. Metal boxes also overcome the concerns associated with plastic boxes about the potential leakage of chemicals from plastics into heated food. In India, tiffin boxes, as such stainless-steel boxes are called, are widely used in food services, for instance in the delivery of ready-made lunches to office workers. In Mumbai alone, some 200,000 tiffin boxes are delivered and picked up every day (Ellen MacArthur Foundation, 2017).

At the same time, this does not mean that any alternative material is better than plastic as a substitute. With plastic being relatively lightweight, the environmental cost per unit of alternative material could exceed that of plastic (UN Environment, 2014). A Trucost study published by a plastics lobby group suggests that, on average, in terms of weight, over four times the amount of material is needed for alternatives, such as paper, wood and metal, to perform the same function. This, as well as the effectiveness of collection and recycling, could potentially lead to a greater environmental footprint if the alternative were also used as a single-use, throwaway packaging item (American Chemistry Council, 2016).

4.2.4 Enhanced recycling

According to the British plastics industry, as much as 80% of existing packaging could be made more recyclable. Design plays a critical role in the end-of-life economics of plastic packaging, with design choices impacting the feasibility of after-use processes, such as sorting and cleaning, as well as the volume of recyclable content available (World Economic Forum et al., 2016).

For packaging items that are typically made from plastic types that have no or low recycling value at present, it may be possible to convert them to plastic types that are easy to recycle and for which a healthy recycling market already exists – particularly PET and HDPE. Yoghurt containers, margarine and ice-cream tubs, for instance, could possibly also be made from PET, the same plastic type used for water bottles.

Additives are also a major concern and can impact recyclability, for instance by making plastic brittle or causing discolouration in the recycling process. They may also pose a health hazard when recycled plastics with additives are used in food packaging, for example. Uncertainties about additives in recycled content can also discourage demand for recycled plastics in new products with specific safety requirements. A chemical protocol that helps reduce the number of allowable additives from thousands to no more than hundreds and requires clear disclosure of hazardous substances could support a healthy recycling market (European Commission, 2018). Creating or improving standards and guidelines that simplify the composition and specification of plastic items would also provide great benefits, as they would reduce the variability in content of recycled plastic types, lowering the risk of suboptimal recycled plastics re-entering the supply chain.

Black plastic packaging – frequently used for single-use food trays – is particularly challenging to recycle, because the infra-red technology widely used in sorting facilities fails to recognise and sort plastics of this colour. Switching to transparent or differently coloured plastic would help overcome this problem (Rosane, 2018).

There is also significant room for improvement and innovation in the optimisation of processes and technologies for mechanical recycling. These include improvements in optical sorting technologies, which recognise different plastic types by illuminating the material and analysing the reflection spectrum, the use of image recognition in sorting to recognise specific packaging items, and the use of chemical markers that can be read by sorting machines.

Nonetheless, even optimised mechanical recycling is unlikely to be able to handle every plastic packaging type or item. This is where chemical recycling may come in, breaking plastics back into chemical feedstocks, enabling potentially 'infinite' loops. However, chemical recycling is not yet used at scale. The various technologies in question, such as pyrolysis and depolymerisation, face challenges that will need to be overcome to make them technically, economically and environmentally feasible.

4.2.5 Self-dispensing from bulk containers

A growing number of grocery stores are starting to set up refill stations with self-dispensers, where customers can fill containers with a desired quantity of products, such as nuts, cereals or dried fruit. Transparent plastic bags are often provided for the customer to fill, which does not necessarily contribute to a reduction in single-use plastic packaging. Rather, a system that allowed customers to take their own reusable bags and containers for refill, or had them use store-provided reusable containers against a small deposit, would be far preferable (Potting et al., 2017).

This is exactly what recycling company TerraCycle aims to achieve with Loop, a platform launched in 2019 and now being tested by a range of well-known brands and grocery chains, including Carrefour and Tesco. Loop offers reusable containers designed for a hundred or more reuse cycles, for which consumers pay a small deposit. Consumers return the empty, used containers to participating stores and can refill with a clean container.

Loop also works with (predominantly) online retailers, which deliver common products in (branded) reusable Loop containers to consumers and, at the same time, pick up empties, which are washed and cleaned for reuse at a central facility. Eventually this could even lead to households having a 'reuse bin' in addition to recycling bins, with empty reusable packaging items for collection (Makower, 2019).

Restaurants and other food services, such as fast-food restaurants, can also be encouraged to reduce single-use packaging through refill systems. Delivery and takeaway food services present a particularly high risk of littering due to their on-the-go nature, with a major proportion of items commonly found in beach clean-ups attributed to this sector (Cuff, 2018). The Heinz company alone, for instance, reportedly manufactures 11 billion single-use ketchup sachets a year. Instead, food or drinks services could set up a dispenser, with condiments, sugar and milk on tables, or on the counter for takeaways (Zero Waste Europe, 2018). Food delivery company Just Eat is trialling a solution for cases where dispensers are not a suitable solution, such as pizza delivery. It is using sachets made from seaweed, which biodegrade in six weeks in a compost bin.

4.2.6 Durable packaging

A variety of increasingly common business and revenue models allow for the introduction of durable reusable packaging for pick-up and delivery, as well as product packaging, with suppliers retaining ownership. These range from online stores, such as supermarkets, where consumers shop regularly; PaaS models, whereby the customer purchases the service, rather than the product; and community-supported agriculture, whereby consumers are delivered a weekly box or basket of local produce. These models are often based on local presence, with shorter distribution distances, helping to facilitate the reuse of packaging (Zero Waste Europe, 2018). Standard sizes for packaging could be used, allowing more goods to fit into a delivery vehicle, with consumers encouraged to fill their boxes completely when ordering. The higher production cost of durable packaging would be offset by its longer operational lifetime, with the cost spread over many uses.

Companies can also move away from single-use plastics beyond consumer packaging. Belgian grocery chain Delhaize, for instance, imports its best-selling wines in bulk, bottling them close to its local market in reusable bottles (World Economic Forum et al., 2016). In some sectors and countries, third-party operators have entered the market, offering reusable business-to-business packaging as a pooling service to companies in a single or multiple industries. Svenska Retursystem operates a large pool of reusable packaging, serving the entire Swedish grocery sector. Almost every perishable product in every grocery chain in Sweden is delivered in a standardised, reusable crate, placed on a reusable plastic pallet. Another example is Brambles, an equipment pooling company, with approximately 500 million pallets, reusable crates and containers. Thousands of companies use Brambles' assets in their supply chains (World Economic Forum et al., 2016).

4.2.7 Leasing and servitisation

Sharing and servitisation models incentivise manufacturers to enhance the durability and modularity of their products, so they can be used for longer and components can be easily replaced when needed. This would greatly increase the utilisation of consumer products and reduce whole-product obsolescence. The longer lifecycle of these products would reduce the 'velocity' at which they travel through the economy and, thus, the number of products produced, delivered and discarded by consumers. Packaging would be functional, ensuring products arrive with and return from consumers in good condition.

For many consumer products, the service they provide is their most important asset. Consumer preferences and behaviours are also slowly shifting to concepts and business models that provide access over ownership. Younger generations, in particular, may more easily forego ownership in exchange for a reliable, guaranteed, high-quality service when they need it. Power tools, for example, often sit idle in garden sheds, whereas a tool rental service allows consumers to access the right tool for a certain job, for the right amount of time, before it's returned and rented out to someone else. A 'circular' appliance leasing service incentivises suppliers to provide durable, modular products that last for a long time, whereby faulty components can be swapped out easily, avoiding the need to replace the entire product.

In Western Europe, many examples of PaaS have been brought to consumers in recent years, from washing machines-as-a-service (Bundles) and lighting-as-a-service (Philips) to bicycles-as-a-service (Swapfiets) and jeans-as-a-service (MudJeans) (Huilema, 2018). Such models reduce single-use packaging by increasing the utilisation and lifespan of common consumer assets, with the supplier retaining ownership, enabling the use of durable, reusable packaging that remains the property of the company (Ellen MacArthur Foundation, 2019).

4.2.8 Multi-material packaging

Many plastic packaging items cannot currently be recycled, as they consist of two or more plastic types, or plastic and another material laminated together. This is particularly the case with 'smart' and flexible packaging, comprising multiple materials. Both types of packaging are on the increase (George, 2018). Many people, for instance, may not realise that a paper cup, which appears to be an attractive alternative to plastic cups, usually ends up in landfill or incineration, because its thin plastic lining makes it very difficult to recycle and requires separate collection and processing.

Emerging innovations may offer a solution to the recycling challenges these packaging items pose. Some use a single material to replicate the utility of the multi-material alternative or contain reversible adhesives, such as water-soluble glues, allowing multi-material layers to be separated after use (World Economic Forum et al., 2016). The University of Pittsburgh in the United States is trialling nanotechnology to create a single recyclable material to replace layered packaging (Nava, 2018).

4.2.9 3D printing

As shops progressively turn into experience centres and pick-up hubs, suppliers could produce more and more goods on demand, providing consumers with options for personalisation and customisation. This could be further enabled by a dense web of 3D printers, producing a variety of goods from basic materials, with same-day pick-up. Production could, thus, become more local, and the short supply chain to the consumer would make single-use packaging mostly redundant.

3D printing holds promise in the production of a variety of common products, altering how and where they are produced, thereby impacting the role and necessity of packaging. Local, small-batch manufacturing allows products to be made much closer to where the demand is, even in the consumer's home. A global network of 3D printers with spare capacity could give consumers access to 3D printing near to where they live. Fairphone's 3D printed phone cases, for instance, negate the need for packaging in plastic clamshells or pouches, with the user collecting the finished product from a nearby point of production (World Economic Forum et al., 2016).

Even plastic waste could be directly converted into new objects through 3D printing. ReDeTec has developed a unique 3D printer, the ProtoCycler, which can be loaded with plastic waste, such as empty bottles and rejected 3D-printed models, and use it to create new filaments, which are then used to print new items (Baker, 2018).

4.2.10 Online shopping

Online shopping has seen tremendous growth and, in some countries, such as the United States, is seeing sales values at certain times of the year approaching those of bricks-and-mortar retail outlets. Multi-channel retailers that have both physical stores and an online presence allow consumers to purchase their in-store items online as well and provide additional product information – for instance, enabling a shopper to use their smartphone in store to look up product features – then deliver the product to a buyer's home or prepare it for in-store pick-up. To reduce the packaging impact of online shopping, LimeLoop rents out 'smart shippers', or reusable packing, to webstores through a subscription service, with the web stores delivering orders to customers in returnable pouches (Ellen MacArthur Foundation, 2019).

In non-OECD countries, a growing generation of internet-savvy citizens is also embracing online technology. In sub-Saharan Africa, the penetration of mobile phones and an increase in internet speed is bringing more people to online marketplaces. At the same time, online reviews have taken off in a big way, ranging from consumer reviews of products on online sales platforms, such as Amazon, and dedicated websites, such as Yelp and Tripadvisor, to search engines like Google. Increasingly, brands need to entice consumers with good reviews rather than flashy packaging (NationMaster, 2019).

Macy's department store in the United States uses an omni-channel approach, driving store customers to the web and online customers to its stores. Its click-and-collect programme allows a shopper to check local in-store availability, reviews and inventories and pick up items in store, while in-store shoppers can have their purchases delivered to their homes (Waldron, 2019). In 2019, Macy's launched 'Story', a narrative-driven retail experience, in a few dozen stores, making shoppers' experiences more experimental, encouraging them to discover emerging brands and attend promotional events. As online shopping means consumers do not need to visit a store to make a purchase, department stores such as Macy's, and Selfridges in the United Kingdom, have started to innovate with unique in-store experiences (Milnes, 2019).

Change is also underway in the grocery sector. In the UK, supermarket chain Iceland – with more than 900 stores, selling a wide range of frozen foods – has now become a leading online grocery retailer. UK grocer Marks & Spencer ships 98% of its products from supplier to store in reusable packaging crates (World Economic Forum et al., 2016). French supermarket giant Carrefour has started allowing customers to bring their own containers from home in a bid to curb plastic packaging (Lugris, 2019). Both Carrefour and British supermarkets are trialling refillable rather than recyclable containers, with consumers paying a small deposit. The empty containers are collected, cleaned and refilled for reuse (Hope, 2019). Meanwhile, British supermarket Morrisons is trialling over 125 plastic-free fruit and vegetable offerings, which consumers can buy loose or in paper bags (Plastic Free World, 2019). Berlin supermarket Original Unverpackt is one of a growing number of supermarkets that sell products free of plastic. The supermarket makes extensive use of self-dispensers (Mann, 2016).

4.2.11 Retailing innovation

Surveys show that consumers are increasingly frustrated with the level of over-packaging of fresh produce – shrink-wrapped cucumber being one of the most emblematic examples. Although such packaging is said to keep produce fresh for longer, thereby reducing food waste, at the same time more than one-quarter of avoidable food waste each year comes from food that is thrown away in its packaging, either opened or unopened. In addition, there is growing concern about the risk of certain plastics leaking harmful chemicals into the fresh food they protect.

Moreover, multi-packs, while boosting sales, can also increase the risk of food waste, with the consumer potentially having to purchase more than they need. Examples include citrus fruits, onions, potatoes and bananas, which are commonly sold in mesh or plastic bags by a certain number or weight. A number of supermarkets in the UK, such as Marks & Spencer, Waitrose, Sainsbury and Aldi, are trialling the sale of loose fruit and vegetables.

To overcome the challenges of conveying information about a product or adding barcodes without the use of packaging, company Laser Food has developed a food-labelling technology that uses laser marking. It does away with the need for packaging or stickers, with a variety of large retailers across Europe trialling the technology (Zero Waste Europe, 2018).

A common problem in many lower-income communities is access to small quantities of household liquid products. Such households are unable to afford bulk quantities and tend to buy single portions of liquids in plastic sachets. The same communities often lack basic solid-waste provision, with the result that there is substantial littering. Algramo has designed a dispensing machine that allows small quantities of liquids to be purchased at an affordable price, using small reusable containers, eliminating the need for disposable packaging.

Where bans on single-use plastics are not possible, another option is to incentivise consumers to forego single-use plastics for a more sustainable option, or to encourage them to keep single-use items in use for longer. In many jurisdictions that do not have a complete ban on single-use plastic bags, consumers are being charged, particularly by grocery stores, for the use of single-use shopping bags and simultaneously offered reusable bag options. Coffee chain Starbucks provides customers with a discount if they bring their own cup and, in certain countries, has introduced a levy on customers who take out single-use coffee cups. The installation of drinking fountains in public places and bottle refill stations for water and other drinks in, for instance, offices and schools can reduce the mountain of single-use water bottles being purchased by consumers every day (5 Gyres Institute, 2018).

Liquids, from dishwashing liquids to shampoos, detergents and flavoured beverages, could be made in highly concentrated form, reducing transport costs by up to 90%. Shampoos and dishwashing liquids could be provided in the form of tablets that the consumer can dilute at home, while beverages could come as small refill packs of highly concentrated liquids ('syrup') or as granules, which are prepared in a beverage maker. Drink dispensers using powdered drink mixes and carbon dioxide cartridges are readily available on the market today (Potting et al., 2017).

Enhanced IT capacities provide better possibilities for retailers to create intelligent products that are able to communicate with the consumer, supplier and other relevant parties, such as fridges that help reduce food waste and packaging that monitors its contents. The startup company Vesta Smart Packaging was established to cut single-use plastic waste. It makes smart, durable, refillable packaging that connects to the retailer and can report back to base, for example when it is time for a refill (Flockett, n.d.). The MIWA pilot system provides standardised, smart-powered reusable capsules to producers, who fill them and send them for direct installation at partner retailers (Ellen MacArthur Foundation, 2019).

4.3 Political economy factors

The packaging sector provides a very plausible political economy context for the change set out in our 2050 vision because, as highlighted by Nielsen et al. (2019b), plastic waste is a disproportionately politicised issue. Plastic packaging waste and pollution are more visible than other kinds of pollutants and, as a result, more widely perceived as societal problems, more than plastics production or consumption. A pathway to change is likely to build on existing public concern and policy momentum globally to address packaging waste.

Individual events and flashpoints can provide the catalyst to spur policy action. For example, Clapp and Swanston (2009) describe how various locally specific circumstances pushed the issue of plastic-bag bans up the agenda. In Bangladesh, their role in blocking drains and causing floodwaters to persist was key; in India, it was the health threat to free-roaming sacred cows; in Taiwan, the release of toxins from plastic waste incineration (substantially increased by rapid economic growth) proved crucial; while in South Africa, it was the unsightliness of plastic bags and their perceived damage to the country's tourist image that did it. In all these cases, individual windows of opportunity were seized by bottom-up campaigns, led by local activists, or 'norm entrepreneurs', that turned public attitudes against plastic waste (Clapp and Swanston, 2009). The visibility of plastic packaging makes it a potential target for public mobilisation against businesses: for example, the Plastic Attack organisation, which originated in the UK, encourages supermarket shoppers to coordinate in removing all plastic packaging from their shopping and leaving it behind at the supermarket.

Plastics polluting marine environments and microplastics entering the food chain, for example, are potent visuals and narratives capturing public attention. As a result, plastic packaging is likely to remain a prominent public issue demanding a policy response. Existing policies to tackle plastic packaging have proved popular; Convery et al. (2007), for example, ask whether the Irish plastic-bags levy is 'the most popular tax in Europe'. The political economy challenge for the 2050 vision is to create incentives for the response to move up the circular economy hierarchy – to reduce and reuse, not just recycle – and to move towards the envisioned world of alternative shopping experiences that require less packaging altogether. In doing so, allies may be found in private-sector actors who would stand to benefit from the decline of the traditional shopping experience – online retailers, for example.

4.3.1 Obstacles

Extensive lobbying and threats of litigation can be expected from the plastics industry. The resistance could be significant, due to the simple fact that very large companies benefit substantially from the continued production of plastic packaging. Members of the Plastic Industry Association include Shell Polymers, ExxonMobil and Chevron Phillips (Lerner, 2019). Coca-Cola, Danone, Nestlé and PepsiCo have all resisted a European Commission proposal for mandatory tethered caps on plastic drink bottles (Morgan, 2018). In the United States, industry opposition has even manifested in pre-emptive bills written and promoted by industry prohibiting bans on plastics (Lerner, 2019).

Clapp and Swanston (2009), for example, compare Bangladesh and the United States, arguing that plastics-industry actors played an important role in determining which policy options were adopted in response to the shift in public norms on plastic bags. In Bangladesh, where the industry's structural, instrumental and discursive power was weak, strong legislation emerged at the national level. In contrast, the strong position of the plastics industry in the US economy limited the national policy discussion on plastic bags. Instead, policy talks have taken place in municipalities where the plastics industry is not a significant local employer – and this may prove a more fruitful initial path to policy change.

In other cases, however, despite formal policies banning taxes on plastic packaging, the implementation of these policies has not been comprehensive, as Chitotombe (2014) describes in Zimbabwe, for example. Where plastic-bag bans and levies have had limited impact, the main reasons have been a lack of enforcement and the emergence of a black market (UN Environment, 2018c). Effective enforcement of policies limiting plastic packaging may be a bigger challenge than getting them legislated in the first place.

The public pressure for action on plastic packaging and waste, at least, is unlikely to diminish. However, brands, manufacturers and the petrochemical industry are all likely to respond in favour of recycling, and with substantial recycling pledges, for public relations purposes, even if they lack feasibility. Industry actors are likely to use these recycling commitments to divert attention from policies designed to reduce plastic production. Resistance can be expected from consumer brands more generally to some of the more radical shifts in the consumer experience that our 2050 vision describes, especially if these do not just reduce packaging, but limit the space for branding – (for example, through the use of bulk sales and refillable containers) – or increase costs (through the use of edible coatings, for instance).

4.3.2 Building a coalition for change

A coalition for change would likely involve working with national policy-makers already working on legislation to tackle single-use plastics, to increase the ambition of these policies. This could include moving from levies on plastic bags to bans but, more importantly, to encompassing a wider range of plastic packaging and to regulations on production. This could be supported by prominent public campaigns on the problem of plastic waste, targeted at policy-makers and at disrupting broader consumer norms. While much of the retail industry may remain sceptical of more radical change, some allies are likely to be found among those companies looking to demonstrate environmental credibility on an increasingly prominent issue.

International policy-makers could also form part of a coalition. The EU has been a leader in driving policy to tackle plastic waste, including a ban on many single-use plastic products, so could be an initial target for advocacy. Borrelle et al. (2017) suggest that a necessary part of an international agreement will be some form of global fund for waste-management infrastructure, as many localities lack the infrastructure to deal with their large-scale imports of single-use plastic products. This may be best targeted at the marine impacts of plastic waste initially, as an issue of public visibility where there is at least some precedent for global regulation, such as the International Convention for the Prevention of Pollution from Ships.

5 Outcomes in 2050

5.1 Materials forecasts

Plastic production for single-use packaging in 2050 could be around 80% lower than the BAU forecast of 411 Mt, under the vision we set out in chapter 3. This would be almost 40% lower than total plastic packaging production in 2015, and the result of dematerialisation and reuse (avoiding packaging demand) and the substitution with non-plastic materials in packaging.

Dematerialisation and reuse would reduce the production of plastics for single-use packaging by 60% compared with BAU, equivalent to 197 Mt.[14] To reduce the use of some single-use plastic packaging, it will be necessary to replace it with durable plastic packaging, which would see a rise in its production. The 2050 vision assumes durable plastic packaging will increase by the equivalent of 4% of the reduction in single-use plastic (in other words, by about 8 Mt).[15]

The substitution of single-use plastic packaging with non-plastic packaging would reduce the consumption of plastic for packaging in 2050 by about 131 Mt compared with BAU. Single-use non-plastic packaging made from compostable or edible materials would replace 25% of single-use plastics projected under BAU, while non-plastic durable packaging would replace 15% (82 Mt and 49 Mt, respectively).

Figure 1 shows how much dematerialisation and reuse and substitution would contribute to a reduction in plastic consumption for packaging in 2050 per our vision (compared with BAU). Around 60% of the reduction would be through dematerialisation and reuse, and 40% through substitution. Figure 7 shows the breakdown by main plastic type.

5.2 Greenhouse gas emissions and sustainability

In 2015, GHG emissions from plastic packaging production and consumption were an estimated 715 Mt CO_2e globally. The level of plastic packaging consumption estimated in our 2050 vision is 178 Mt CO_2e, a reduction of about three-quarters. This reduction in the consumption of fossil plastics by the packaging sector compared with BAU could reduce global GHG emissions by almost 2 giga tonnes (Gt) CO_2e a year in 2050. Achieving this reduction will depend on the end-of-life disposal of plastic waste from the sector, the GHG impact of non-plastic alternatives and the rate of recycling achieved. If a high proportion of plastic packaging waste is incinerated rather than recycled in 2050, the reduction in GHG emissions could be 1.7 Gt CO_2e.

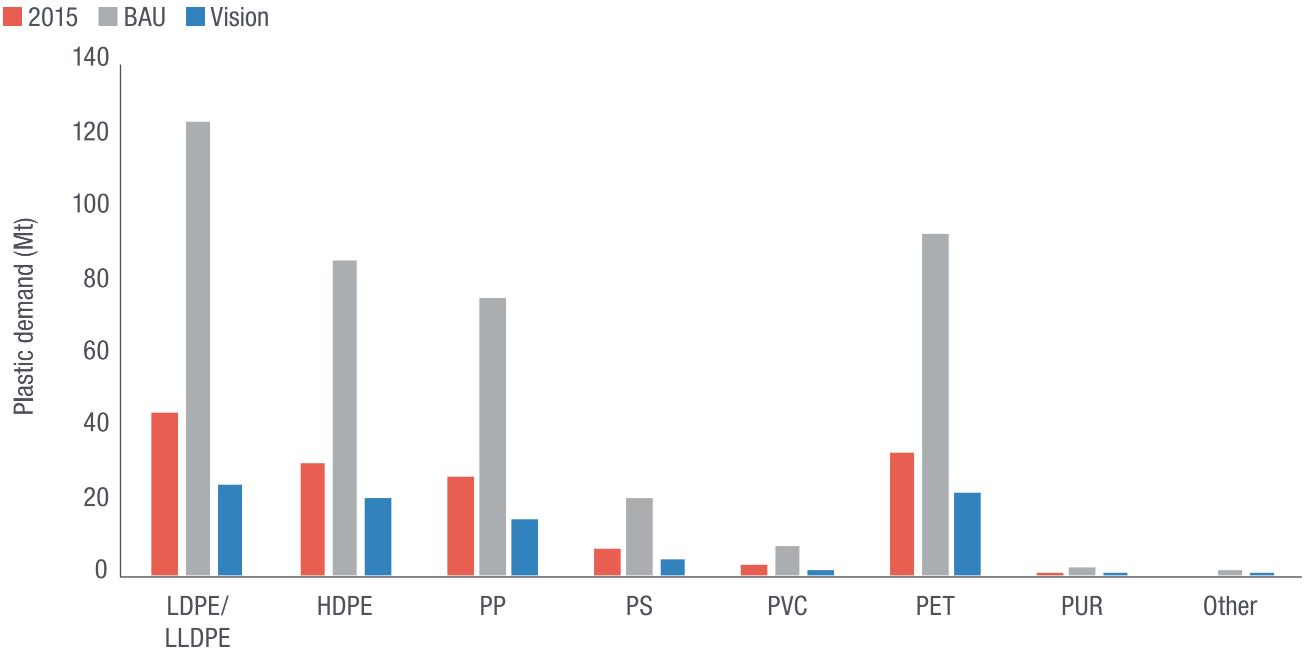
5.3 Waste

The production of plastics for the packaging sector under our 2050 vision will continue to generate plastic packaging waste. Over 90% of the plastic packaging produced would be single-use items (estimated at 82.2 Mt), while a little under 10% would be durable packaging (7.9 Mt). Total waste from single-use plastic packaging in 2050 would, therefore, be 82.2 Mt, assuming the lifetime of single-use packaging was the same as today. However, we assume that 100% of the plastic used for single-use

14 Single-use plastic accounts for 80% of total plastic packaging output.

15 This conservatively assumes that 1 kg of durable plastic packaging replaces 25 kg of single-use plastic packaging. A deposit scheme in the Netherlands found that one reusable plastic bottle replaced 50 single-use bottles.

Figure 7 Scenario comparison, by plastic type used in packaging



Sources: Author's analysis; Geyer et al. (2017)

packaging in 2050 is recycled. Though durable packaging has a longer lifespan, we assume it would still be less than a year, so estimate durable plastic packaging waste in 2050 at 7.9 Mt.

The recycling rates of single-use and durable plastic packaging in 2050 are assumed to be different. The proportion of single-use packaging collected for recycling is assumed to be about 76% and, with 11% losses during processing (Hundertmark et al., 2018), this yields 53.4 Mt of recycled plastic. Waste from durable packaging would yield 6.3 Mt of recycled plastic. Some of this, recycled mechanically, would be of lower quality than its source material and downcycled into plastic products for other market sectors. We estimate, however, that 44% of single-use plastic packaging and 66% of durable plastic packaging could be produced from recycled plastic packaging in 2050.

6 Conclusions

BAU projections of growth in the production of plastic packaging point to a near tripling of the quantity of plastic used for packaging by 2050 on current trends. As plastics are currently made from fossil-fuel raw materials, this increased quantity of plastic would be accompanied by an increase in GHG emissions, as well as plastic waste. Yet, by 2050, GHG emissions need to be net zero if the world is to have a chance of averting catastrophic climate change.

Plastic waste pollution from the packaging sector has attracted the attention of consumers and policy-makers around the world. Concerns about pollution of the marine environment and microplastics in the food chain have prompted increased regulation and outright bans of single-use plastic packaging items, such as plastic bags, in some jurisdictions. However, even with these measures, the production of plastic packaging is expected to increase substantially, and the waste problem cannot be tackled only through higher rates of collection and recycling. Currently, only 26% of plastic waste is recycled globally.

In 2015, each tonne of plastic generated an estimated 4.9 tonnes of CO_2e GHG emissions, but less than 10% of this came from waste (end-of-life) processing. Most of the GHG emissions from plastic packaging were generated during the manufacture of plastic resin and its conversion into packaging items.[16] Tackling plastic waste, therefore, would not significantly reduce the impact of plastic packaging on climate change. Reducing emissions will require action in the production and use stages of the plastic packaging value chain.

Under our low-plastic-consumption scenario for 2050, the production and use of plastic packaging would be about 80% lower than BAU and 40% lower than in 2015. The reduction could be achieved through changes in the manufacture of plastics and packaging, the way packaging is used and waste treatment.

The largest potential reduction in plastic packaging would come from action to dematerialise and reuse packaging, avoiding the demand for new packaging material. This would entail changes in consumer behaviour and business models, supported by regulations to deter single-use plastic packaging.

The second main strategy to reduce plastics in packaging is to substitute them with other materials, be it traditional materials, such as glass and cardboard, or innovative biodegradable materials. The emissions intensity of packaging made from alternative materials would need to be assessed to determine the net effect on GHG emissions.

The action required to achieve our 2050 vision would be an extension of trends and a scaling up of activities that can already be found on a small scale today. Public concern and the current political salience of plastic waste, much of which is from packaging, provide an opportunity to move towards the vision of much reduced plastic packaging and the phase-out of new fossil plastics for packaging uses.

16 Emissions from waste would be more significant if a larger proportion of plastic waste were incinerated as current trends suggest may occur in the future.

References

5 Gyres Institute (2018) *Better alternatives now – B.A.N. list 2.0*. Santa Monica CA: 5 Gyres Institute (https://static1.squarespace.com/static/5522e85be4b0b65a7c78ac96/t/5acbd346562fa79982b268fc/1523307375028/5Gyres_BANlist2.pdf).

American Chemistry Council and Trucost (2016) *Plastics and sustainability: a valuation of environmental benefits, costs and opportunities for continuous improvement*. Washington DC: American Chemistry Council (https://plastics.americanchemistry.com/Plastics-and-Sustainability.pdf).

Baker, M. (2018) 'How to eliminate waste and plastic pollution with science and engineering'. Interesting Engineering, 16 August (https://interestingengineering.com/how-to-eliminate-plastic-waste-and-plastic-pollution-with-science-and-engineering).

Borrelle, S.B., Rochman, C.M., Liboiron, M., et al. (2017) 'Opinion: why we need an international agreement on marine plastic pollution' *Proceedings of the National Academy of Sciences* 114(38): 9994–9997 (https://doi.org/10.1073/pnas.1714450114).

Chitotombe, J.W. (2014) 'The plastic bag "ban" controversy in Zimbabwe: an analysis of policy issues and local responses' *International Journal of Development and Sustainability* 3(5): 1000–1012 (https://isdsnet.com/ijds-v3n5-6.pdf).

Clapp, J. and Swanston, L. (2009) 'Doing away with plastic shopping bags: international patterns of norm emergence and policy implementation' *Environmental Politics* 18(3): 315–332 (https://doi.org/10.1080/09644010902823717).

Conversio (2019) *Global plastics flow 2018*. Conversio and Global Plastics Alliance.

Cuff, M. (2018) '"World first": Just Eat to trial seaweed-based compostable ketchup packaging'. Business Green, 23 July (www.businessgreen.com/bg/news/3036336/world-first-justeat-to-trial-seaweed-based-compostable-ketchup-packaging).

Environment Canada (2019) *Economic study of the Canadian plastic industry, markets and waste*. Ottawa: Environment Canada.

Environmental Technology (2019) 'Norway recycles 97% of plastic bottles'. Environmental Technology, 20 April (www.envirotech-online.com/news/business-news/44/breaking-news/norway-recycles-97-of-plastic-bottles/48873).

European Commission (2018) *A European strategy for plastics in the circular economy*. Brussels: European Commission (https://ec.europa.eu/environment/circular-economy/pdf/plastics-strategy-brochure.pdf).

European Plastics Converters (2017) 'Packaging'. Webpage (www.plasticsconverters.eu/project-1).

European Union (2019) Directive (EU) 2019/904 of the European Parliament and of the Council on the reduction of the impact of certain plastic products on the environment, 5 June 2019 (https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32019L0904&from=EN).

Ellen MacArthur Foundation (2017) *The new plastics economy: rethinking the future of plastics and catalysing action*. Cowes, UK: Ellen MacArthur Foundation (www.ellenmacarthurfoundation.org/assets/downloads/publications/NPEC-Hybrid_English_22-11-17_Digital.pdf).

Ellen MacArthur Foundation (2019) *Reuse: rethinking packaging*. London: Ellen MacArthur Foundation (www.ellenmacarthurfoundation.org/publications/reuse).

Flockett, A. (n.d.) 'Smart packaging to reduce plastic waste'. Startups Magazine (https://startupsmagazine.co.uk/index.php/article-smart-packaging-reduce-plastic-waste).

GAIA – Global Alliance for Incinerator Alternatives (2019) *Discarded: communities on the frontline of the global plastic crisis*. Berkeley CA: GAIA (https://wastetradestories.org/wp-content/uploads/2019/04/Discarded-Report-April-22.pdf).

Gaster, P. (2019) 'Do we really need plastic packaging?' Blog, 7 January. WoodMackenzie (www.woodmac.com/news/editorial/do-we-really-need-plastic-packaging).

Geyer, R., Jambeck, J. and Law, K.L. (2017) 'Production, use, and fate of all plastics ever made' *Science Advances* 3(7): e1700782 (www.researchgate.net/publication/318567844_Production_use_and_fate_of_all_plastics_ever_made).

George, S. (2018) 'Why can't all plastic waste be recycled?' The Conversation, 2 August (http://theconversation.com/why-cant-all-plastic-waste-be-recycled-100857).

Grubler, A., Wilson, C., Bento, N., et al. (2018) 'A low energy demand scenario for meeting the 1.5°C target and sustainable development goals without negative emission technologies' *Nature Energy* 3: 515–527.

Hawkins, G. (2018) 'The skin of commerce: governing through plastic food packaging' *Journal of Cultural Economy* 11(5): 386–403.

Hope, K. (2019) 'Tesco and Carrefour to trial refillable container scheme'. BBC News, 24 January (www.bbc.co.uk/news/business-46863114).

Huilema, L.J. (2018) 'Circular business model patterns and their relevance towards a more circular economy'. Masters thesis. Delft: Delft University of Technology (http://resolver.tudelft.nl/uuid:00e4ca0f-f52e-474c-958e-4511e8de8fe9).

Hundertmark, T., Mayer, M., McNally, C., et al. (2018) *How plastics-waste recycling could transform the chemicals industry*. London: McKinsey & Company (www.mckinsey.com/industries/chemicals/our-insights/how-plastics-waste-recycling-could-transform-the-chemical-industry).

Lempert, P. (2018) 'Ikea switches to packaging made from mushrooms'. Winsight Grocery Business, 21 June (www.winsightgrocerybusiness.com/retailers/ikea-switches-packaging-made-mushrooms).

Lerner, S. (2019) 'Waste only. How the plastics industry is fighting to keep polluting the world'. *The Intercept*, 20 July (https://theintercept.com/2019/07/20/plastics-industry-plastic-recycling/).

Lugris, M. (2019) 'French supermarket chain allows customers to bring their own reusable containers'. TheThings.com, 19 March (www.thethings.com/french-supermarket-chain-allows-customers-bring-reusable-containers/).

Makower, J. (2019) 'Loop's launch brings reusable packaging to the world's biggest brands'. Greenbiz, 24 January (www.greenbiz.com/article/loops-launch-brings-reusable-packaging-worlds-biggest-brands).

Mann, M. (2016) '5 revolutionary supermarkets changing the shopping experience'. Goodnet, 17 March (https://goodnet.org/articles/5-revolutionary-supermarkets-changing-shopping-experience).

Material Economics (2018a) *The circular economy: a powerful force for climate mitigation*. Stockholm: Material Economics (https://materialeconomics.com/publications/the-circular-economy-a-powerful-force-for-climate-mitigation-1).

Material Economics (2018b) 'Sustainable packaging. The role of materials substitution'. Stockholm: Material Economics (https://materialeconomics.com/publications/sustainable-packaging).

Milnes, H. (2019) 'How Macy's is making its stores more experiential'. Digiday, 11 April (https://digiday.com/retail/year-acquiring-story-macys-using-format-refresh-stores).

Morgan, S. (2018) 'Drinks giants rail against EU bottle cap plan'. EURACTIV, 28 October (www.euractiv.com/section/circular-economy/news/drinks-giants-rail-against-eu-bottle-cap-plan/).

Morrisons (2019) 'Is this UK supermarket edging towards plastic-free shopping?' Press release, 24 May. Plastic Free World Conference (www.devplasticfree.pierrot-testsg.co.uk/uk-supermarket-advancing-towards-plastic-free-shopping/).

NationMaster (2019) 'Online shopping trends 2019 & key figures – what you need to know'. NationMaster, 14 January (www.nationmaster.com/ecommerce).

Nava, M. (2018) *Fighting ocean plastic pollution. Bringing opportunities in the circular economy*. Houston TX: Banco Bilbao Vizcaya Argentaria (BBVA) Research US (www.bbvaresearch.com/wp-content/uploads/2018/10/181010_US_PlasticPollution.pdf).
Nielsen, T.D., Holmberg, K. and Stripple, J. (2019) 'Need a bag? A review of public policies on plastic carrier bags – where, how and to what effect?' *Waste Management* 87: 428–440.
Nielsen, T.D., Hasselbalch, J., Holmberg, K. and Stripple, J. (2019) 'Politics and the plastic crisis: a review throughout the plastic life cycle' *Wiley Interdisciplinary Reviews: Energy and Environment* (https://doi.org/10.1002/wene.360).
Potting, J., Hekkert, M., Worrell, E. and Hanemaaijer, A. (2017) *Circular economy: measuring innovation in the product chain*. Policy Report. The Hague: Netherlands Environmental Assessment Agency (PBL) (www.pbl.nl/en/publications/circular-economy-measuring-innovation-in-product-chains).
Rosane, O. (2018) 'Only a third of UK's plastic food packaging is recyclable'. EcoWatch, 6 August (www.ecowatch.com/uk-plastic-food-packaging-2593326528.html).
Ryberg, M., Laurent, A. and Hauschild, M. (2018) *Mapping of global plastic value chain and plastic losses to the environment, with a particular focus on marine environment*. Nairobi: UN Environment (http://wedocs.unep.org/bitstream/handle/20.500.11822/26745/mapping_plastics.pdf).
UN Environment (2014) *Valuing plastic: the business case for measuring, managing and disclosing plastic use in the consumer goods industry*. Nairobi: UN Environment (https://wedocs.unep.org/handle/20.500.11822/9238).
UN Environment (2018a) *Single-use plastics: a roadmap for sustainability*. Nairobi: UN Environment (www.unenvironment.org/resources/report/single-use-plastics-roadmap-sustainability).
UN Environment (2018b) *Exploring the potential for adopting alternative materials to reduce marine plastic litter*. Nairobi: UN Environment (www.unenvironment.org/resources/report/exploring-potential-adopting-alternative-materials-reduce-marine-plastic-litter).
UN Environment (2018c) *Legal limits on single-use plastics and microplastics: a global review of national laws and regulations*. Nairobi: UN Environment (www.unenvironment.org/resources/publication/legal-limits-single-use-plastics-and-microplastics-global-review-national).
Verghese, K., Lewis, H., Lockrey, S. and Williams, H. (2015) 'Packaging's role in minimizing food loss and waste across the supply chain' *Packaging Technology and Science* 28(7): 603–620 (https://onlinelibrary.wiley.com/doi/abs/10.1002/pts.2127).
Waldron, J. (2019) 'Is Macy's guiding the future of retail?' Blog (https://etaileast.wbresearch.com/macy-future-of-retail).
World Economic Forum, Ellen MacArthur Foundation and McKinsey & Company (2016) *The new plastics economy: rethinking the future of plastics*. Geneva: World Economic Forum (www3.weforum.org/docs/WEF_The_New_Plastics_Economy.pdf).
World Economic Forum and Ellen MacArthur Foundation (2019) 'Reusable packaging: 6 benefits beyond sustainability'. Geneva: World Economic Forum (www.weforum.org/agenda/2019/07/reusable-plastic-packaging/).
WRAP (2016) *Plastics market situation report*. Banbury: WRAP.
Zero Waste Europe (2018) *Unwrapped: how throwaway plastic is failing to solve Europe's food waste problem (and what we need to do instead)*. Brussels: Zero Waste Europe (https://zerowasteeurope.eu/library/unwrapped/).