

# Headache fractions in mixed municipal waste



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## 1 Introduction

Municipal solid waste (MSW) accounts for 27 % of all the waste generated in Europe, excluding major mineral wastes (Eurostat, 2022). Its complex character, due to its composition, generation from many sources, and its strong link to consumption patterns, gives it a very high political profile. The Waste Framework Directive requires 55 % of all municipal waste to be recycled by 2025, with further targets for 2030 and 2035 of 60 % and 65 % respectively.

Furthermore, the 2020 Circular Economy Action Plan (CEAP) aims to halve residual municipal waste by 2030. Residual waste is defined as waste that is neither recycled nor prepared for reuse, i.e., waste material not collected separately for recycling or composting/digestion, and residues from sorting processes. Residual municipal waste is either incinerated or landfilled, two options that pose environmental threats, destroy resources and preclude the circularity of material flows.

The EEA has estimated that, even if all EU Member States were to reach their binding 60 % recycling target by 2030, current trends indicate that the amount of residual municipal waste may exceed 80 million tonnes in that year, missing the target of halving this waste fraction by more than 23 million tonnes (EEA, 2022a; P&S Intelligence, 2020).

Over the last five years, the amount of residual municipal waste generated each year has stabilised at about 113 million tonnes per year, even though the EU recycling rate grew slightly from 45 % of all municipal waste in 2015 to 48 % in 2020. Reaching the target of halving residual municipal waste by 2030 would mean reducing the amount of residual municipal waste by around 56.5 million tonnes, equivalent to around 130 kg per person per year.

Although noteworthy progress has been made across the EU during the last decade, finding a way of dealing with difficult wastes, i.e. those that are difficult to handle and possibly dangerous, will be critical in the efforts to reduce residual waste. Appropriate management of these wastes is essential for the protection of health and environment, but presents significant handling and processing challenges. Meeting the targets described above will require that authorities reduce the use of disposal methods, and tackle these waste streams with effective reuse and recycling approaches.

Table 1.1 shows the average shares of recyclable materials in mixed municipal waste in the EU27 <sup>(1)</sup>. These are materials that could have been collected through separate collection systems and sent to recycling. On the average, these make-up 74 % of the mixed household waste; the remaining 26 % include many non-recyclable or more difficult to recycle materials. Moreover, even the listed materials included in mixed municipal waste might not all be recyclable, for example, cardboard contaminated with food residues. The spread by country is considerable, with 48–91 % of mixed household waste being recyclable.

**Table 1.1 EU27, average share of recyclable materials, and variation among Member States, in mixed municipal waste, per cent**

	<b>Average</b>
<b>Paper and cardboard</b>	13 % (7–23 %)
<b>Metals</b>	3 % (1.3–3.9 %)
<b>Glass</b>	4 % (2–9.2 %)
<b>Plastic</b>	14 % (8.9–22.9 %)
<b>Biowaste</b>	34 % (18–48.4 %)
<b>Textiles</b>	5 % (2–14 %)
<b>Wood</b>	1 % (0.25–4.1 %)

<sup>1</sup> EEA survey 2020–2022, non-published material. The reference years vary between 2010 and 2020, depending on when the latest national investigation was carried out.

The Joint Research Centre (JRC) proposed in 2020 the following definition for quality of recycling: “the extent to which, through the recycling chain, the distinct characteristics of the material (e.g. polymer) are preserved or recovered so as to maximise their potential to be reused in the circular economy” (Grant et al., 2020). For that, sorting prior to high-quality recycling is needed to preserve the characteristics of materials which make them most useful. High-quality recycling thus implies rigorous sorting of waste into homogenous fractions and an absence of hazardous compounds.

A significant part of products commonly used by today’s consumers lack circular solutions, or the solutions are limited for technological or economic reasons. Ultimately discarded in mixed MSW, no other solutions exist other than incineration or disposal in landfills. From both circular economy and waste management perspectives, such products can be considered headaches when striving to reach the targets for recycling and reducing residual municipal waste. This report looks at product groups which today are:

- a) not easily recycled;
- b) make up a significant part of current residual waste; and
- c) present an elevated risk to human health and the environment in current end-of-life systems.

The EEA conducted a consultation with the EIONET members to identify specific products or waste fractions that require more attention and to broaden the knowledge base on possible solutions <sup>(2)</sup>. This consultation was followed by discussions by staff from the EEA and the European Topic Centre on Circular economy, which resulted in a list of eight waste streams which were considered the most relevant. Table 1.2 lists the products chosen with a short explanation of why these are considered “headaches”.

**Table 1.2 Headache products analysed in this report**

<b>Product</b>	<b>What causes the headache?</b>
Disposable diapers	voluminous, wet, hygiene and odour challenges, growing issue
Beverage carton cups	recycling processes not developed, few options for reuse
Smart consumer textiles	composite products, may contain sensors and/or connectors but are usually disposed of with conventional, non-smart products, emerging issue
Expanded polystyrene (EPS)	very light and bulky, risk of contamination with, for example, flame retardants. Many kerbside recycling programmes will not accept EPS materials or do not have recycling capabilities
Products containing per- and polyfluoroalkyl substances (PFAS)	environmental and health hazards at the end-of-life stage (fluorinated compounds)
Mattresses	voluminous, complex composite structure, may contain flame retardants and thus difficult to recycle
Furniture	voluminous, complex, multi-material products
Multi-material gadgets for children	Multi-material products, often contain electronics and batteries

<sup>2</sup> Emerging issues for circular resource use. 16 March 2022

## 2 Disposable diapers

Disposable diapers and sanitation pads (absorptive hygiene products (AHP)) make up a considerable part of residual municipal waste, and there are currently few recycling options. The products are typically very complex, containing both natural fibres and various polymers. In addition, their end-of-life management presents challenges related to pathogens and odour, and consequently has strict hygienisation requirements, further complicating recycling options.

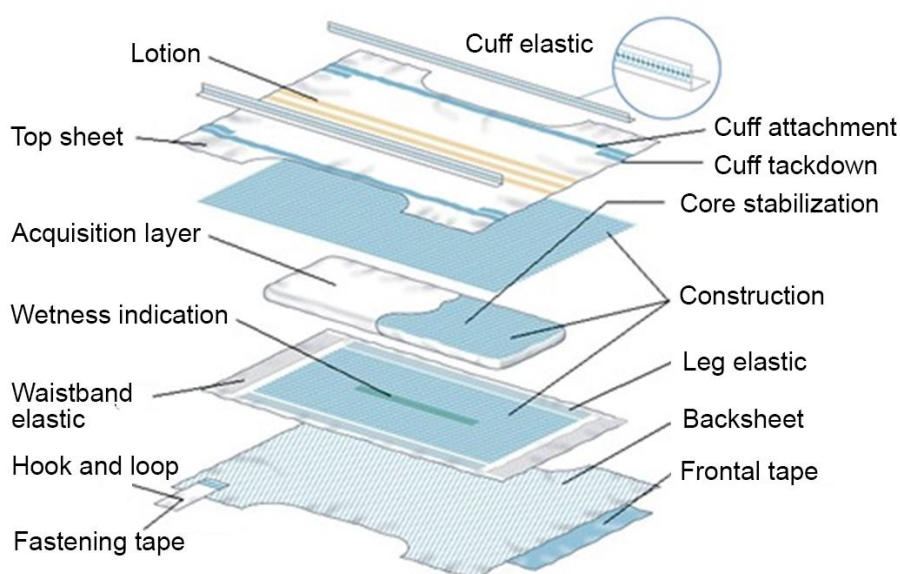
### 2.1 Current situation

#### Products and consumption

Disposable AHPs – baby diapers, sanitary pads/tampons and adult incontinence products – are a growing product group with huge global markets. Baby diapers are the dominant product within the market with a share of 80 % (P&S Intelligence, 2020). While disposable diapers are undoubtedly convenient, they are currently made from fossil plastics, primarily polypropylene (PP), polyethylene (PE) or polyethylene terephthalate (PET) that has been converted, in combination with wood pulp, superabsorbent polymers (SAP) and elastics, into nonwoven fabrics.

The products are quite complex, which makes their recycling challenging. A baby diaper typically consists of around 16 separate functional components in a complex engineering system (Fig 2.1). Advances in the construction of diapers have led to their weight dropping by more than 50 % over the past 20 years, and simultaneously, their performance has improved (BCC Research, 2020).

**Figure 2.1 Construction of a baby diaper**



**Source:** BCC Research (2020).

The global adult and baby diaper market has been growing and is currently forecast to increase by around 6 % per year to 2029 (Facts and Factors Research, 2022). Of the annual worldwide market of 30 million tonnes of diapers, Europe accounts for around 28 % (European Commission, 2019).

Although the baby diapers make up the majority of the global diaper market, adult diapers are the fastest growing market segment due to the increasingly elderly population. The growing number of adult incontinence cases, increasing awareness of adult diapers, reduced hesitation among adults and the easy availability and affordability of adult diapers and incontinence products have led to the rise of the adult diaper market (P&S Intelligence, 2020).

### Current end-of-life management

Although diaper wastes include a significant proportion of organic materials, their final destination in most European countries is incineration or landfill, 45 % (Table 2.1). In municipalities with a high level of separate waste collection, disposable diapers account for a significant part of the residual waste fraction and constitute one of the main problems in increasing recycling levels (Colón et al., 2011). Currently, 30 million tonnes of AHPs are landfilled or incinerated worldwide. This means that 1.5 billion diapers are disposed of globally on a daily basis – or about 18 000 per second (BCC Research, 2020).

The volume of disposable diapers in municipal waste and their final destination in the EU and selected countries are listed in Table 2.1. Disposable diapers make up 2–4 % of total household waste in the EU, while the share in residual municipal waste is generally higher, depending on the intensity of source separation and collection of recyclables in individual countries.

**Table 2.1 Current management of diaper waste, EU and selected countries**

Geographical area	Year	Generation of disposable diapers	Share of municipal waste generation	Landfilled or incinerated	Source
EU28	2017	6.7 million tonnes	2.7 %	87 % landfilled and 13 % incinerated	(Copello, 2021)
Finland	2016	98 400 tonnes	8.2 %	100 % incinerated	(Marjamäki, 2016)
Italy	2019	900 000 tonnes	4 %	landfilled/incinerated	(Osservatorio sulla casa, 2021)
Sweden	2015		9.4 %	100 % incinerated	(Vukicevic, 2015)

Note: in 2020, 23 % of municipal waste was still landfilled in Europe (Eurostat, 2020).

As seen in Table 2.1, recycling does not appear in the statistics. A few emerging technology options for recycling of diapers and recovering the cellulose and polymer fractions do, however, exist in Europe and the United States (Table 2.2).

**Table 2.2 Recycling solutions for diaper waste**

Country	Short description of the case
Netherlands (Klinger, 2021)	The diapers are melted in a reactor, using high pressure steam. During the cooling process, they turn into a liquid containing plastic granules. The liquid is enriched with digested sewage sludge and used to produce biogas and fertiliser, and the granules go for further recycling. The main output of the diaper recycling plant is plastic granules that can be further processed into various products – bottle tops, flower pots, etc.
Netherlands (Diaper Recycling Europe, nd.)	Diapers are collected from municipalities, day-care centres and care institutions. The material is first shredded, washed and sterilised. The next step is the chemical deactivation of the super-absorbing polymers (SAPs) with a process patented by Diaper Recycling Europe. Fibres and SAPs are separately recovered. The fibres continue to mechanical washing, cleaning and screening, producing a long-length fibre which is baled and sold as material for cardboard packaging, insulation materials and pet bedding.
Wales (NappiCycle, nd.)	The company provides kerbside collection to all 22 local authorities in Wales for used diapers and adult hygiene



Country	Short description of the case
	<p>products. They offer a zero-waste-to-landfill option for disposable diapers. The plastic and cellulose content are separated and directed to recycling. The cellulose fibre can be used in the production of fibre boards and acoustic panelling, with the plastics sent to secondary reprocessors for recycling as, for example, material for pavements.</p>

### Why are absorptive hygiene products a challenge for circularity?

Absorptive hygiene products are increasingly popular but have few sustainable end-of-life solutions. These products are typically complex composites including a significant share of polymers, and at their end of life, they are associated with hygiene and odour problems, which, from the recycling point of view, add both complexity and costs. Today 18 000 diapers are disposed of globally each second, ending up either in landfills or incineration plants. In addition, 30 000 tonnes per minute of industrial AHP waste is generated in manufacturing plants (BCC Research, 2020).

A small share of the disposable diapers on the market are biodegradable, though their full decomposition has been questioned, even in the case of industrial composting (BCC Research, 2020; Khoo et al., 2019). More frequently, brand owners market so-called green diapers, claiming environmental benefits. A Swedish study, however, concluded that the amount of biobased carbon, either biobased plastics such as polylactide (PLA) or cellulose, in so-called “green diapers” can be quite modest (20–53 %) though this is higher than 13-15 %) typically in conventional peer products (Nealis, 2021). Solutions for extended lifecycles do exist, primarily in the form of reusable diapers, which currently have less than 15 % of current global markets (P&S Intelligence, 2022). Reusable diapers are made of layers of fabric, mainly cotton but also hemp, bamboo, microfibre, or synthetic fibres such as polylactide (PLA) or polyurethane (PU) are used. The variety of different materials used, and possible composite structures, may pose challenging at their end of life in terms of their recyclability.

## 2.2 Response and outlook

### What needs to change

The use of disposable AHPs currently generates a significant amount of waste, in some cases the largest single waste fraction in mixed household waste (Marjamäki, 2016). While technical end-of-life solutions do exist, there are very few actual examples their implementation. It should also be noted that efficient recycling also requires changes in waste collection systems, i.e., the separate collection of the used diapers.

In 2019, a survey of the circularity of AHPs was carried out amongst companies, institutions and organisations in ten European countries with the aim of identifying major obstacles to circular economy efforts and the development of specific end-of-waste (EoW) criteria. The survey showed that most respondents understood that efficient technical knowledge on material recovery was available but that the main obstacles to AHP recycling were the lack of adequate separate collection systems and the markets for secondary raw materials, which is linked to national EoW criteria. In this context, it is worth noting that an EoW legislative decree specifically for the AHP was signed in Italy in 2019 by the Ministry of the Environment (Mattioli, 2019).

Cloth diapers are commonly acknowledged to reduce environmental impact, yet reusable diapers are still considered an unconventional and inconvenient choice by most parents. To counteract the trend, various

public initiatives to promote reusable diapers have taken place across Europe (Table 2.3) offering economic incentives or establishing other measures to encourage the use of reusable diapers.

Reusable diapers are not, however, without environmental challenges linked to the use of natural and fossil raw materials, and energy in the manufacturing process and washing.

Extended producer responsibility can be an efficient tool to enhance the circularity of selected product categories and the use of this financial/policy tool has also been discussed in the context of single use diapers. Though no European cases exist, the Republic of Korea is an example of a country that applies an advanced disposal fee to support the waste management costs dealing with hard to recycle wastes, such as disposable diapers. Currently, the Republic of Korea is the only country to have implemented such a system for disposable diapers, but in 2021, the Republic of Vanuatu became the first country to officially ban AHPs, including disposable diapers (Płotka-Wasyłka et al., 2022).

### Good practice

Circular solutions for disposable AHPs require strict hygienisation, thus almost all existing circular solutions for them are based on recycling. Technically recycling of the plastic and cellulose fractions of the diapers is possible and some examples on emerging recycling systems were given in Table 2.2.

In Italy, about 900 000 tonnes of AHPs end up in landfills and/or incineration plants every year. The first system with an industrial capacity for processing AHP waste in Italy operates at a recycling centre in Treviso. The plant is processing up to 10 000 tonnes of AHP waste annually. The process involves an autoclave process for sterilising AHPs, which are then separated into individual streams of reusable plastics and a combination of cellulose and superabsorbent polymers, both of which have some, if currently limited, commercial value. From 500 kg of waste materials and 500 kg of body fluids, the system can recover 350 kg of sterilised cellulose and SAPs and a separate stream of 150 kg of sterilised plastics, which are recycled into hard plastic products such as pallets and furniture. The sterilized cellulose finds a second life as a viscose fibre as well as in applications such as seedbed mats, cat litter and paper, while the superabsorbent polymers can be used in such products as industrial absorbers and pet mats (Mattioli, 2019).

Table 2.3 lists some public initiatives promoting reusable diapers in Europe, offering economic incentives or setting up other measures to encourage their use. Moreover, laundry services that collect, clean and distribute diapers to nurseries, kindergartens and families exist in many larger European cities (Copello, 2021) mitigating the additional effort involved using them.

Shifting to reusable diapers has clear economic benefits. For the municipalities, the potential waste reduction could be translated into savings due to lower management and treatment costs. Furthermore, reusable diapers can provide economic savings of more than EUR 200 per year for parents. Even taking into account the laundry costs, the savings could be up to EUR 1 800 per child (Copello, 2020; Krautsuk and Ojala, 2017).

**Table 2.3 Incentives to encourage the use of reusable diapers**

<b>Country</b>	<b>Incentive</b>
Belgium	About 40 % of cities give subsidies to families that use cloth diapers. On the presentation of an invoice to the city council, families receive a refund of typically EUR 100 or more.
Italy	In Colorno, Emilia Romagna, the local administration offers a EUR 50 voucher to buy a reusable diaper kit that costs EUR 120.
UK	More than 70 municipalities offer economic incentives, such as cash-back schemes, free trial kits and vouchers, to promote reusable diapers.

**Source:** (Copello, 2021)

**Conclusion**

Disposable diapers make a significant contribution to the volume of mixed waste in Europe. Though recycling is technically possible, very few full-scale processes exist. Implementation requires the separate collection of used diapers, which is generally available, while odour and hygienisation requirements pose some challenges.

Reusable diapers are a waste-preventing alternative, which comes with cost savings for the consumer. Due to the inconvenience, however, this alternative is not commonly used.

## 3 Biobased beverage cups

### 3.1 Current situation

#### Products and consumption

Traditionally, single-use beverage cups were typically made from high impact polystyrene (HIPS), EPS, PP, (recycled) PET or Polylactic acid (PLA). Most biobased beverage cups are made from paperboard, often lined with PE or wax to provide a barrier against water, grease and heat.

In Europe, since the introduction of restrictions and conditions set by the Single-Use Plastic (SUP) Directive, more beverage-cup producers have successfully launched biobased plastic cups, made of starch-based or cellulose-based PLA, polybutylene succinate (PBS). etc., as well as paperboard-based ones with innovative, biodegradable coatings and liners. Alternatives to regular or recycled kraft paper include paperboard made from grass, bamboo, sugarcane and fungi mycelia amongst others. Especially for hot drinks, the paperboard will typically contain sizing agents, such as alkyl ketyl dimer (AKD), alkyl succinic anhydride (ASA) or fluorochemicals, to prevent penetration by liquids. Biobased liners that are used as an alternative to PE include thermoplastic starch (TPS), PLA, biobased polybutylene succinate (bioPBS), and polyhydroxyalkanoates (PHA). Often, blends of biobased plastics are used in liners (UNEP, 2021).

Beverage cups are targeted by Directive (EU) 2019/904 on the reduction of the impact of certain plastic products on the environment. The following Articles and associated measures are specifically applicable to beverage cups.

**Table 3.1 Articles and associated measures from Directive (EU) 2019/904 applicable to beverage cups**

Article			Measures applicable to beverage cups, including their covers and lids
Article 4	Consumption reduction		Member States shall take the necessary measures to achieve an ambitious and <b>sustained reduction in the consumption</b> of beverage cups. The measures may include national consumption reduction targets, measures ensuring that reusable alternatives are made available at the point of sale to the final consumer, economic instruments and agreements such as those ensuring that beverage cups are not provided free of charge at the point of sale to the final consumer and agreements.
Article 5	Restrictions on placing on the market		Member States shall <b>prohibit the placing on the market</b> of cups for beverages, their covers and lids, made of EPS.
Article 7	Marking requirements		Member States shall ensure that cups for beverages placed on the market bear a <b>conspicuous, clearly legible and indelible marking</b> informing consumers of appropriate waste management options for the product or waste disposal means to be avoided for that product, in line with the waste hierarchy; and of the presence of plastics in the product and the resulting negative impact of littering or other inappropriate means of waste disposal of the product on the environment.
Article 8(2)	Extended producer responsibility		Member States shall ensure that the producers of cups cover the costs pursuant to the extended producer responsibility provisions, insofar as not already included; the <b>costs</b> of the <b>awareness raising</b> measures; the costs of <b>waste collection</b> for those products that are discarded in public collection systems, including the infrastructure and its operation, and the subsequent <b>transport and treatment</b> of that waste; and the costs of <b>cleaning up litter</b> resulting from those products and the subsequent transport and treatment of that litter.
Article 10	Awareness raising measures		Member States shall take measures to inform consumers and to incentivise responsible consumer behaviour in order to <b>reduce litter</b> , and shall take measures to inform consumers of cups on: <ul style="list-style-type: none"> <li>(a) the availability of reusable alternatives, reuse systems and waste management options, as well as best practice in sound waste management;</li> <li>(b) the impact of littering and other inappropriate waste disposal, in particular on the marine environment; and</li> <li>(c) the impact of inappropriate means of waste disposal on the sewer network.</li> </ul>

These measures contained in Directive (EU) 2019/904 on SUPs of both fossil-based and biomass origin have driven the pursuit of more sustainable of beverage cups, often by changing the cups' material composition with growing shares of biobased and biodegradable materials (Triantafillopoulos and Koukoulas, 2020).

End users of biobased and/or biodegradable single- or multiple-wall beverage cups for hot or cold drinks include coffee shops, event organisers, educational institutions, and households. The use of disposable beverage cups is expected to rise in line with changing food trends that favour consumer convenience (UNEP, 2021).

The lining produced from PLA is biobased, biodegradable and non-toxic. Therefore, PLA-lined paper cups are increasingly replacing the traditional 100 % plastic ones, boosting the growth of the market for biodegradable as opposed to entirely fossil-based cups. Additionally, manufacturers are in the process of further improving biodegradable cups with such features as heat resistance for oven applications, heat sealing, and ensuring that their water-based elements pose no risk to human health. New paper composites are also being developed that do not require a barrier in cups, allowing them to effectively biodegrade (Transparency Market Research, 2022a).

The value of the global biodegradable cups market is projected to rise from US\$ 449.7 million in 2022 to US\$ 578.7 million by 2027 (GlobeNewswire, 2022). Europe, with high landfill disposal costs, a solid legislative framework and significant public awareness, is the world's leading market for biodegradable cups (Mordor Intelligence, 2022) and its demand for them is expected to grow by around 6.35 % per year between 2021 and 2026.

### Current end-of-life management

With respect to the feasible and probable end-of-life management, a distinction must be made between the different types of beverage cups.

In the case of cellulose-based cups, plastics liners of either fossil-based PE or PLA often hinder fibre recovery at recycling mills. Although these liners only make up about 5 % of the cup's weight, most paper recycling mills lack the equipment to filter them out. Another issue that affects the recovery of fibres from paper-based cups is the need for de-inking. The de-inking process is facilitated if soy, vegetable and water-based inks are used (BASF SE, 2022; Stora Enso, 2022; GIE Media, Inc., 2021).

In Europe, driven by the Directive 94/62/EC on packaging and packaging waste, a majority of municipalities have implemented a separate collection system for (co-mingled) plastic packaging from households. Usually, traditional fossil-based **plastic cups** from households can be discarded together with plastic packaging.

In some municipalities, **paper cups** from household are accepted within the kerbside collection of paper and cardboard and sometimes biodegradable plastics are accepted in the organic waste fraction (Triantafillopoulos and Koukoulas, 2020; EcoWerf, nd.). Households, however, only use a very small share of disposable beverage cup market; commercial clients dominate a share of about 75 % (Grand View Research, 2022). Some quick-service restaurants and coffee shops have implemented in-store take-back systems and dedicated collection bins (UNEP, 2021).

Nonetheless, single-use beverage cups, including biodegradable ones, most frequently end up in residual waste fractions and are either incinerated or landfilled. Typically, dedicated separate collection systems are not in place, and industrial composting and digestion facilities are not equipped to recognise biodegradable beverage cups and separate them from their non-biodegradable look-alikes efficiently. Therefore, to avoid contamination, composting and anaerobic digestion plants generally do not accept beverage cups (UNEP, 2021; Garrison et al., 2016).

**Table 3.2 Technical possibilities for recycling and composting of single-use beverage cups**

Type of beverage cup	Home composting	Industrial composting	Fibre recycling	Plastic recycling
Paper-based cups with aqueous coating	Yes	Yes	Yes	No
Paper-based cups with biodegradable (PLA or wax) coating	No	Yes	Limited (*)	No
Paper-based cups with PE coating	No	No	Limited (*)	No
Fossil plastics cups (PP, HIPS, EPS, PET)	No	No	No	Yes
Bioplastic cups (starch-based, cellulose-based PLA, PBS)	Yes	Yes	No	No

\*(Stora Enso, 2022)

### Why are biobased beverage cups a challenge for circularity?

Single-use beverage cups are convenient and cheap for takeaway drinks, and their use has become widespread. As a result, they are amongst the most frequently found items in litter. As most beverage cups are made from non-biodegradable plastic or polymer-lined paperboard, when littered, they contribute to long-term terrestrial and marine pollution and impact economic activities such as tourism, fishing and even shipping (UNEP, 2021).

Biodegradable cups can be composted or collected for recycling. The subsequent recycling operations aim to recover either the fibre content from paper-based cups with (biodegradable) liners in paper mills; or part of the cup’s carbon content through of composting in industrial plants. Fibre-recycled and also composted cups can be considered as more circular single-use cups, even though composted plastic does usually not deliver any benefits to the compost. Often, however, compostable plastics only biodegrade under specific, controlled conditions of temperature, moisture and the presence of microorganisms that are achieved in industrial composting plants, and will not fully compost in home composters (EEA, 2022b).

## 3.2 Response and outlook

### What needs to change

Although biobased plastic and paper-based beverage cups are often promoted as the more environmentally sustainable options as compared to fossil-based plastic ones, this intuitive conclusion cannot be unambiguously confirmed by comparative lifecycle assessments (LCA) (Van der Harst and Potting, 2013). Furthermore, despite the fact that suitable and circular end-of-life solutions are available for all types of beverage cup, most end up in landfills or incinerators as part of the residual municipal waste fraction.

To decrease the impact of both single-use and reusable beverage cups, the share of them that is collected separately at end of life and then directed to a material recovery facility, be it a composting facility, a material recycling facility, a plastic recycler or a fibre recycling mill (Table 3.22), must increase.

### Good Practice

Developing clear and consistent labelling and instructions on using and disposing of biodegradable/compostable plastics is of utmost importance. The current EU Circular Economy Action Plan envisages creating a clear policy framework, including harmonised rules for defining and labelling compostable and biodegradable plastics and performing research to identify the applications for such plastics that offer more environmental benefits (EEA, 2022b; 2020). In addition, the introduction of a levy for single-use beverage cups is considered an effective prevention action that is being considered in some European countries, for example Ireland<sup>3</sup>.

<sup>3</sup> <https://www.gov.ie/en/press-release/611a5-minister-of-state-smyth-launches-consultation-on-draft-regulations-for-environmental-levy-on-single-use-disposable-cups/>

An interesting case study, available from the Scottish government, presents a comprehensive approach to addressing single-use disposable beverage cups. Scotland has proposed a sustainable model of consumption to be introduced by 2025 which aims to facilitate a transition to the sale of beverages in reusable cups. The recommended measures relate to five key themes (EPECOM, 2019).

#### *Culture of sustainability*

1. Using Scotland-wide social marketing measures to promote sustainable consumption and help make unsustainable consumption socially unacceptable.

#### *Prevention*

2. The introduction of a national, mandatory requirement to sell beverages and disposable cups separately, including an initial minimum price of between GBP 0.20–0.25 per cup.
3. Retailers and businesses should, in anticipation of future regulation, be supported and encouraged to put in place voluntary separate pricing for the beverage and cup to promote behavioural change.
4. The Scottish government should consider introducing an ambitious national consumption-reduction ambition or target for single-use disposable beverage cups.
5. A ban on the sale of non-recyclable EPS/PVC beverage cups by 2021, in line with the EU Single-Use Plastics Directive.

#### *Promoting reuse*

- 6-8 Various measures for promoting reusable cups as a substitute for single-use cups.

#### *Recycling*

9. Promoting the uptake of recycling when reuse is not yet possible by:
  - innovation in disposable cup design to move to a position in which they are more readily and widely recyclable and can be recycled through existing collection infrastructure;
  - ensuring clearer consumer messaging and labelling, to avoid confusion about the recyclability of cups, especially those made of biodegradable or compostable materials, and signalling the desired behaviour;
  - building on future implementation of changes to packaging producer responsibility schemes to support further improvements in the recyclability of cups and collection arrangements, including in the recycling infrastructure.
10. Developing, synthesising and learning from evidence ... to inform policy development and promote behavioural change, especially on expanding the drivers of responsible consumption.
11. Embedding robust analyses and evaluation of tests of change within a Scottish context:
  - publish/share the lessons learned and encourage sharing knowledge from the private sector to enable and support change.

#### **Conclusion**

Biobased beverage cups can be made from paper or biobased plastics and, in general, are meant for a single use only. For them to be biodegradable or (home) compostable, a cup's coating material(s) should be biodegradable or (easily) compostable too. It is very challenging for the user of a biobased beverage cup, as well as for the composting or recycling facility that receives beverage cups in waste fractions, to differentiate fossil-based cups from biobased ones, and biodegradable and compostable cups from non-biodegradable ones. Where possible, reusable cups should be preferred over single-use cups. In those cases where single-use biobased cups offer practical, operational and/or environmental benefits, harmonised definitions and unambiguous labelling of the biobased, compostable and/or biodegradable nature of these types of consumer products should be put in place.

## 4 Smart textiles

### 4.1 Current situation

#### Type of products and materials

The past decade has seen a remarkable growth in the popularity and increasing improvement of high-tech consumer goods. One type of product emerging from years of research and development are e-textiles, otherwise referred to as smart clothing, wearable technology or simply wearables (Köhler et al., 2011). Wearables are clothing or accessories into which manufacturers seek to seamlessly integrate information and communication technology, such as sensors. These technologies can then react to the physical condition of the user, the exposed environment, and mechanical and electrical stimuli, yielding increased functionality (Veske and Ilén, 2021). Furthermore, with recent advances in flexible, stretchable and body-conformable electronics for wearables, the targeted applications are expanding to fields such as medical monitoring and smart, or digitally enabled fashion, in addition to the existing fitness, health and wellness wearable devices (Schischke et al., 2020). These products have been developed with the overall objective of having direct benefits for health and comfort.

There is no internationally accepted definition of wearables. These technologies, however, can be classified based on their proximity to the human body (GEC, 2021), such as the International Electrotechnical Committee's <sup>(4)</sup> definition of near-body, on-body and in-body electronics, and electronic textiles. Since items such as smart watches and fitness trackers, smart eyewear and at-home health monitoring devices fall under a specific category in the EU Directive on Waste Electric and Electronic Equipment (WEEE) (Directive 2012/19/EU), the focus of this section is on these smart e-textiles, as this is a rapidly evolving field the environmental impacts and disposal strategies of which still remains unclear. Many wearable technologies developed thus far are powered by traditional rechargeable batteries, however, these tend to be relatively heavy and cannot withstand laundering, thus cannot be fully integrated into the textile (Dolez, 2021). To combat this, researchers have developed products that harvest energy from various sources using the garment or textile itself as a substrate, such as harvesting the body's thermal and mechanical energy, or, for example, through the integration of solar cells (Dolez, 2021; Chen et al., 2020). These energy harvesting components are integrated through woven, knitted or an overlaid mat, which increases the complexity of the disposal of these items. There are now even various types of solar yarns, in which tiny silicon solar cells are linked by copper wires embedded within textile yarns themselves (Satharasinghe et al., 2020; Yun et al., 2015).

The market for smart textiles is projected to see strong growth in the coming decade, although, given that these products are only now emerging from years of research and development, market growth estimates are still uncertain. Some estimates suggest that this technological development is creating a fourth industrial revolution for the textiles and the fashion industry, and that the market for them will be worth more than USD 130 billion by 2025 (Cientifica Research, 2016). In 2020, these estimates predicted that smart textiles would grow at a compound annual growth rate (CAGR) of 29 % over the forecast period, increasing from just USD \$5.31 billion in 2019 (Research and Markets, 2020).

#### Current end-of-life management

Given that e-textiles are relatively new products, there is little publicly available information on their end-of-life management. A look at the textiles and electronics industry individually can, however, provide a sense of how consumers may dispose of their unwanted or obsolete e-textiles. Smart textiles have usually a relative short lifespan, with most e-textiles ending up in landfills, being incinerated (Niinimäki et al., 2020) or donated to charities. Much donated clothing, however, eventually ends up in developing nations where it may be dumped, as evidenced for example by the mountains of textile waste that litter the shores of Ghana (Britten, 2022). Recycling of textiles is already a difficult process, and dealing with e-textiles is especially challenging due to material incompatibility with other textile fractions.

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<sup>4</sup> <https://teslasuit.io/blog/detailed-wearables-classification-by-teslasuit-team/>



Electronic waste has similar, known disposal problems. Consumer electronics often have short lifespans which leads e-waste to be one of the fastest growing global waste streams. In 2019, the United Nations (UN) estimated that a record 53.6 million tonnes (Mt) of e-waste was generated worldwide, a rise of 21% in just five years, and it is estimated that by 2030 e-waste will increase to 74 Mt by 2030 (UNITAR, 2020). This waste contains valuable materials such as aluminium, copper, iron and gold as well as toxic components (Widmer et al., 2005). However, of this massive waste stream, the UN estimated approximately 17 % was recycled, with a majority of it being sent to landfill or shipped abroad (Baldé et al., 2022).

### Why are digital products a problem for circularity?

Both electronics and textiles are consumer products with relatively short lifespans. There is a fear that if e-textiles proliferate as predicted, without thought to their sustainability or rethinking their design, they will become mass-consumption products subject to fleeting fashion trends (Gurova et al., 2020). That could lead to premature obsolescence and virtual wear-out, due to short innovation cycles and software incompatibility, eventually resulting in them having even shorter lifespans than traditional electronics or textiles (Köhler et al., 2011). Furthermore, there is a growing trend of rapid consumer dissatisfaction. In a 2016 survey (Ericsson, 2016), one third of individuals questioned reported that they had abandoned or discarded their product within weeks of purchase. The reasons for this varied from limited functionality, poor integration with smartphones, and that newer devices with better features were available on the market. It is also expected that, as with other textiles and electronic devices, unused e-textiles will be kept by consumers at home due to a lack knowledge about the products' recyclability and of precisely where to take them, contributing even further to global resource depletion (Gurova et al., 2020).

With the relatively recent development of these smart consumer products, very limited information is currently available on sustainability issues (Schischke et al., 2020). Given that e-textiles aim for seamless integration and unobtrusiveness, one of the major challenges will be their recyclability. The nature of the complex heterogeneous mixture of these e-textiles that they contain small volumes of valuable materials that are dispersed over and woven through comparably larger textiles (Köhler et al., 2011).

Existing recycling technology cannot currently accommodate e-textile waste. The present recycling and waste management systems are not yet equipped to handle such new, heterogenous and unique waste streams (Köhler and Som, 2014). Currently, e-waste is often recycled by a process of dismantling and mechanical separation, but e-textiles are likely to cause various technical problems, such as jamming the shredding and crushing mechanisms. Additionally, processing e-textiles made from synthetic fibres in the plastic recycling systems are likely to contaminate the plastic recycling streams with e-waste. Thus, the processing of discarded e-textiles in established recycling system is problematic.

There is also the issue of the toxicity or direct environmental impact of the materials that make up e-textiles. The washing of e-textiles could potentially release contaminants into the wastewater – it is well known that simple washing of clothing made from synthetic fibres releases numerous microplastics (Cai et al., 2020). There would likely also be an issue of releasing any nanoparticles, as nanotechnology is highly relevant to the functions of e-textiles and wearables (Schischke et al., 2020; Gupta and Xie, 2018).

## 4.2 Responses and outlook

### What needs to change?

The concept of the circular economy includes a systematic change in product design, which allows for extended product lifetimes with valuable materials eventually cycling back into the economy. In the circular economy users are thus also encouraged to repair and eventually recycle products so that valuable, finite resources contained within these consumer products can be recovered and reused. This overhaul of manufacturing would consequently yield less material usage. The relatively recent introduction of e-textiles and wearables provides an opportunity to influence the end-of-life management

or recyclability of e-textiles before their mass manufacturing renders environmental improvements difficult (Köhler and Som, 2014). By encouraging or requiring manufacturers to consider these issues from the design and development phase, there is a chance to redirect the production to advance sustainability. There is also a call for the development of wearable and e-textile design guidelines for companies to utilise to addressing the question of how fashion wearables could best meet consumer needs and preferences in an environmentally sustainable way (Gurova et al., 2020).

In a first attempt to develop guideline for green wearables, including e-textiles, Schischke et al. (2020) laid out best practice cases from the existing literature and their own research on heterogeneous electronic systems. These guidelines describe how manufacturers could reconsider material choices to include components with lower toxicity and fewer upstream environmental impacts and processing technologies, together with suggestions for understanding and extending product lifespans and usage. Similar calls for a greater focus on the specification and sourcing of more sustainable materials and on developing design strategies to allow for recycling and the reuse of valuable components have been made by others (Veske and Ilén, 2021; Gurova et al., 2020; Köhler and Som, 2014; Timmins, 2009). This includes developers and manufacturers making the lifecycle inventory information available to opensource LCA databases, in an effort to help better manage the environmental aspects of e-textiles (Köhler and Som, 2014).

Given that e-textiles have electric and electronic components, these products may end up in e-waste recycling systems. E-textiles are not, however, explicitly addressed by the 2012/19/EU WEEE Directive and are thus likely to be rejected at collection points (Köhler et al., 2011). The European Eco-design Directive, which mandates eco-design requirements for energy-related products, may, however, serve as a model also for e-textiles (European Commission, 2022). In the recent proposal for the Directive's revision, the EU aims for all textiles to be long-lived, recyclable and produced with regard to current social and environmental aspects by 2030. Clarifying the legislature regarding e-textiles is necessary for providing a clear path forward for developers and manufacturers, and if the revision is adopted, the Eco-design Directive may just be the legislative vehicle to clarify e-textile requirements.

Significant improvements in the recycling systems are needed to take account of these novel e-textiles. In interviews, e-waste recyclers emphasised the need to improve the ease of e-textile recycling, such as by developing mechanical shredders designed and equipped to handle their complexities (Köhler et al., 2011). Moreover, the valuable elements in traditional WEEE are mostly found concentrated in their printed circuit boards, which is not the case for e-textiles. Thus, personnel at WEEE recycling centres need to be trained to recognise when e-textiles enter waste collection systems, so they can be handled separately (Köhler et al., 2011).

Given how recently these products have been introduced, it is clear that e-textiles need to be designed for repairability and consumers information on and access to e-textile repair and reuse services, a used product market, and, as mentioned, clear recycling options. This would require systemic changes in numerous aspects of society. In recent years, for example, the younger generations' interest in learning to mend clothing has been in apparent decline leading Gwilt (2014) to make the case for textile manufacturers and society to start thinking of fashion as a community of suppliers, designers, retailers, menders and recyclers, and the need for a re-engagement with seeing clothing as repairable, instead of simply use and disposal (Gwilt, 2014). Such a change might further encourage the repair and reuse of e-textiles, once they are ubiquitous.

### Good practice

The primary issue with e-textiles and wearables is their technological integration. One research group decided to examine the possibility of designing smart textiles for disassembly. The researchers investigated various techniques for reclaiming and reusing the valuable resources in e-textiles and explored how these techniques could be incorporated into their original design. They successfully demonstrated that with various modifications to knitted and woven fabric structures, a designed-for-disassembly e-textile could

be created and called on manufactures to include such designs into their product developments (Wu and Devendorf, 2020).

Another innovative idea is including pre-arranged delivery to a recycling centre at the end of a product's life. The so-called Hitchhiker Service is a platform that automates and simplifies the return of smart devices to ensure their recycling. The idea is that the platform, through a digital smart contract, would take over the connection between the smart device, logistics providers and a recycling centre in the vicinity of the device's location when the product has exceeded its lifetime. While originally intended for e-waste in general, the usefulness of such a system for e-textiles and other wearables requires further exploration. This work is currently in development and has yet to be integrated into products available on the market (Lawrenz and Leiding, 2021).

### Conclusion

Given that e-textiles are only just recently emerging as mainstream consumer products mainstream, there is still the chance to integrate more sustainable strategies into their design and ensure easier disassembly. The issues associated with e-textiles provide manufacturers a clear opportunity to incorporate more circular strategies into their product lifecycles now, before unsustainable disposal and the loss of valuable resources becomes uncontrolled.

## 5 Expanded Polystyrene

### 5.1 Current situation

#### Products and applications

Expanded polystyrene (EPS) is a rigid thermoplastic <sup>(5)</sup> with good electrical insulating properties and strength. During its manufacturing, small polystyrene (PS) pearls are heated under pressure in the presence of pentane, which acts as a blowing agent to foster a cellular structure. The pearls widen into balls that consist of 98 % air and 2 % PS. The immobile air within the plastic cells makes EPS very light and gives it the ability to isolate cold from hot and *vice versa*. An excellent insulator, EPS is strong, lightweight and affordable, can resist abrasion and retains its flexibility at low temperatures (BCC Research, 2021).

Expanded polystyrene is currently used widely in the building and construction industry and in packaging applications. In the building and construction industry, EPS is used for various applications because of its insulation ability and lightness. For example, EPS is used in exterior and interior insulation and finishing systems, cold storage facilities and lightweight structures in which some rock material is replaced with EPS. It is currently widely used as protective packaging for lightweight, fragile and shock-sensitive products, particularly in the electronics industry. A key attribute of EPS for packaging applications is its ability to be shaped so as to protect devices of various shapes and sizes (BCC Research, 2021).

Globally, around 50 % of the total market volume of EPS is used in building and construction applications, and around 30 % in packaging applications. Consumer products account for around 10 % of the demand for EPS and around 8 % is used in automotive applications. There is a need for lightweight, recyclable and chemically stable materials in, for example, automobile parts and packaging solutions and thus, the demand for EPS is expected to grow in the coming years, although the current focus on reducing the use of plastic has increased the use of alternatives such as corrugated paper and cellulose. In the construction industry, EPS consumption is driven by the need for insulation required to increase the energy efficiency of buildings. Globally, markets for EPS are forecast to grow by 4-6 % per year to 2025, depending on the segment (BCC Research, 2021). In Europe, the growth rate is slightly higher (Technavio, 2021).

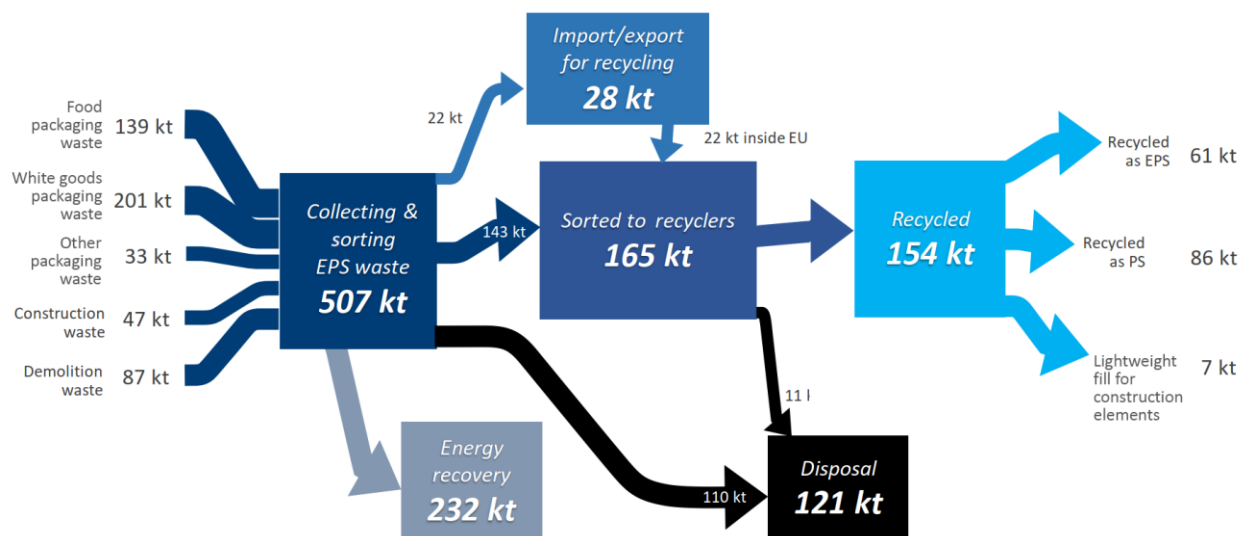
#### End-of-life management

In 2019, 507 kilotonnes (kt) of EPS waste was collected in Europe, most of which was generated by Germany, 114 kt, followed by France, 76 kt, Italy, 59 kt and Poland, 39 kt. Of the total EPS waste collected in 2019 in Europe, 372 kt, 73 %, was packaging waste and 134 kt, 27 % was construction waste. The flow diagram (Figure 5.1) shows that 46 % of EPS waste is incinerated with energy recovery, about 30 % is recycled and 24 % is landfilled (Conversio, 2021).

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<sup>5</sup> Thermoplastics are a family of plastics that can be melted when heated and harden when cooled. Thermoplastics can be repeatedly reheated, reshaped and solidified (PlasticsEurope, 2021).

**Figure 5.1 The collection and sorting of extended polystyrene waste, Europe, 2019.**



Source: Conversio (2021).

Table 5.1 gives data on the end-of-life management for EPS packaging and EPS construction applications separately. In this context, it should be mentioned that because of the high prevalence of litter in the marine environment and the availability of alternatives, single-use food and beverage containers and cups made of EPS have been restricted under the Single-Use Plastics Directive. Food containers made of EPS for immediate consumption as well as EPS beverage containers and cups cannot be placed on the market.

**Table 5.1 Post-collection treatment of expanded polystyrene packaging and construction waste, EU27, Norway, Switzerland and the UK, 2019**

EPS Waste	Total amount (kt)	Recycling	Energy recovery	Landfill/ Disposal
EPS Packaging	373	38 %	38 %	24 %
EPS Construction	135	10 %	66 %	24 %

Source: Conversio (2021)

Fifty-six per cent of the EPS packaging waste comes from commercial activities while households generate 44 %. More than 55 % of that commercial packaging waste is recycled, while the recycling rate for household EPS packaging waste is much lower at 15 %, mostly due to the lack of separate sorting and collection (Conversio, 2021).

Compared to EPS packaging waste, the amount of EPS collected from construction is significantly lower, and 65 % of this is from demolition activities. The recycling rate for EPS demolition waste is, however, currently very low at 1.4 %, likely because most of it is generally collected in mixed construction waste streams. Moreover, the risk of contamination with flame retardants hampers recycling (Wiprächtiger et al., 2020). The overall recycling rate for EPS construction and demolition waste is 9.6 %, based on information collected from 22 European countries (Conversio, 2021). However, low recycling rates have also been reported, including by the Life EPS-Sure project (CicloPlast, 2019), which might reflect the fact that plastic recycling is generally a quite new and fast developing area.

In 2018, the Association for European Manufacturers of Expanded Polystyrene (EUMEPS) signed a pledge to increase the recycling activities of EPS waste. The Association committed to recycling 257 kt of EPS waste in 2025, which will represent 46 % of all collected European EPS waste. This amount is planned to be reached by recycling 185 kt, 50 %, of packaging waste and 72 kt, 38 % of construction waste (EUMEPS, 2018).

Some European countries, however, have already reached a recycling rate of EPS packaging higher than the industry's pledged target for 2025. The countries with high performances in recycling EPS packaging are Portugal, 83 %; Norway, 76 %; Denmark, 60 %; Netherlands, 59 %; Austria and the UK, 56 % each; and Ireland and Belgium, 52 % each. Moreover, Austria, Denmark, Ireland, Norway, Portugal, Turkey and the UK are all targeting a recycling rate of more than 80 % by 2030. In Portugal most of recycle originates from EPS fish boxes and the waste is first recycled as general purpose polystyrene (GPPS) and thereafter as extruded polystyrene (XPS), which is used in construction.

### Why is EPS a problem for circularity

During the last decade, polystyrene has made up around 10 % of global by weight of overall, and due to poor recycling rates, it is a post-consumer waste of high concern (Hidalgo-Crespo et al., 2022). Furthermore, removing food residues and odours from waste polystyrene is challenging. In particular EPS fish boxes, which, although in principle 100 % recyclable, mostly end up in landfill, 45–50 % in Europe and 55–60 % in Spain (CicloPlast, 2019). Due to the 'expanded' characteristic of EPS, it presents some specific additional recycling challenges. Being composed mainly of air, EPS is very bulky from a handling and storage point of view but with actually relatively little material content to generate value as a secondary raw material. Additionally, its light weight makes it easily swept away in the wind or water, adding to the problem of littering and ocean plastics.

As EPS is highly flammable, flame retardants are commonly added to many EPS products, especially those used in construction. Thus, there is a high risk that EPS demolition waste contains hazardous brominated flame retardants (BFRs) such as hexabromocyclododecane (HBCDD) (Turner, 2020). This further complicates the handling and recycling of this material.

## 5.2 Response and outlook

### What needs to change?

Efficient recycling of used products usually requires that the waste is collected separately at source. In Europe, post-consumer EPS is generally collected commingled with other plastics or with mixed waste. Though mechanical separation of EPS is challenging, examples from Sweden shows that EPS can be sorted from mixed post-consumer plastic waste and recycled at scale (Svensk Plaståtervinning, 2021). Examples from initiative in Finland, Portugal and Spain show that centralised collection of food boxes from the industry and retailers can deliver the economy of scale necessary to invest in recycling including appropriate deodorisation, and thus enable that the material can be recycled into other products, such as insulation (Kesko, 2022; Svensk Plaståtervinning, 2021).

The EU is restricting placing single-use take-away food containers on the market, however there is still a growing demand for lightweight, reusable and chemically stable materials for this application. For this reason, usage of EPS is not likely to decrease in the short-term, underlining the need for EPS recycling systems to be further developed. Emerging technologies in this area include depolymerisation or pyrolysis, both of which can allow the inclusion of contaminated EPS flows, although the status of such approaches, termed chemical recycling, as a sustainable recycling method are still being debated.

### Good practice

Most of Portugal's recycles originate from EPS fish boxes and the waste is first recycled as GPPS and then used in construction as XPS. The construction and packaging product company Bewi Circular started collecting, compacting and recycling EPS fish boxes from all harbours and fish markets in Portugal in 2020 and by the end of that year, the recycling rate for fish boxes was 70 % (Conversio, 2021).

Some other sectors, for example toy and home furnishing producers are working to replacing EPS foam with fibre-based materials including corrugated or moulded paper, which are easier to recycle. To keep the durable and lightweight properties of EPS foam, honeycomb constructions of fibre-based materials,

which are both strong and light, have been tried out as recyclable shock absorbers in packaging solutions. The home furnishing company IKEA took four years to phase out EPS foam in almost all its flat packs and replace it with the new recyclable packaging solutions. The company reported that the change to fibre-based materials meant a reduction of 8 000 tonnes of EPS foam per year (IKEA, 2015).

The [PolyStyreneLoop](#) cooperative, counting more than 70 members and supporters from the entire PS-foam value chain across Europe, was founded in November 2017 in the Netherlands with the aim of developing and offering a sustainable solution for PS-foam demolition waste containing hexabromocyclododecane (HBCD), a flame retardant. PolyStyreneLoop uses solvolysis technology, a physical process, which allows the recycling of PS without changing its molecular structure by separating it from the HBCD. The HBCD is subsequently treated in a bromine recovery unit, which allows for the recovery of elemental bromine and the safe destruction of HBCD. Following PolyStyreneLoop's bankruptcy in early 2022, its activities were bought by a German consortium and operations are continuing (Polystyreneloop, nd.).

### Conclusion

Several initiatives in Europe demonstrate that EPS is a readily recyclable material but to increase its overall recycling rate, separate collection both from households and the construction industry must increase. Economically viable logistics to and from central collection points need to be established. Direct reuse of packaging and construction EPS is difficult due to contamination issues, but fibre-based alternatives have been developed, which could, at least partly, replace EPS in packaging.

## 6 Per- and polyfluoroalkyl substances/fluorinated polymers containing products

Per- and polyfluorinated alkyl substances (PFAS) are a group of more than 4 700 chemicals that are, or degrade to, very persistent compounds. They are widely used as surfactants, stain and water repellents, emulsifiers and lubricants in consumer products, pharmaceuticals, pesticides and industrial processes. As a consequence, PFAS have been found everywhere, even in the most remote parts of the world. PFAS are considered moderately to highly toxic to humans and particularly toxic for children’s development (EEA, 2019).

The European Chemical Agency (ECHA) describes PFAS as follows: *“They all contain carbon-fluorine bonds, which are one of the strongest chemical bonds in organic chemistry. This means that they resist degradation when used and therefore accumulate over time in humans, animals and the environment. PFAS have been frequently observed to contaminate groundwater, surface water and soil. Most PFAS are also easily transported in the environment covering long distances away from the source of their release. Due to this persistence and mobility, cleaning up polluted sites is technically difficult and costly”* (ECHA, 2022).

### 6.1 Current situation

#### Type of products and materials

The use of PFAS has grown vastly since they were first used in the 1950s due to their excellent water, oil and dirt repellent characteristics (Buck et al., 2012). Thousands of different PFAS are used in a range of applications in textile and fabric treatments, furniture, cooking equipment, electronics, construction products and upholstered furniture (Hill et al., 2017). They are also used in the manufacture of fluoropolymers, for example, PTFE – often known as Teflon.

Fluoropolymers may contain residual PFAS or PFAS may occur from polymer degradation. Table 6.1 gives illustrative examples of consumer PFAS containing products that could be discarded in municipal waste streams.

**Table 6.3 Examples of mixed municipal waste containing PFAS and fluoropolymers in mixed municipal waste**

Product group	Specification (use of PFAS/fluorinated polymers)
<b>Paper and cardboard: packaging</b>	Various PFAS/fluorinated polymers are used in paper and cardboard packaging materials, for example, popcorn bags, pizza boxes, fast-food containers and baking papers (Bokkers et al., 2019).
<b>Cookware</b>	Non-stick (PTFE) coatings are used various kitchenware, such as frying pans and other cooking utensils (Cousins et al., 2019a), due to their high chemical and thermal stability as well as oil/water repelling and non-stick properties.
<b>Textiles: clothes</b>	Outdoor clothing and other oil- and dirt-water-repellent textiles made of multiple layers (Knepper et al., forthcoming; Holmquist et al., 2016).
<b>Textiles: carpets and furniture</b>	PFAS are used extensively as stain, soil, dirt and water repellents in carpets and rugs and furniture (Rojello Fernández et al., 2021).
<b>Cosmetics and personal care products</b>	Fluorinated substances are used , for example, in hair products – up to 2.4 % PTFE; mascaras – up to 13 % PTFE; face powders – up to 3 % PTFE; eye shadow, dental floss, sunscreen and protective masks (Gaines, 2022; Brinch et al., 2018; Johnson and Zhu, 2018).
<b>Technology</b>	Solar panels PFTEs are used as a protective layer in the backsheet of photovoltaic (PV) panels, making up roughly 3 % of the backsheet material’s weight or approximately 0.2 % of weight of the whole panel (Aryan et al., 2018).



Product group	Specification (use of PFAS/fluorinated polymers)
	<p>Electronics</p> <p>Fluorinated polymers are used in numerous electronic applications, including flat panel displays, liquid crystal displays; electronic devices and equipment used for testing, such as sensors; as heat transfer fluids/cooling agents; in cleaning solutions; and for etching piezoelectric ceramic fillers due to their dielectric properties and chemical stability. The share of the fluorinated polymers is, however, typically rather low relative to the total weight of the application. For example, in lithium-ion batteries polyvinylidene fluoride (PVDF), which is used as a binder in the electrode layer, makes up just 1–2 % of the total weight (Mossali et al., 2020).</p>
<b>Construction products</b>	<p>Many construction elements, including roofs, facades, stones, floors and windows, are surface treated with chemicals containing PFAS, some of which have been banned in recent years but may still be present in products in use.</p> <p>Glass treated with PFAS can be used in hard-to-access locations, such as building facades and solar panels on roofs, access to which for cleaning would be difficult (Rojello Fernández et al., 2021).</p>

Since 1951, PFAS have been used in outdoor clothing to impart water and dirt repellence (Gaines, 2022). For example, PFAS-based impregnation agents are used for various outdoor clothing for children and found in a test campaign to be present in 10–30 % of all children’s clothing (Lassen et al., 2015). The impregnation treatment can be applied during production of clothes or by treating clothes afterwards with dispersion agents to regain water repellence lost during use. Typically, the fluorochemical makes up 0.05–0.5 % by weight of the textile to deliver durable repellence (Gaines, 2022). The loss of PFAS from clothes to the environment can occur in the use phase due to wear and tear enhanced by ultraviolet radiation, high temperatures and humidity, which degrade dirt-water repellent (DWR) polymers (van der Veen et al., 2020; Gremmel et al., 2016). In the post-treatment of textiles, a potential source of human exposure to PFAS may occur through the inhalation of impregnation sprays.

There is no data on how many textile products actually containing PFAS/fluorinated polymers. Based on the PRODCOM sales data and additional analysis, it is estimated that 45 000–80 000 tonnes of PFAS are consumed in textiles, upholstery, leather, apparel, and carpets (TULAC) in the EU annually (Whiting et al., 2020). Even though the industry producing, for example, outdoor textiles is increasingly moving away from using PFAS, many of these textiles are still in circulation and may end up in secondhand shops for further use.

### End-of-life management

Currently, the only way to safely handle PFAS and fluoropolymer containing waste is to incinerate it at very high temperatures. Although data is not available, it is likely that most fluorinated polymer containing wastes are sent to municipal waste incineration plants. Within the EU, these facilities have a minimum requirement that flue gases reach temperature of at least 850 °C for 2 seconds, but it is possible that PFAS do not undergo complete degradation in these conditions and may persist <sup>(6)</sup>. There is also a lack of measurement data on PFAS emissions from municipal waste incineration plants. The formation of volatile fluorinated gases during waste incineration has been identified as a possible source of PFAS pollution (Danish EPA, 2019).

Landfilling PFAS containing waste is a source of groundwater pollution. Concentrations have been detected in European landfill leachates due to the high-water solubility of PFAS compounds and there are challenges in capturing PFAS through leachate treatment. The efficiency of the treatment technologies is substance specific and degradation of PFAS to other hazardous substances may occur. Besides efficiency,

<sup>6</sup> If the halogen content exceeds 1 % (recalculated for fluorine), temperatures of 1 100 °C with a minimum residence time of 2 seconds are needed to mineralise all organic compounds. High fluorine content, however, does not generally occur in consumer products.

the treatment costs, such as costly regeneration and energy costs, and the challenges involved in handling of the high volume of wastewater sludge need attention(ETC WMGE and ETC/CM, 2021).

According to a review by Tansel (2022), inhalation of PFAS is a significant exposure route for the workers at WEEE recycling operations, and this issue is also relevant to the handling of textile and carpet waste. Since PFAS are not chemically bound to waste materials, they are released to air during processing, for example, shredding and sorting, and are then transported by atmospheric diffusion.

In the EU, separately collected end-of-life textiles are reused or recycled by charities or industrial enterprises. The reusable clothes are sold, mainly on foreign markets. The unused textile waste is incinerated or landfilled or in some cases may be downcycled to rags, upholstery filling or insulation (ETC WMGE, 2019).

### Why are PFAS a challenge for circularity?

Toxicity and persistence issues mean that PFAS containing products should be removed from material loops and in principle neither reused nor recycled. Adequate labelling of products is a key challenge for limiting reuse and recycling of PFAS containing waste. Currently, PFAS and also other legacy substances like flame retardants are reused/recycled in, for example, carpets.

Besides concerns about their waste management, a specific challenge of the PFAS and fluoropolymer containing products relates to their production. Especially during PFAS/fluorinated polymer production, not only do toxic emissions of PFAS to air, soil and water occur but also the use of raw materials and chemicals induce high emissions of greenhouse gas and ozone-depleting substances, which needs attention. Furthermore, hazardous wastes are generated in the process (ETC WMGE and ETC/CM, 2021).

## 6.2 Response and outlook

### What needs to change?

The concept of essential use was introduced in the EU Chemicals Strategy for sustainability towards a toxic-free future. The Committees for Risk Assessment and Socio-Economic Analysis that support the ECHA propose the restriction of PFAS with some PFAS classified as substances of very high concern (SVHC). One option presented by experts in some Member States is to limit the use of PFAS and fluorinated polymers only for essential use, i.e., for which no substitutes are available (Cousins et al., 2019b). For the oil- and dirt-repellent effect required for protective work clothing and medical textiles, for example, no comparably effective PFAS-free options are yet available. This concept requires a broad in-depth analysis of the benefits and risks associated with the use of fluorinated polymers in different applications and calls for the development of a framework with criteria for the categorisation of different applications as essential or non-essential.

### Good practice

The substitution of PFAS with other chemicals or raw materials offers a solution for several product groups such as textiles.

Water-repellent textile surfaces with a variety of polymer architectures, including linear polyurethanes, hyperbranched polymers, silicones, waxes and nanoparticles, have been created (Cousins et al., 2019b; Holmquist et al., 2016). For example, for outdoor apparel, similar water-repellent properties can be achieved with non-fluorinated finishes (Hill et al., 2017). In the textile sector, some brand names (including H&M, Adidas, Lindex and Jack Wolfskin) have recognised the problems with PFAS and now market textile products free of PFAS.

In considering good practice, attention needs to be paid to the concept of “regrettable substitution”, when there is insufficient information available on the substituted chemicals. Some non-fluorinated alternatives,

for example, do not perform as well as fluorinated ones in repelling oil (Schellenberger et al., 2019; Holmquist et al., 2016) and might not be sufficient for use as occupational protective clothing for workers such as those on oil platforms (Schellenberger et al., 2019). Furthermore, substitution is also not available for protective textiles used to minimise risks from exposure of infectious agents for medical staff and patients.

### Conclusion

Labelling of products containing PFAS and fluorinated polymers is missing – this is especially important for waste management to ensure the suitable disposal of end-of-life products.

Action to phasing PFAS and fluorinated polymers out, for example, in textiles is needed. Awareness raising among various stakeholders, including product designers, for them to consider their material choices, authorities and enforcement bodies, and consumers would be an important first step. General and specific guidance to consumers and businesses on how to find PFAS-free alternatives is provided by consumer organisations and some national institutions.

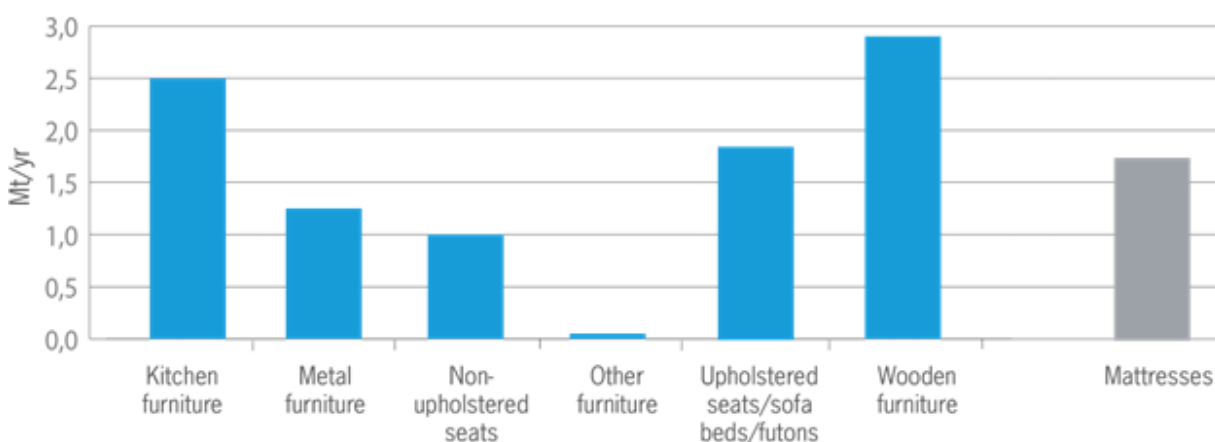
## 7 Furniture

Furniture is a broad product group that encompasses beds, chairs, tables, wardrobes, shelves, cupboards and more, made of various materials with very different uses – in schools, offices, homes, outdoors, etc. The product group is defined in the Council decision EC 2016/1332 as “free-standing or built-in units whose primary function is to be used for the storage, placement or hanging of items and/or to provide surfaces where users can rest, sit, eat, study or work, whether for indoor or outdoor use” (European Commission, 2016).

### 7.1 Current situation

The consumption of different categories of furniture per year is shown in Figure 7.1.

**Figure 7.1 Furniture consumption by category, EU28, million tonnes.**



**Note:** mattresses are included here but excluded in the definition from Council decision EC 2016/1332 (European Commission, 2016). Data refers to 2016 or earlier (exact reference year not available).

**Source:** Forest et al. (2017)

Furniture comprises multiple raw materials including wood, chipboard, sawdust, fibreboard, metal, plastic, textiles, foam materials and metal/electronic appliances, for example, in adjustable beds, and plastic (Wagner et al., 2022; Silas, 2019; Bauer et al., 2018; Forrest et al., 2017). Table 7.1 presents indicative data on the composition of furniture, wood being the dominant material across most categories.

Depending on the type of furniture, the average useful life ranges between eight and 15 years, with large differences in individual cases. Furniture made of wood, such as chairs and kitchen furniture, and metal furniture is likely to have longer lifetimes than plastic and composite furniture (Wagner et al., 2022).

**Table 7.1 Indicative composition of selected furniture, main categories, EU28, per cent**

Furniture item	Indicative composition (principal materials only)						
	Textile	Aluminium	Steel	Wood	Plastic/latex	Polyurea foam	Chipboard
Kitchen			2 %	40 %	2 %		54 %
Metal furniture		20 %	80 %				
Non- upholstered seats			80 %		20 %		
Other furniture				50 %	50 %		
Upholstered seats/sofas	15 %		10 %	45 %		30 %	
Wooden furniture				50 %			50 %

Source: Forrest et al. (2017)

### End-of-life management

There are no explicit statistics on the amount of waste furniture. Used furniture can be collected as bulky or wooden waste or even as metal scrap. Furthermore, pieces of small furniture may also end up in household waste bins. If the furniture contains integrated electronic components, it is classified and managed as WEEE. These different collection methods make the quantification of furniture waste difficult.

One approach for estimating furniture waste, including mattresses), is presented in a European Environmental Bureau (EEB) report (Forrest et al., 2017), which assumes that the furniture waste makes up 3.75 % of the municipal waste – in the EU27 and the UK, its share is reported to vary between 2 % and 5 % of MSW. Additionally, the furniture waste from businesses is here added to the calculated amount by using a factor 1.18. As result, the total annual furniture waste is estimated in this report to have been around 10.8 Mt in the EU27 and the UK, or 21 kg/person (Forrest et al., 2017).

The amount furniture waste can also be calculated from PRODCOM, assuming that all furniture produced, corrected for imports and exports, will end up in the waste stream. This approach was used in a German study (Wagner et al., 2022) to estimate furniture waste generated in Germany. As PRODCOM only contains information of pieces/units of furniture, the estimate was calculated based on units of 27 common types of furniture, the average weight of different furniture units and expected lifetimes. As result of the calculation, furniture waste estimated to be generated in Germany was 3.6 Mt, or 43 kg/person/yr, of which 1.7 Mt, or 20 kg/person/yr, is collected separately in bulky waste. The German study indicates significantly higher waste amounts per person compared to the EEB study. Apart from the different methodology, other reasons contributing to the higher amounts of furniture waste could include population growth, the rising number of single-person households, the amount of living space per person and increasing employment (Wagner et al., 2022) Similar trends can be expected in many other EU countries.

According to European Federation of Furniture Manufacturers statistics, 80 % to 90 % of the EU furniture waste in MSW is incinerated or disposed of in landfills, and only 10 % is recycled (Forrest et al., 2017). Low recycling rates might be the result of furniture being treated as bulky waste, not sorted from other municipal waste appropriately, and there being a lack of suitable recycling services. Materials that are recycled from furniture are mainly valuable ones such as steel and aluminium.

Reuse occurs only to minor extent and is selective. For example, the demand for high-quality solid wood furniture generally tends to be high; durable and valuable furniture in good condition is quite frequently resold by private individuals at auctions, in flea markets, through secondhand shops or online portals. The number of items traded through these channels is not covered by any statistics and this makes it difficult to estimate how much furniture is reused. For heavy and large items, such as large wardrobes, the resale is limited by distance due to available transport and its cost. Furthermore, the demand of secondhand

furniture is depressed by the availability and affordability of new low-cost products (Wagner et al., 2022; Forrest et al., 2017).

### Why is furniture a challenge for circularity?

One of the challenges in meeting circularity goals for end-of-life furniture relates to its non-circular design – for example, not being sufficiently durable or lacking possibilities for repair, remanufacture or recycling or even the reuse of components. If lifetimes of furniture could be extended, furniture manufacturers would experience reduced sales, creating a need to find new business concepts. The European furniture industries confederation EFIC claims that pieces of furniture imported from outside Europe should also meet the same circular economy rules applied for furniture made in EU (EFIC, 2020).

A lack of consumer information is also a challenge in extending the lifetime of furniture; consumers are rarely given guidance on how to maintain and repair individual items, although online resources on repair techniques help to address this issue. The availability of the repair services and labour costs related to repair, especially for upholstered furniture, may also be a barrier. Furthermore, the transport of reusable furniture needs more effort than its shipment for material recycling as furniture needs to be handled carefully to avoid damage. Finally, storage of furniture pending reuse presents a challenge due to its bulky nature and also the need to protect stored items from damage by water, rodents, etc. (Cooper et al., 2021a; Öhgren et al., 2019; FURN360, 2018).

One challenge in furniture recycling relates to a lack of information on the potential presence of chemicals. In some cases, textiles and leather containing flame retardants and chemicals for repelling dirt have been used in furniture manufacturing – for example, PFAS have, in the past, been used as dirt repellents and, as toxic legacy substances, remain a barrier to the recycling of upholstered furniture (Rojello Fernández et al., 2021).

Moreover, furniture is often made of several different materials which need to be separated for material recycling. Upholstered furniture, for example, may contain wood, metals, textiles and foams that are tightly connected by glues, staples or nails. Dismantling the furniture for material recycling incurs high labour costs whereas shredding makes recovery of only some materials, such as metals, economically feasible (Wagner et al., 2022). Often, there is a weak market for many of the material streams that can be recovered from furniture.

In particular, the high share of wood-based materials, such as chipboard, and recyclable composites which are technically difficult to recycle, limit the potential to increase furniture recycling – kitchen furniture, for example, is typically wood based. Wooden furniture generally contains glues, paints, varnishes and staples, and information on these materials is often lacking. The use of such furniture as a source of energy is often the preferred option, however this presents an environmental risk due to potential release of toxic compounds in combustion gases.

## 7.2 Response and outlook

### What needs to change?

Furniture manufacturers should introduce ecodesign for their products. Additionally, the use of hazardous substances, such as flame retardants, should be phased out, and, if they are used, they should be clearly labelled to avoid the recycling of materials containing them. The European Commission has published ecolabelling criteria for furniture (European Commission, 2016) as well as voluntary green public procurement criteria for furniture (European Commission, 2018), which provide a good base for furniture design to support circular economy goals. The criteria concern material choices as well as aspects related to the longevity of furniture.

The benefits of introducing extended producer responsibility (EPR) schemes for furniture need to be explored.

In the use phase, action to prolong the lifetime furniture is needed; an easy way of doing this is to provide guidance to consumers on maintenance and repair. For this, the availability of spare parts to replace lost, damaged, or worn-out components helps to prolong lifetimes. Consumer information about the importance of purchasing sustainable furniture, such as the benefits of prolonging product lifetime, also needs to be increased. Municipalities could provide information to households on marketplaces for the resale of furniture and charity organisations taking used furniture (Miliós, 2016; Cooper et al., 2021b).

An idea for promoting reuse is for municipalities to collaborate with moving companies to transport end-of-life furniture carefully to prevent and so maintain its value and functionality. For consumers, the effort needed for arranging transport of old furniture for reuse is relatively high, and being offered an easy way to dispose old furniture is considered of great importance (Miliós, 2016).

The reuse of office furniture, rather than household furniture might be easier to implement. Office furniture is usually expensive and durable, and there is a high potential for restoring used furniture through, for example, textile washing, changing frame parts or textiles and repair of scratches. Here, too, collaboration between companies relocating or restructuring their offices and reuse centres have shown good results – in Vienna, Austria, for example, reuse centres find customers for secondhand furniture before it arrives at the centre, thus optimising the transport of furniture for reuse (Miliós and Dalhammar, 2020; Öhgren et al., 2019).

Improved collection and sorting systems for furniture at recycling centres are also required, enabling recycling of valuable materials. Crucial is here information on the material composition of furniture. Information on potential legacy substances is also important to ensure safe waste management and that furniture containing toxic materials is removed and not recycled.

To achieve circular economy goals, the following policy instruments have been suggested (Wagner et al., 2022; Forrest et al., 2017).

- Ecodesign: reuse, recycling, separability of materials/disassembly, material choices and durability. Standardisation and compatibility, which entail manufacturing modules, parts and elements that can be used in different products, have also been recommended.
- EPR schemes (<sup>7</sup>): collection and take-back systems organised by manufacturers, which can promote eco-design and improve product information.
- Green public procurement (GPP) (<sup>8</sup>): implementation of the circular economy by the public sector in purchasing products that fulfil defined criteria, for example, establishing demand for recyclable or recycled content, repairability, etc.
- Ecolabelling: criteria supporting a durable and high-quality product that is easy to repair and disassemble.
- Tax initiatives: the reduction of value-added tax (VAT) on repairs and remanufacturing.
- Standardisation: methods to test product characteristics and performance such as durability.
- Financial support for innovation.

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<sup>7</sup> EPR is a policy approach in which the responsibility of producers is extended to the post-consumer stage of a product's lifecycle. EPR schemes are a diverse policy instrument mix that aims to make producers – financially, and sometimes also organisationally – responsible for the collection, sorting and treatment of end-of-life products. It thereby aims to increase the separate collection of end-of-life products and enable their (more) circular treatment.

<sup>8</sup> A process whereby public authorities seek to procure goods, services and works with a reduced environmental impact throughout their life cycle when compared to goods, services and works with the same primary function that would otherwise be procured.

Several of these policies are linked. According to the EEB report, the first step is to establish a common, more comprehensive ecolabelling system, including ratings, that can be used to support the different policy tools. Although the uptake of the current ecolabelling regulation is limited, a system, similar to the EU energy label, could provide consumers and procurement professionals with clearer information on the environmental and circularity features of furniture products. A report from Germany's Central Environmental Authority (*Umweltbundesamt*) recommends the introduction of an EU-level EPR scheme, including ecomodulated fees set by Producer Responsibility Organisations (PROs) (Wagner et al., 2022).

The impact of a combination of the different policy options listed above have been assessed in the EEB report (Forrest et al., 2017). Fully mandatory EPR schemes, ecodesign and GPP would lead to the highest reduction of greenhouse gas emission, up to 5.7 Mt of carbon dioxide equivalent annually. Furthermore, the EEB report estimates that by implementing this combination of instruments, about 157 000 new jobs could be created. A significant increase over the current European workforce of about 11,600 employees involved in repair of furniture and home furnishing in EU 27 (2019) (ETC/CE, 2022).

### Good practice

In France, an EPR scheme has been used, since 2012, to finance the collection, recycling and reuse of furniture. The main objectives of this scheme are (Hogg et al., 2020):

- reducing waste furniture sent to landfills;
- increasing recycling/reuse; and
- stimulating furniture manufacturers to adopt ecodesign principles.

The following specific targets were set for 2020 (Au-Dev-ant, 2020):

- a collection target of 31 % for separately collected furniture waste;
- a target in terms of the coverage of the collection system: 91 % of the French population;
- treatment targets for collected furniture: up to 85 % for recovery (including energy recovery) and 45 % for reuse/recycling in 2020.

A graduated environmental fee, depending on the furniture category, material and size (weight) is paid by the end consumer at the time of purchase as an eco-contribution. The fees are collected by accredited recycling organisations, *Éco-Mobilier* for household waste streams and *Valdelia* for commercial ones (Hogg et al., 2020). Furniture that meets certain environmental criteria, for example, furniture containing more than 95 % of wood from certified forests<sup>9</sup> and without upholstery, making it easy to recycle, benefits from a reduction in the environmental fee of about 15 % (Micheaux and Aggeri, 2021).

*Éco-Mobilier*, (2019); nd.) has reported examples of the increased rate of collection since the introduction of the EPR scheme (*Éco-Mobilier*, (2019); nd.):

- In 2011 more than 50 % of used furniture ended up at landfills;
- from 2015 to 2019, the amount of collected used furniture increased from 250 000 tonnes to 874 052 tonnes;
- in 2019 about 57 % of the collected used furniture was recycled and 36 % used incinerated with energy recovery – no data are given on the type of recycling;
- In 2021, 1.2 million tonnes of used furniture were collected, of which 94 % was either incinerated with energy recovery or recycled and 5 % reused –no data are given on the type of recycling.

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<sup>9</sup> Forest certification is a mechanism for forest monitoring, tracing and labelling timber, wood and pulp products and non-timber forest products, where the quality of forest management is judged against a series of agreed standards, e.g. those of Forest Stewardship Council (FSC).



### Conclusion

In the short term, to promote the achievement of circular economy goals, prolonging the life and the reuse of high-quality furniture made from wood and/or metal could be supported through the fostering of repair services and the establishment of marketplaces for secondhand furniture. In the longer term, furniture should be designed for disassembly and recycling, and the introduction of EPR schemes could effectively support circularity.

## 8 Mattresses

### 8.1 Current situation

#### Products and consumption

Mattresses are available in a variety of sizes and price ranges, though each type of mattress is composed of a similar set of materials, mostly arranged in a multilayer configuration.

Mattresses are typically built up from a support core that provides structure, an upholstery comfort system for softness, and a (removable) outer tick that facilitates maintenance. Different types of mattresses are distinguished by the main materials used for their support core. Innerspring mattresses have steel coils wrapped in polyester or PP fleece, whereas latex and foam type mattresses have latex blends or (high density) polyurethane cores. Upholstery layers include natural and/or synthetic latex, low resistance polyurethane foam, memory or viscoelastic foam, natural and/or styrene-butadiene rubber (SBR) latex blends, polyurethane gel, polyester, wool, cotton, coconut fibre, feather, hemp or horsehair. Ticks are usually woven fabrics made of cotton, polyester, silk, PP, nylon (polyamide), wool or viscose. The use of many material combinations allows for different levels of contouring, motion isolation and temperature and humidity regulation (OneCare Media, 2022; Deliege and Nijdam, 2010).

In France, where an EPR scheme for mattresses has been in existence since 2012, the collected material has been catalogued in detail (Recyc Matelas Europe, nd.). Data from a UK study (Chapman and Bartlett, 2012) also provide compositions details of the average mattress. Both studies show that approximately one quarter of the weight of discarded mattresses consists of polyurethane (Table 8.1).

**Table 8.1 Material composition of mattresses, France and the United Kingdom, per cent by weight**

Material category	Weight % (France)	Weight % (UK)
<b>Polyurethane</b>	23%	27%
<b>Metals/steel</b>	18%	31%
<b>Latex</b>	11%	3%
<b>Mixed textiles</b>	10%	
<b>Polyester</b>	8%	4%
<b>Residues</b>	8%	-
<b>Felt</b>	8%	1%
<b>Wood</b>	8%	-
<b>Wool</b>	5%	4%
<b>Cotton</b>	2%	-
<b>Non-woven cotton</b>	-	16%
<b>Woven cotton</b>	-	6%
<b>Fibre</b>	-	7%

**Note:** percentages may not sum due to rounding

**Sources:** Recyc Matelas Europe (nd); Chapman and Bartlett (2012)

Polyurethane foam is manufactured from chemicals commonly derived from crude oil. According to polyurethane foam producers, nearly 90% of mattresses produced in the EU contain one or more types of it. The EU's production of flexible polyurethane foam is of around 900 000 tonnes per year (Recticel NV, nd.).

The total European production of mattresses is around 50 million units annually. Of those, almost 90 % contains 2–30 kg of polyurethane foam. About 50 % of mattresses produced in Europe are innerspring ones, 40 % foam, and about 7 % latex. The share of PU core mattresses is slowly growing, especially thanks

to the strong growth of *bed-in-a-box* mattresses <sup>(10)</sup> (EUROPUR, 2022b). The EU27 mattresses market is forecast to grow from USD 5.87 billion in 2016 to around USD 8.96 billion in 2026 (Statista, 2022).

The key factors responsible for this growth include the growing healthcare and hospitality sectors. It is further explained by the rising purchasing power of people in Europe, which allows them to buy premium mattresses but also to replace them more frequently than in the past (Bonafide Research & Marketing Pvt. Ltd., 2022; PR Newswire, 2022).

Mattress composition has changed dramatically in the last decades. In particular, there has been an increase in use of pocket springs, from less than 10 % of the market 15 years ago to nearer 40 % today, with most of this growth occurring the last 10 years. Pocket springs are typically lighter as compared to open-coil spring sets, which means the steel content of newer mattresses is lower (Bell et al., 2019).

### Current end-of-life management

The average weight of mattresses received by recyclers in the UK has been calculated at 24 kg per mattress (Bell et al., 2019).

Mattress lifetimes vary greatly between different types, material combinations and the intensity of use. Lifespans vary from 5–8 years for innerspring mattresses, more than 8–10 years for hybrid and memory foam types, and up to 12 years for higher quality foam and latex mattresses (Sleepopolis UK, 2022; Casper, 2020).

In the EU, more than 30 million mattresses annually reach their end of life and it is estimated that 60 % go to landfill and 40 % are incinerated (European Bedding Industries' Association, 2014). Assuming an average unit weight of 24 kg, mattresses thus account for more than 700 000 tonnes of waste.

Technically it is possible to recycle most of the material in a mattress. In practice, recycling activities concentrate on the most valuable materials and the easiest to recover, in particular polyurethane foams and aluminium and steel coils and frames.

The recycling of mattresses requires separate collection systems to be in place. Since mattresses are very diverse with heterogeneous material combinations, organised in complex multilayer structures, the discarded and collected units need to be separated into different categories and disassembled in order to produce different material fractions to be recycled into secondary raw materials that can be used. The disassembly process typically consists of:

- reception: unloading and dry storage to avoid contamination, sorting by mattress type;
- sanitising: applying chemical or heat treatments for sterilisation;
- filleting: cutting the mattress' outer fabric cover and the binding flanges;
- disassembly and sorting: segregating the different materials by type;
- handling materials: baling processes, product storage as bales, loose material (sorting residues) or in containers (metals), before delivery to downstream processes, such as the recycling of metals.

Textile fibres, both woven and non-woven fabrics containing cotton, wool, linen or polyester, can be reprocessed into geotextiles, oil filters, insulation, etc. Metal springs and frames are recovered as metal scrap, and wood can be used for chipboard or energy recovery (European Commission, nd.). The separated and sorted PU fractions can be recycled either mechanically or chemically.

### Mechanical recycling of polyurethane foam

The polyurethanes used for mattresses are thermosets, which means they cannot be remelted and reshaped. As a consequence, the common mechanical methods used for recycling thermoplastics are not

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<sup>10</sup> Foam mattresses, usually sold online that have been rolled and compressed to be shipped and delivered to the end user's door in a box

applicable. Mechanical recycling of polyurethane foam is therefore limited to shredding the foam scrap into smaller pieces, which can then be used for re-bonding, adhesive pressing, compression moulding, and injection moulding of the PU particles along with a molten polymer or additional isocyanate monomer resin.

Applications of rebonded foam include sound dampening, impact resistance, vibration dampening, and cushioning used in products such as carpet underlay, gym mats, acoustic insulation and shock pads under sports and artificial grass pitches (EUROPUR, 2021a).

Most of the existing EPR systems in the EU rely on mechanical methods for processing discarded mattresses and recycling the polyurethane foam fraction. Discarded mattresses are collected through a central point, such as a civic amenity site; bulky waste kerbside collections; on-demand collection; or through (voluntary) retailer take-back systems. An example is RetourMatras in the Netherlands, that receives mattresses from civic amenity sites and retailers. It operates a production line for manufacturing rebonded foam from collected mattresses. The production process produces large rolls of polyurethane foam that are steamed into flakes, glued and compressed by a mechanical process. The sheets, which can be cut to any desired thickness and length, are used as insulation materials and underlays for sports floors, artificial turf and playgrounds (RetourMatras, 2022).

#### *Chemical recycling of polyurethane foam*

Chemolysis includes acidolysis, glycolysis, hydrolysis, aminolysis and phosphorolysis differentiated by the base material for dissolving the foam.

Through chemolysis, the foam waste can be gradually depolymerised to form organic compounds, original reactants or other low molecular weight oligomers. The properties of the chemolysis products depend greatly on the type of degradation reagents used during the process. Currently, these chemical recycling technologies focus on the production of high-quality recycled monomers of polyol, to be used as a feedstock for new polymers.

The glycolysis technology has been in use at an industrial scale in Europe since 2013 for post-industrial waste, i.e., production offcuts, and is increasingly used to recycle post-consumer foams. (EUROPUR, 2021a) Acidolysis is also a mature technology applied at industrial scale. Hydrolysis has been introduced in pilot projects, while aminolysis and phosphorolysis have only been studied in the lab (Grdadolnik et al., 2022).

Thermochemical treatment techniques, such as pyrolysis, gasification and hydrogenation, are also used to convert discarded mattress PU-based foams into either valuable monomers, feedstock chemicals, syngas or hydrogen. The thermal treatment of a copolymer, such as polyurethane, always gives rise to several chemicals, with different possible applications (Deng et al., 2021; Gadhav et al., 2019).

#### **Why are mattresses a challenge for circularity?**

Reuse options are limited for mattresses due to hygiene concerns and low consumer demand. Some initiatives for refurbishing them have been identified <sup>(11)</sup>, but the associated health risks and liabilities remain a major challenge.

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<sup>11</sup> <https://www.linkedin.com/pulse/mattress-refurbishing-done-right-barbara-eastwood-coombs/>

For discarded mattresses to be considered recyclable, they must:

- be collected for recycling and sorted into specific material fractions;
- have market value, and/or be supported by a legislatively mandated programme;
- allow disassembly, separation, sorting and recycling with mature, commercially available processes;
- generate recycled output materials that is in demand for use in the production of new products.

(RecyClass, 2022)

The bulkiness of mattresses makes them difficult to handle during waste collection and subsequent transport. In the EU, most mattresses are nevertheless effectively collected through municipal collection systems for bulky waste, and transported to disposal facilities, mainly landfills (60 %) and waste incinerators (40 %) (European Commission, nd.). In incineration, because of their bulkiness, mattresses need to be cut down and mixed with other lower calorific wastes before being fed into the waste burner. Metal coils can easily jam the shredding and feeder equipment, leading to costly process disruptions. Additionally, the incineration of mattress materials can cause damage to flue gas installations. Mattress incineration is therefore complicated, expensive and potentially polluting (ABN-AMRO, 2019).

Mattresses are thus a problematic and costly waste stream because of their weight, bulkiness and difficult compression. For end-of-life options besides disposal, such as reuse and recycling, other challenges are added to the list, such as low reuse potential and the low value of the recoverable materials.

Looking to the recyclability criteria, mattresses are indeed collected, but at high cost and not for recycling. They have a low market value, however, and in only three EU countries, Belgium, France and the Netherlands is end-of-life mattress collection and treatment supported by legislatively mandated programmes, in particular through the establishment of specific EPR schemes. The disassembly of mattresses, prior to the separation and sorting of materials, is complex and labour-intensive, and current commercially available recycling routes are mainly limited to the mechanical recycling of PU foam into low value insulation and padding-like products. The complex structure of mattresses, their multilayer architecture, the presence of many different materials, often in combination, and the diversity of sizes, types and quality add to the challenge of their recycling.

## 8.2 Response and outlook

### What needs to change?

#### *Design*

All product design-for-recycling guidelines underscore the need to use as few different materials as possible. For mattress, however, added value for purchasers is obtained by adding specialised features and providing more flexible and customer-specific solutions that unfortunately seem to require ever more complex material combinations.

Another design issue relevant to recycling is the avoidance of hazardous substances, in order to avoid the contamination of recycling loops by legacy substances. Mattresses may contain carcinogens and other hazardous components, particularly in the PU foam, adhesives and flame retardants. These substances include polybrominated diphenyl ethers (PBDE), formaldehyde, and antimony trioxide, among other (Barner et al., 2021).

Finally, especially for multilayer products, design for recycling should consider reversible connections. Layers that are connected to one another should be easily to disassemble – glued connections and composite materials make recycling more difficult.

### *Recycling systems*

Currently, most discarded mattresses in the EU are collected through municipal bulky waste collection systems and incinerated or landfilled. In 2021, 1.305 million tonnes of pre-consumer trim foam were produced globally, and EU exports increased to 300 000 tonnes. Post-consumer trim foam from the disassembly and treatment of collected discarded mattresses was only 145 000 tonnes in 2020. It is, however, doubtful whether markets could absorb additional volumes of foam scrap generated by increased mechanical recycling of post-consumer mattresses in the EU.

By further developing and implementing large scale chemical recycling methods, it would be possible to boost material recovery from discarded mattresses. These could become an economically-sound option to complement the existing mechanical disassembly of metal, fibre and wood from mattresses by enabling the production of chemicals such as polyols and diamine-rich substance mixtures that can be used for the production of di-isocyanates, for which there is strong market demand (EUROPUR, 2021a). However, the environmental and health impacts of this approach would require careful investigation prior to commencement of commercial operations.

### **Good practice**

#### *Collection and recycling systems*

In the EU, Belgium, France and the Netherlands have implemented EPR systems to support end-of-life mattress collection and treatment. In Belgium, since 2021, a take-back obligation applies to discarded mattresses. As a result, manufacturers and importers of mattresses are responsible for the collection and processing of waste mattresses and must meet collection and recycling targets. The take-back obligation applies both to discarded mattresses from private individuals, companies and institutions such as hotels, holiday parks, hospitals and residential care centres.

Belgian mattress producers and importers are affiliated to a producer responsibility organisation (PRO), Valumat vzw, the management body for discarded mattresses that has assumed their take-back obligation. Valumat reimburses recycling centres for the collection, transport and processing costs of discarded mattresses and provides financial compensation to retailers who voluntarily accept discarded mattresses when selling new ones. Valumat also reimburses companies and institutions that dispose of their discarded mattresses. To finance the Valumat system, the producers/importers pay an environmental fee into a fund for each mattress sold. This cost is passed on to the customer who pays an environmental contribution for each new mattress, which may or may not be shown separately on the invoice or receipt (OVAM, 2022).

The first operational scheme in Europe that targeted mattresses was the French Eco-Mobilier, which started in 2013. Eco-Mobilier also takes care of the collecting, sorting, recycling and recovering of end-of-life furniture, pillows and blankets. The scheme is financed by an eco-participation fee paid by consumers, similar to the environmental contribution in Belgium.

In the Netherlands, an EPR scheme has been set up, with the objective of recycling 75 % of waste mattresses by 2028. As of 1 January 2022, all mattress manufacturers pay a waste management contribution for mattresses that they place on the Dutch market. Municipalities are compensated for their recycling costs – rental of civic amenity site container, transport and recyclers' fees – for the mattresses they collect and offer to registered and certified mattress recyclers. This reimbursement starts at 15 % of the costs in 2022 and increases to 100 % in 2028 (NVRD, 2021).

The Netherlands is currently the frontrunner in mattress recycling, with an estimated 75% of mattresses being collected and recycled annually. The company RetourMatras, of which IKEA and the waste management company Renewi are stakeholders, reported that it handled 1 million mattresses in 2020. The mattresses are disassembled in five facilities, located in the Netherlands and Belgium, with a total recycling capacity of 1.5 million mattresses per year (EUROPUR, 2021a; Ingka, 2021). The textile fraction is baled, and the metal is also sorted for recycling. The mattresses are shredded, and the latex and PU foam are pressed into bales weighing around 300 kilos.

Currently PU foam is mechanically recycled (RetourMatras, 2022) but industrial scale or pilot plants for its chemical recycling are either planned or under construction in Belgium, France, Germany, Netherlands and Spain (EUROPUR, 2021a). Typically, these initiatives result from multisectoral collaboration efforts and are undertaken by partnerships that include waste management companies, chemical recycling technology providers, research institutes, chemical companies, foam producers and brand owners. Most of the initiatives target the production of polyols from recovered pre- and post-consumer PU foams by chemolysis. Others, such as Triple Helix Molecules as a Service (Innovation Origins, 2022) in Belgium and PReSmart in Germany (PReSmart, 2019) also claim to be able recover the diisocyanate segment of the polymer.

Significant research efforts have been set up in the EU, including several under Horizon 2020, that aim to facilitate the development of chemical recycling technology, boost material recovery from discarded mattresses and increase the market potential of the recycled outputs (Recticel NV, 2022).

#### *PReSmart (PolyUrethane Recycling towards a Smart Circular Economy)*

Recticel, a Belgian company, coordinates the PReSmart project (2019–2023). The PReSmart consortium, nine partners from six different countries, seeks ways of transitioning from the current linear lifecycle of PU products to a circular economy model.

#### *Valpummat (Valorization of Polyurethane MATresses)*

The ValPUMat Project is an Eco-Mobilier France initiative, in collaboration with the Belgian PU processor Recticel, and Tesca, a French automotive supplier for textiles and seat components. The objective is the development of new products based on end-of-life foam derived from collected mattresses. Mechanical recycling options are under investigation. At the same time, there is a need to eliminate all legal and technical constraints hindering the reuse of end-of-life mattress materials, and to develop effective sorting methods.

#### *NIPU-EJD (Synthesis, Characterisation, Structure and Properties of Novel Non-Isocyanate Polyurethanes – European Joint Doctorate)*

The NIPU-EJD programme, set up by a consortium of seven academic and eight non-academic partners, aims to develop novel non-isocyanate polyurethanes.

### *Design*

Driven by consumer preferences for more sustainable lifestyles, sales of mattresses based on biobased materials are projected to grow significantly as a result of people's rising awareness products made from organically sourced materials. This includes biobased materials such as natural latex or memory foam, wool, horsehair, organic cotton, plant-based fibres and foams, made from, amongst other things, from bamboo and silk. Additionally, these mattresses, commonly referred to as organic mattresses, offer advantages such as being odour free and more durable than conventional mattresses. Market analysis shows that global demand for organic mattresses increased by 9.2 % in 2021 over 2020, growing to 1.9 million units. Worldwide sales of organic mattresses are expected to increase at a CAGR of 8.2 % and reach a market value of USD 13.87 billion by the end of 2032 (Fact.MR, 2022).

Apart from an increasing share of organic mattresses and of organic content in other types of mattresses, it seems likely that recyclers will be faced with more changes in the average material composition of discarded mattresses. A higher share and more different types and qualities of latex and PU foams is likely together with a lower metal content (Chapman and Bartlett, 2012).

### Conclusion

Mattresses are voluminous, multilayer products made of a diverse and often very complex range of materials. Currently, nearly half of the weight of the 50 million mattresses discarded annually consists of PU foams and aluminium and steel coils and frames. Both PU and metals are valuable materials for which mature recycling technologies are available. Market outlets for mechanically recycled PU are, however, limited. The collection of more mattresses for material recovery, driven by the implementation of EPR schemes and chemical recycling technologies, such as chemolysis for recovering polyols from PU foam, would offer a good opportunity for increasing the circularity of a significant and challenging waste product stream.



## 9 Multi-material products for children

### 9.1 Current situation

#### Types of product and current use

Children's toys include everything from building blocks, through sports equipment and dolls, to consumer electronics such as large gaming consoles. Similarly, gadgets for children can consist of everything from bottle holders or bath devices, such as floating water temperature sensors, to teething soothers. While these items may appear simple, they are often rather complex mixtures of plastics; rubber and silicone; electronic components; textiles; and metals, including those found in paints. Each type of material may also be a mixture of various components, including some with chemicals or elements which are now on the SIN list <sup>(12)</sup> (Chemsec, 2022); or substances of concern to be regulated under the REACH Regulation (ECHA, 2022); restricted or prohibited in toys under the EU's Toy Safety Directive (European Commission, 2009); or even banned under the Stockholm Convention (2004). As the movement towards a circular economy encourages recycling, there is a risk that these legacy substances are reincorporated into the newly manufactured products.

As in other areas of society, toys and gadgets designed for children are becoming more wirelessly connected and smart, allowing for an interactive experience. Specifically, this market is trending towards the inclusion of near field communication (NFC) technology and science, technology, engineering, and mathematics (STEM) based toys (The Business Research Company, 2022). Near field communication technology allows for a smart phone to wirelessly interact with nearby objects containing an NFC microchip through an app (Montegriffo, 2021). Parents looking for educational toys are also driving the STEM-based toy market (Business Research Company, 2022). This diverse field includes toys made of mixed materials from plastics, through metallic pieces to electronic components.

The most common materials found in children's toys and gadgets are plastics (UNEP, 2014; Pérez-Belis et al., 2013). Similarly, silicone and synthetic rubber are commonly found in many products for children. During the manufacture of toys and gadgets, most plastics are mixed with various additives, to improve their performance, engender flexibility, enhance product durability, and/or add a level of flame retardancy (Hahladakis et al., 2018). Some of the most common current or historic additives include some chemicals of concern under the REACH Regulation or are substances banned by the Stockholm Convention including bisphenol A; brominated flame retardants, such as polybrominated diphenyl ethers and PBDEs; phosphate flame retardants; chlorinated paraffins; phthalates; and heavy metals, such as lead and cadmium (BCC Research, 2022; Turner and Filella, 2021; Hahladakis et al., 2018).

The second most common materials found in various toys and gadgets are electrical and electronic components, by some estimates accounting for up to 12 % by weight on average (Pérez-Belis et al., 2013). This is a vast category and encompasses small devices such as LED lights in plush dolls to larger devices with PCB components, such as remote-controlled model cars, and those powered with standard or solar charged batteries.

Finally, another broad category of material found in children's toys and gadgets are textiles and fillers, which occur mostly on or in plush toys and dolls but can also be found in gadgets such as weighted swaddles or baby carriers. These tend to be mixtures of synthetic fibres (polyester), cotton, wool, plastic pellets, bamboo fillers or synthetic PU foams. In the past, synthetic foam fillers contained PBDE additives but these have since been replaced with other additives such as PFRs (Pantelaki and Voutsas, 2019).

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<sup>12</sup> The SIN (Substitute It Now!) List is a database developed by the International Chemical Secretariat (ChemSec).

In addition, several textiles or fillers found in or on toys can also contain chemicals such as thermo-chromatic inks, engineered nanoparticles or, potentially, PFAS. Thermo-chromatic dyes and ink are temperature sensitive and are used to generate colour changing properties (Woodford, 2021). They commonly contain BPA (He et al., 2016). Moreover, silver nanoparticles are increasingly being added to textiles for their anti-microbial properties (Schacht et al., 2013) and have been found in plush toys and gadgets including blankets and sippy cups (Quadros et al., 2013). Finally, given the prevalence of using PFAS for waterproofing fabrics, it is likely they could also be found in the filler or on the textiles in toys or gadgets, though no literature specific to children's products was found.

### *Volumes and market growth*

The global toy market has experienced steady growth in the last decade alone, seeing constant increases from USD 81.56 billion in 2016 to USD 107.13 billion in 2021 (The Business Research Company, 2022).

In 2021 the largest market for toys, dolls and games was the Asia Pacific region with a market share of just over 30 %, followed by Western Europe and North America. Western Europe was the second largest market, generating USD 29.02 billion or about 27 % of the total market. Eastern Europe had a market share of about a 9 %, worth approximately USD 9.64 billion (The Business Research Company, 2022).

Similarly, over the past decade, the breakdown between the electronic and non-electronic toy segments has also changed. In 2021 electronic toys accounted for more than 64 % of the toy market and non-electronic toys almost 36 %. Electronic toys had the higher CAGR, 6 % for 2016–2021. With society growing ever more connected and toy complexity and functionality increasing, this segment is expected to grow at a CAGR of 13.58 % for 2021–2026 (The Business Research Company, 2022).

At the same time, with public environmental consciousness increasing and the demand for critical raw materials rising, the sustainable toy market, or toys made from biodegradable and/or recycled materials, is expected to see rapid growth in the coming years. This will be a result of a widening interest of toy manufacturers in utilising used and recycled materials rather than dwindling virgin resources. The sustainable toy market was valued at about USD 18.9 billion in 2020 and is expected to reach USD 59.6 billion by 2030, equating to a strong CAGR of 12.5 % (Anil and Roshan, 2021).

The demand for sustainable toys will also increase the global demand for biobased and recycled plastics. It is expected that value of the recycled plastic market will rise to \$76 billion, or just more than 11 % of the expected market, by 2029 (Market Research Report, 2021) as more toy and gadget manufacturers turn towards sustainable production.

### *Current end-of-life management for toys and multi-material gadgets for children*

Current end-of-life management for many toys and gadgets does not consider circularity. Until recently, most toys were designed for short-term use, followed by disposal (Levesque et al., 2022). Some estimates suggest that up to 80 % of all toys end up either in landfills or incinerators, with an estimated 40 million tonnes of toys from France alone ending up as waste annually (Levesque et al., 2022a). A survey in 2019 revealed that more than 25 % of parents surveyed admitted to disposing of children's toys that were still in perfect working condition after a loss of interest by their child (Robertson-Fall, 2021).

Exact statistics of the amount of waste in landfills that can be attributed to toys, however, is lacking. This is due in part to the nature of the mixed materials found in toys. In a 2014 study looking at the overall composition of landfill material, Chinese researchers determined that more than 10 % of the landfill samples could be attributed to plastic, with about 31 % of that being attributed to non-plastic-bag plastic (Zhou et al., 2014). Toys would likely fall into this waste fraction (Levesque et al. 2022) due to plastics being the primary component of most toys (UNEP, 2014; Pérez-Belis et al., 2013). In addition, the increasing amount of smart, electronic toys means that these should actually be considered as WEEE.

### Why are multi-material children's products a problem for circularity?

A key problem for circularity in toys comes with consumerism itself. Manufacturers of many consumer products design them for rapid consumption and short lifespans by a supposed planning for obsolescence (Levesque et al., 2022; Satyro et al., 2018). In the toy industry, this occurs, for example, when manufacturers slightly tweak a product's design twice over the course of one year, solely to increase sales (Levesque et al., 2022a). In a 2018 study, researchers found that supposed planned obsolescence reduces the consumers perception of value of a product and increases the likelihood that they will purchase the slightly newer version (Kuppelwieser et al., 2019). In the toy industry, this is due in part to the industry's heavy marketing towards children and the subsequent demand directly from children for the latest toys (Levesque et al., 2022a). This quick turnover has significant consequences for the volume of waste being generated.

Another problem lies with the fact that recycled plastic has different mechanical properties. Recyclate plastic, plastic that has been recycled, for example, often has considerably different mechanical properties compared to virgin polymers (Hahladakis et al., 2018), affecting performance and likely discouraging usage by manufacturers. Furthermore, the breakdown of plastic into micro- and nanoplastics by ultra-violet sunlight is a widespread and well documented problem (Wang et al., 2021), that can release additives in plastics into the environment (Sørensen et al., 2021). The improper disposal of toys and gadgets containing plastics likely contributes to this problem.

The European Commission has announced the establishment of a right to repair to facilitate the development of a circular economy (European Parliament, 2022). Rates of repair depend on the type of a product, with the cost being the most important reason consumers avoid it. Research shows that consumers favour products that can easily be repaired, but their willingness to pay (more) for such products depends on what it is and the way information on its reparability is presented. The legislation on the right to repair is currently being considered for eventual inclusion into the Circular Economy Packages of the European Commission.

In general, consumers are familiar with the suitable means of disposing of large WEEE, such as household appliances and computers. Consumers, however, know less about the recycling of products, which traditionally have not included electronics. This leads to such items being deposited in the household trash with other waste (Pérez-Belis et al., 2013; Dimitrakis et al., 2009). Furthermore, the cost of collecting, separating, processing and transporting specific multi-material waste streams often exceeds the cost of collecting and disposing of the material as mixed waste (Gradus, 2020; Bohm et al., 2010).

Another challenge to improving the circularity of toys and gadgets for children is the diversity of chemicals of concern detected in imported items. In Europe, it has been reported that more banned chemicals have been found more frequently in toys than in any other product type (Santos, 2018). Small discrepancies in definitions can potentially lead to the exploitation of loopholes in environmental legislation intended to ensure toy safety. Furthermore, e-commerce that has enabled consumers to buy toys, which may not be compliant with EU standards, directly from outside Europe. This suggests that the EU's efforts to safeguard consumers might be inadequate (Almroth and Slunge, 2022) and e-commerce can increase the likelihood of putting toys containing unsafe levels of contaminants into circulation.

The threat of substances restricted under REACH or banned under the Stockholm Convention still being detected in toys and gadgets in circulation in the EU comes not only from the direct importation of new products produced from virgin materials. Studies show that legacy additives have been detected in newly manufactured plastic products produced from recycled materials (Kajiwara et al., 2022; McGrath et al., 2021; Guzzonato et al., 2017; Ionas et al., 2014; Chen et al., 2009), including toys containing PBDEs made from recycled plastic originating from WEEE (Straková et al., 2018). While concentrations of these chemicals is generally low, the enhanced exposure of children and infants could have implications for human health.

There are other contaminants of concern found in toy materials that cause problems for circularity. The transition to a circular economy encourages the use of vintage toys as a means of waste prevention, potentially leaving toys with high concentrations of chemicals, such as Cd and/or Pb, in circulation. (Miller and Harris, 2015). Similarly, children's products containing antimicrobial agents, such as silver nanoparticles, can have long-term impacts on mammals (Lyu et al., 2021), though more research is needed into the health effects on children.

## 9.2. Response and outlook

### What needs to change?

Broad and systemic changes are needed tackle the many problems facing the market of toys and other children's products. One option for change could be through legislation that fosters durability in products, such as requiring longer product warranties (Maitre-Ekern and Dalhammar, 2016). France has adopted legislation on improving the reparability of products by requiring manufacturers to inform the consumers of availability of parts as well as being the first country to adopt planned obsolescence legislation (Maitre-Ekern and Dalhammar, 2016). It is not clear, however, if this legislation applies to toys.

Another option for change could be as simple as increasing the transparency and information about a toy's environmental impact, as a means of counteracting the pressure to buy the newest toy models from their children felt by parents (Levesque et al., 2022b) and the marketing pressures from toy manufacturers. Finally, increasing consumer awareness of toy repair and recycling options would allow for more informed decisions on extending a product's lifecycles and disposal. According to the non-governmental organisation Right to Repair Europe, 70 % of electric and electronic toys and 76 % of non-electronic ones brought to repair cafés can be repaired successfully ([Repair café](#), 2021).

With regard to the chemicals of concern found in toys, there are many changes that could be made to make toys safer. The exemption in the Stockholm Convention permitting higher concentrations of certain bromated flame retardants in recycled plastics allows for weaker chemical safety standards for products made from plastics recyclate (Straková et al., 2019). The level of oversight on the prevention of this recyclate ending up in new toys is unclear.

Similarly, as discussed earlier, some of the additives found in plastics need to be replaced by more sustainable alternatives. This would require integrating more ecodesign that would at least consider end-of-life material recycling into plastic production (Hahladakis et al., 2018). Furthermore, there are calls for manufacturers in Asia, the largest exporter of toys, to increase toy safety and production standards (Almroth and Slunge, 2022), such as the 2020 appeal to the Association of Southeast Asian Nations (ASEAN) to produce its own directive or policy on toy safety to further facilitate global trade (Ismail et al., 2020). Finally, vintage toys with high concentrations of chemicals or additives of concern may have to be removed from circulation and, particularly, the recycling chain.

### Good practice

Since 2011, the Repair Café Foundation, not-for-profit organisation. has provided professional support to local groups in the Netherlands and other countries wishing to start their own repair cafés. These provide tools, materials and expert support for the repair of various consumer products including toys, electrical appliances and bicycles. The Foundation's activities also include on-line repair guidelines and visits to school to encourage and teaching young people to repair their gadgets. According to the Foundation, there are now more than 2 200 repair cafés in Europe ([RepairCafe](#), 2022).

One example of innovative solutions to the problems of toy waste is demonstrated by the Belgian company, Ecobirdy<sup>(13)</sup>. Its founders used their experience in the international fashion and design industry to address the environmental problem of toy waste through the production of ergonomic children's furniture, such as chairs and tables. The plastic used in Ecobirdy's furniture is 100% upcycled from used and broken plastic toys. The company also does not use dyes to colour the furniture. Instead, it relies on

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<sup>13</sup> <https://www.ecobirdy.com/>

the colours of the upcycled toys to provide a speckled appearance to their products. In addition, Ecobirdy has developed a method for the recycling of mixed plastics, often considered too difficult to recycle (European Circular Economy Stakeholder Platform, 2019).

Possible solutions can come from existing toy manufacturers themselves. Such an example is the PlayBack programme started by the global toy manufacturer Mattel. The programme encourages consumers to return end-of-life Mattel toys and the company then recycles them into components needed to build modern playgrounds, which are donated to children's charities. A consumer can download a free shipping label from Mattel's website and return to the company any broken toy from four of Mattel market brands <sup>(14)</sup> (Mattel Inc., 2022).

### Conclusion

There is a growing public awareness of various issues associated with the disposal of children's toys and gadgets. Many consumers lack knowledge about the disposal and possible repair of toys and gadgets, especially toys containing electronic components, which can be disposed of as e-waste. It is probable the increasing public consciousness of dwindling critical raw materials and the harmful effects of many chemicals of concern, the demand for more sustainable toys will increase. Together with legislation on right to repair, this could have the potential to drive a significant change in the market for toys and gadgets.

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<sup>14</sup> Brands currently accepted are Barbie®, Matchbox™, Fisher-Price® and MEGA™ toys. Mattel plans to add further brands in the future (<https://www2.mattel.com/en-gb/playback>).

## 10 Conclusions

If municipal waste generation continues growing, at least 72 % of it would need to be recycled to meet the CEAP target of halving the amount of residual municipal waste by 2030. This is a significantly higher rate of recycling than at present. Alternatively, the target could be achieved by reducing the amount of waste generated by around one third or through a combination of these approaches.

This report analyses eight product categories which today largely end up in residual municipal waste and are considered challenging to reduce. These are disposable diapers, beverage cups, digital consumer products, products made of or containing EPS and PFAS, furniture, mattresses, and multi-material children's gadgets and toys. Complex structures and health and environmental perspectives are the main factors hindering the reuse or recycling of these product.

Generally, the larger the volume of a particular waste stream, the more ecological, economic and social benefits can be provided through specific measures. Moreover, large waste streams offer better conditions for using large-scale recycling facilities, thereby achieving better economies of scale in their end-of-life management. For several product categories analysed in this report, such as furniture and mattresses, EPR schemes are seen as instruments with significant potential to increase circularity.

Preventing the generation of waste, especially non-recyclable waste, can deliver the greatest benefits for the environment. The reduction in waste needed to meet the CEAP target would require very ambitious waste prevention measures to be implemented at both EU and Member State levels, for instance by increasing the lifespan of consumer goods through ecodesign and ensuring strong support for product reuse. Most of the products need a redesign that enables and allows for more circularity, including an extension of lifespans through greater durability and repair.

Assuring health and safety aspects is a prerequisite of greater circularity, and a special concern in the products categories containing PFAS and flame retardants, such as carpets, furniture, products containing or made of EPS, and demolition waste. Though considerable development of safer alternative components is on-going, hazardous fractions will continue ending up in waste when products containing previously banned substances reach their end of life.

For some of these problematic waste streams, extended producer responsibility schemes are delivering promising outcomes in terms of improved collection and recycling rates. This model offers good potential for wider application to other 'headache products' – both in terms of driving improved waste management, and stimulating greater interest in upstream approaches such as design-for-recycling and safe-by-design.

Finally, increasing the information of product repairability, together with support for an increased network of repair cafés and the greater availability repair guidelines are important life extending and waste preventing actions, which, in most cases, also provide cost savings for consumers.

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