chemsec
INTERNATIONAL CHEMICAL SECRETARIAT

What goes around

Enabling the circular economy by removing chemical roadblocks

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Much of the basis for this report and its scope is the result of ChemSec´s work with Circular Economy and our close discussions with different stakeholders, from brands to recyclers and policymakers.

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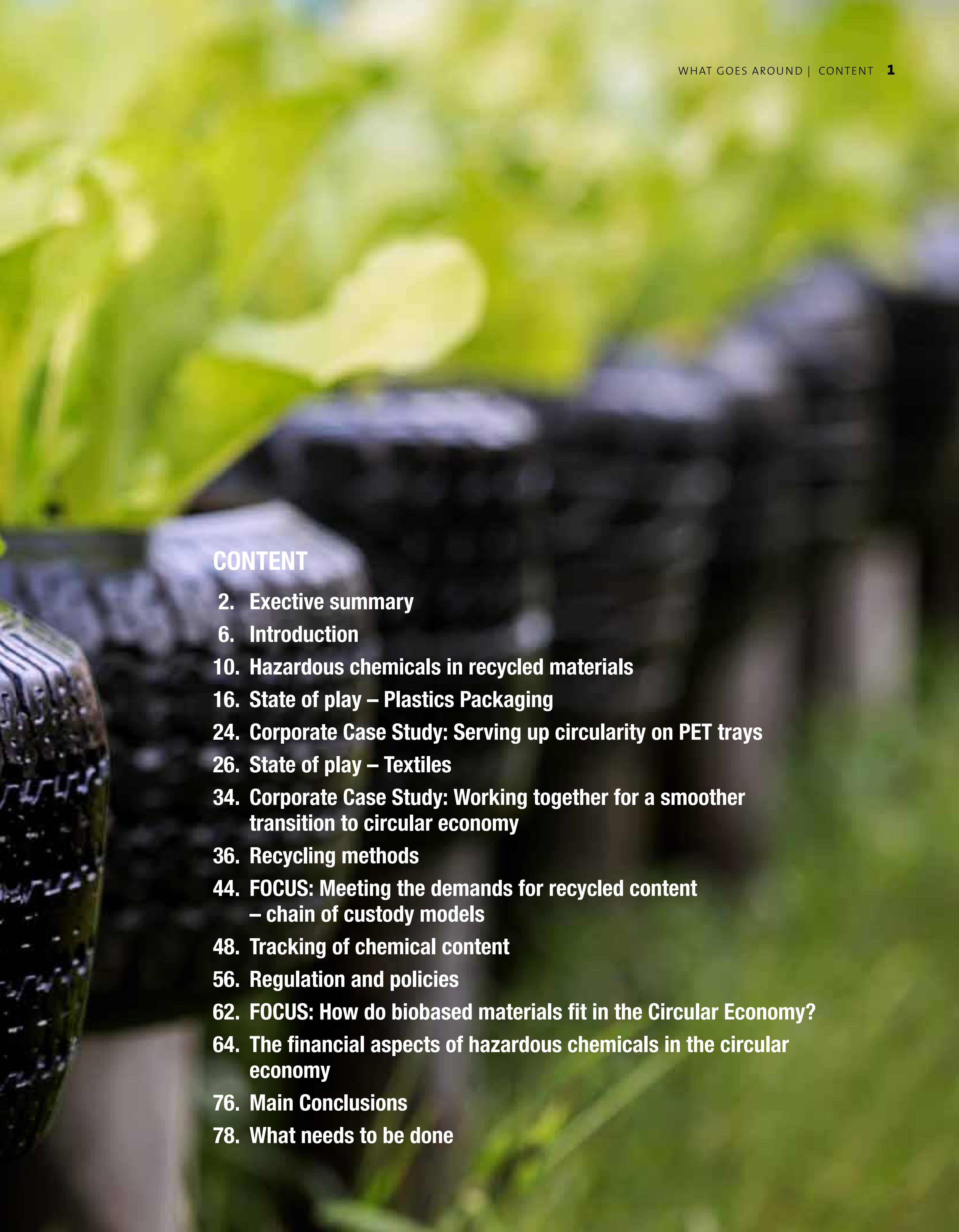
While all these contributions have been invaluable for the creation of the report, ChemSec is solely responsible for its content, its conclusions and opinions.

Laudes Foundation



CONTENT

Executive summary

The Circular Economy is a proposed economic system, aimed at eliminating waste and the continual exploitation of natural resources. It is based on a set of principles that include designing out waste and pollution, keeping products and materials in use, and regenerating natural systems.

Reducing, re-using, repurposing, mending and recycling products and materials are all important parts of this. Action is urgently needed to address the fundamental challenges that we face today, including climate change and resource constraints.

While there is a substantial buy-in to these principles from decision-makers and companies, *the steady increase in use of virgin materials, while recycling levels remain low, points at the need to do something more – and different.* A number of roadblocks still need to be removed for the circular economy to gain momentum.

THE MISSING PIECE

There are several good initiatives and reports that address some of the actions needed to accelerate the implementation of the circular economy, including infrastructure, standardisation, collaboration and modified business models. However, one important roadblock remains surprisingly unaddressed: the issue of chemicals of concern in current material flows. This is why this report is needed. We can be certain that what goes around, comes around.

Projections suggest that chemical production will double between 2017 and 2030. *62% by volume of the chemicals on the EU market are classified as being hazardous to human health or the environment.*

84% of Europeans are worried about the impact that chemicals in everyday products have on their health, and even more are worried about their impact on the environment.

HAZARDOUS SUBSTANCES ACCUMULATE – AND REMAIN

As long as the production of materials involves chemicals of concern to such a large extent, re-using and recycling these materials is problematic. An additional concern is legacy chemicals remaining in the system from previously produced materials. In this report, we look at what is known about chemicals of concern in recycled materials. How chemicals accumulate in these materials over repeated recycling loops, and remain in the system for many years after the chemical has ceased to be used in new products.

The report focuses on plastic packaging and textiles. Both are ubiquitous in our everyday lives and produced in chemical-intensive processes. Recycling of plastic packaging has developed over decades, and yet the recycling rates are only about 10%. Recycling of textiles is an underdeveloped sector, and only about 1% of textiles are recycled into new clothes.

Our discussions and interviews with companies and recyclers have informed us that many companies find it problematic to use recycled materials in their consumer products. ***Companies struggle to increase their use of recycled materials in products while staying compliant with chemical requirements, both legal and their own.***

NO MAGIC FIX ON THE HORIZON

This report takes a closer look at available and proposed recycling methods, and their ability to tackle and eliminate chemicals of concern from input waste materials. Of the various techniques under the umbrella of "chemical recycling," no viable large-scale solutions were identified. While these techniques might be justified for use in specific situations, they are costly in terms of energy and there are uncertainties over additional environmental impacts.

This means that mechanical recycling is the main large-scale technology to rely on both today and in the future. However, in mechanical recycling the chemical content of the recycled materials is dependent on the input waste.

TRANSPARENCY, TRACEABILITY, AND DESIGNING OUT

For this reason, it is necessary to improve both the transparency and traceability of the chemical content of the materials destined for recycling. This report takes a closer look at available and proposed techniques for this. For such systems to be implemented on a larger scale, a substantial part of the market must accept and use these tools, and regulations will play an important role in their uptick and use.

It is obvious that the most efficient solution to stop circulating hazardous chemicals is to dramatically speed up the phaseout of chemicals of concern from the production of new materials. ***Recyclability, including chemical content, must be considered right from the design stage.***

After reviewing different aspects of treating waste and tracking chemicals, this remains the main conclusion of the report. New recycling technologies and tracking methods will play an important role, but their contribution is limited, which means that the circular economy cannot expand as long as new materials contain chemicals of concern.

MUCH TO GAIN – AND EARN – FROM A SAFE CIRCULAR ECONOMY

This report also presents a new and unique analysis, aiming to look into the financial opportunity that could be realised if the stumbling block of "chemicals of concern" was removed from the path to a circular economy.

Acknowledging the many uncertainties about future market developments, coupled with developing policies and technologies, we have analysed a number of different scenarios. While the potential market opportunities vary, even a conservative estimate shows a substantial market potential, which can be added to the many reasons for ridding the economy of chemicals of concern. ***A small increase of 10% in the recycling of plastic packaging would correspond to an annual increase in EU market value of €2.6 billion, while an increase of 30% would mean €7.7 billion.***

Increased use of virgin materials and low recycling levels show that a circular economy is far from being realised. The presence of chemicals of concern in materials is an important reason for this. Mechanical recycling will remain the main recycling technology for the foreseeable future, which makes establishing non-toxic waste streams the key to scaling up the circular economy.

Chemicals of concern must therefore be designed out of new products. Along with this decreased use of chemicals of concern, a substantial market opportunity can be realised through the increased usability of recycled materials.

Introduction

In the ideal circular economy, no new resources are brought in and no waste is produced. While this is a utopian situation, all actions taken towards "closing the loop" are in line with the idea of circularity.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This includes actions that are intended to reduce the inflow of virgin materials and reduce the amount of waste produced. Actions that are intended to keep a product within the economy for a longer time, for example by reusing, remaking, refurbishing and improving the quality of products, are also central elements of a circular economy.

Eventually though, most products will reach the state when they are regarded as waste. This is why recycling is key to maintaining circularity, by turning waste into secondary raw materials that can be used to produce new products.

The name of this report – what goes around – refers to the fact that when we close the loop, we are "stuck" with what is in the system, for good and for bad. This is especially problematic for chemicals of concern.

Recycling in perspective

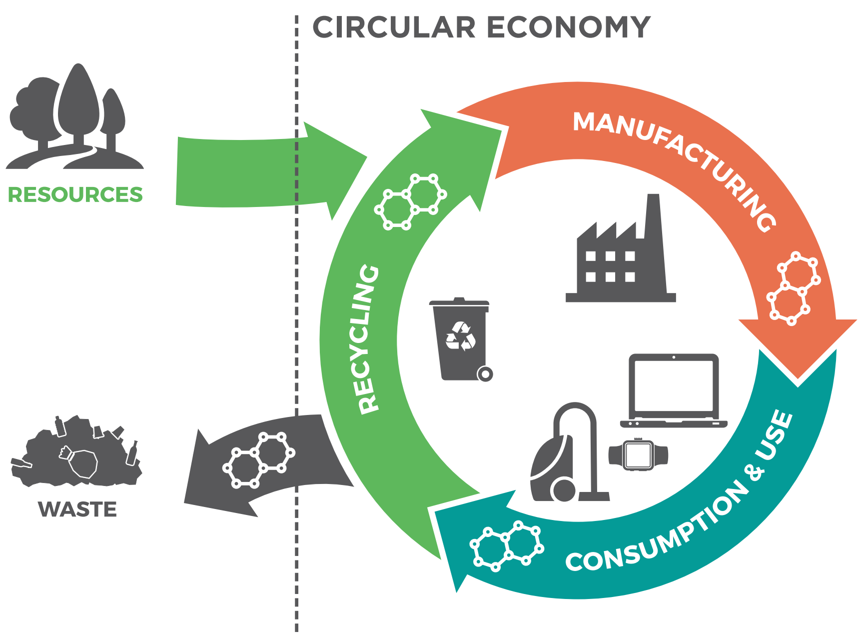
The need and will to recycle is not new, although in earlier times it was driven mainly by resource constraints. Over a few decades of the twentieth century the "take-make-dispose" mindset took over, and this is what we now refer to as a linear economy. From 1966 onwards, visions of a "closed economy", "spaceship earth[1]" and "cradle to cradle", driven primarily by environmental concerns, grew and became part of the concept we today call a circular economy.

In recent years the Ellen MacArthur Foundation[2] has commissioned a number of reports that show the importance of a circular economy and how it could more practically be achieved.

Recycling was introduced in the 1960s and 70s. Until then, landfill and dumping were the main methods of waste disposal and people started to react to this accumulation of waste in their surroundings. Incineration was presented as one solution and became widely used.[3] Due to the increasing prices of energy it was recognised that large amounts of energy could be saved by recycling some materials instead of producing new. These were mainly aluminium, glass and paper.

This report focuses on two additional materials: plastic packaging and textiles. These materials were chosen because they are both high-volume materials that result

Figure 1. *In the ideal circular economy, no waste is discarded and no virgin raw material is needed. This means that hazardous chemicals in products are not discarded along with the waste, but are transferred into new products made from the secondary raw material. This must be addressed before scaling up the circular economy.*



from chemically-intensive production. While recycling of plastics began back in the 1970s, only a small proportion, less than 10%, is actually being recycled today.[4] The recycling of textiles is in many ways in its infancy.

It is vital to increase the recycling of both plastic packaging and textiles, but the presence of chemicals of concern must be taken into account at the same time.

In this report we focus on the EU and other regions with more developed waste handling systems and policies. While acknowledging the urgent need in some parts of the world to tackle a situation where people try find a living by mining garbage dumps for materials to sell, those situations are outside the scope of this report.

The bar is set high for increased recycling

Looking at the current situation, we see that over the past 50 years, the demand for materials has tripled and is expected to double again by 2060.[5] So-called "circular material use" (CMU) was only 11.7% in the EU in 2019[1], while global levels are even lower.

There is a political will to speed up the transition to a circular economy. In late 2019 the EU Commission presented its Green Deal, with an action plan[6] to "boost the efficient use of resources by moving to a clean, circular economy". As part of this, the Commission released its Circular Economy Action Plan[7] in March 2020. It proposes various measures, such as designing for re-use and recycling, educating consumers, and establishing new global agreements. It also sets a target to ***double circular material use within the next ten years.***

Interestingly, there are huge opportunities for environmental, as well as financial gains if material recycling increases. Financially, the current low recycling rates have been estimated as a lost value of €87 billion each year in the EU, and that is just for steel, plastics and aluminium.[8]

Diving into the details, figures and recommendations

In this report, we take a closer look at the chemicals that prevent safe recycling, as well as the available recycling methods. We compare different recycling methodologies based on how they handle hazardous chemicals and look into emerging techniques that effectively track chemical content.

In addition, we analyse the financial aspects of hazardous chemicals in the circular economy. What are the costs of not addressing hazardous chemicals, and what are the market opportunities to do so? Finally, we give recommendations to both policy makers and businesses on how to move towards a non-toxic circular economy.

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4. *Ellen MacArthur Foundation, The New Plastics Economy: Rethinking the Future of Plastics (2016)*
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8. *Material Economics 2020. Preserving value in EU industrial material, a perspective on the use of steel, plastics and aluminum.*

Hazardous Chemicals in Recycled Materials

What is the problem with hazardous chemicals in recycled materials and what do we know?

The answers to these questions are outlined in this chapter, where we also discuss how chemical levels can accumulate over cycles of recycling, and how long a chemical may remain – even if it is banned in new materials.

Finding hazardous chemicals in recycled materials is not a new phenomenon. An anecdotal example is that some book covers produced in the 19th century were made from medieval parchment, decorated with arsenic paint. These books have now been identified as a hazard for librarians.[9]

Wide range of hazardous chemicals found

In the early 1970s, PCBs were detected in food packaging and it was concluded that they came from the use of reclaimed or recycled paper.[10, 11] To date, due to increasing awareness and better techniques to measure chemicals, a wide set of hazardous chemicals have been found in various recycled materials, including paper, plastics, rubbers, and textiles.[12, 13, 14, 15]

Several general observations can be made from the existing studies:

1. Different kinds of hazardous chemicals can be present in recycled materials.
2. Some hazardous chemicals occur in multiple recycled materials. Bisphenol A (BPA) is found in recycled paper and plastics, and some phthalates are present in recycled paper, plastics and rubbers, see Table 1.
3. The levels of hazardous chemicals in recycled materials vary considerably. For example the amount of Tetrabromobisphenol A (TBBPA) in 27 recycled plastic samples ranged from below the limit of detection to 26 mg/g.[16]

Dozens, even hundreds of (hazardous) chemicals have been identified in recycled materials, and yet this is likely to be the tip of the iceberg. Over 4,000 substances may have been used in plastic packaging, 60% of which gene-

Table 1. Some examples of hazardous chemicals detected in recycled materials. For plastic packaging and textiles, see the respective chapters. LOD = Level Of Detection.

RECYCLED MATERIALS	CONTAMINANTS	DETECTED LEVEL RANGE [MEAN (MIN.–MAX.)]
PAPERBOARD	Mineral oil	845 (50-3800) mg/kg [20]
PASTRY PACKAGING	Benzophenone (CAS 119–61–9) Pentachlorophenol (CAS 87–86–5) DBP (CAS 84–74–2) DEHP (CAS 117–81–7)	0.018 (0.004-0.035) mg/dm^2 0.027 (0.007-0.044) mg/dm^2 0.045 (0.009-0.096) mg/dm^2 0.123 (0.025-0.263) mg/dm^2 [21]
FOOD CONTACT PAPER AND PAPERBOARD	BPA (CAS 80–05–7) DEHP (CAS 117–81–7) Nonylphenol monoethoxylate (NMP) Nonylphenol diethoxylate (NDP)	7.29 (0.50-20.1) mg/kg [22] – (<LOD-39.8) mg/kg – (<LOD-0.69) mg/kg 0.32 (0.11-0.61) mg/kg
TOYS	OctaBDE (CAS 32536–52–0) DecaBDE (CAS 1163–19–5)	1–161 ppm 3–3310 ppm
HAIR ACCESSORIES	OctaBDE (CAS 32536–52–0) DecaBDE (CAS 1163–19–5)	1–70 ppm 2–2491 ppm
KITCHEN UTENSILS	OctaBDE (CAS 32536–52–0) DecaBDE (CAS 1163–19–5)	1–25 ppm 1–195 ppm [23]
PLAYGROUND SURFACES	Polycyclic aromatic hydrocarbons (PAHs) Benzothiazole (BTZ, CAS 95–16–9) Butylated hydroxytoluene (CAS 128–37–0) DEHP (CAS 117–81–7)	23.4 (1.25-178) mg/kg 9.6 (0.47-39.9) mg/kg 7.08 (0.11-23.9) mg/kg 20 (3.95-63.8) mg/kg [24]

rally lack public hazard information.[17] More than 17,000 substances may have been use in paper and paperboard [18] and over 3,500 substances may have been used in textiles.[19] Furthermore, little is known about the hazardous properties exhibited by many of these identified chemicals.

Chemical levels accumulate over time in a circular economy

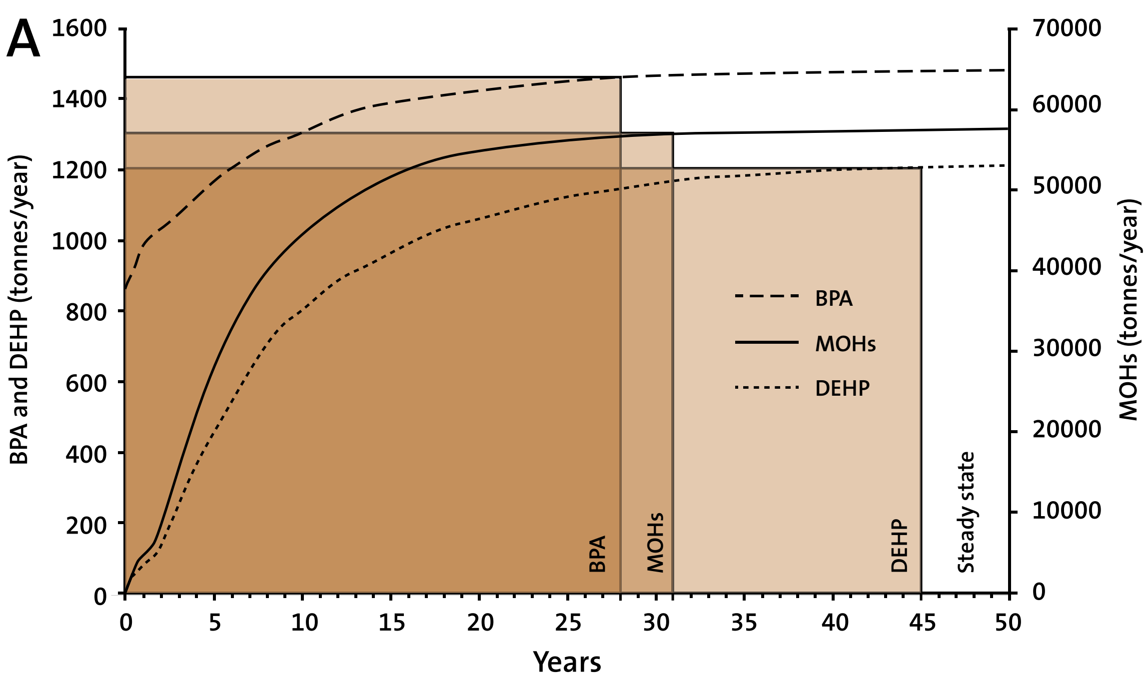
In a linear economy, once a chemical is identified as problematic and removed from new production and imported materials, it is no longer a problem.

In contrast, in a circular economy, the chemical content of a product depends not only on what is added during the production process, but also on what is already present in the material.

As a consequence, continuous use of a chemical results in the accumulation of that chemical over the recycling cycles.[25, 26, 27, 28]

A study [29] of paper recycling, modelled the amounts of Bisphenol A (BPA) and the phthalate DEHP that accumulate over time in a recycling system. When it was assumed that constant amounts of the chemicals were added to new paper products (see Figure 2), the levels continued to rise for 25 years for BPA and 45 years for DEHP. It wasn't until a steady state was reached, that the amounts "lost" in the recycling process were in the same range as the amount introduced through new materials.

Figure 2. Evolution of amounts of BPA, DEHP and MOHs (mineral oil hydrocarbons) over time, resembling the paper system in Europe in 2012 and assuming that constant amounts of the chemicals were added in the products. The shaded areas represent periods of accumulation for BPA, DEHP and MOHs, as well as the (quasi) steady state achieved.



Chemicals remain in the system even after ceased use

This study also investigated different options to remove chemicals from the recycling system, exemplified by DEHP in paper (Figure 3).

The first scenario focussed on sorting the paper prior to recycling, thus removing the suspected contaminated paper and separating it for incineration.

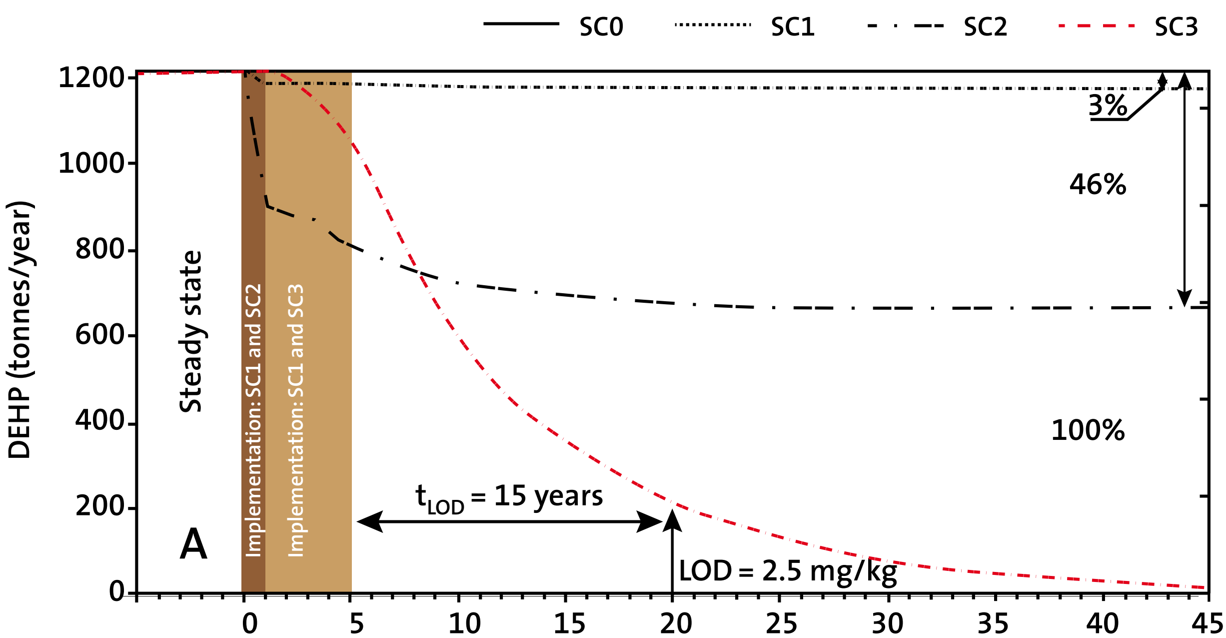
A second scenario relied on an improved recycling process that had enough capacity to remove twice as much DEHP compared to the prior process.

In the third scenario, the use of DEHP decreased for five consecutive years in new paper products, and then stopped entirely. This was obviously the most efficient scenario, but even then, DEHP remained in the recycled material for 15 years, until the levels were below detection limit.

As we have seen, there are many hazardous chemicals present in recycled materials. Some are perpetuated through the production and processing of recycled materials, while others are linked to cross-contamination during recycling.

The continuous use of a chemical will result in the accumulation of that chemical in recycled materials. In addition, even after a rapid phase-out of production and use, legacy hazardous chemicals may remain in material cycles for a long time, resulting in long-term exposure and potential human health impacts.

Figure 3. *Evolution of the amounts of DEHP in the paper products in four different scenarios over time.*
Scenario 0 = no measures taken
Scenario 1 = optimising the collection of paper for minimizing the levels of DEHP
Scenario 2 = doubling the removal efficiency of DEHP in paper recycling
Scenario 3 = assuming a five-year linear decrease of DEHP use until no more DEHP was intentionally added.
The shaded areas represent the implementation periods for scenarios 1, 2 and 3. LOD = limit of detection; tLOD = time required to achieve insignificant concentrations of DEHP in the paper products.



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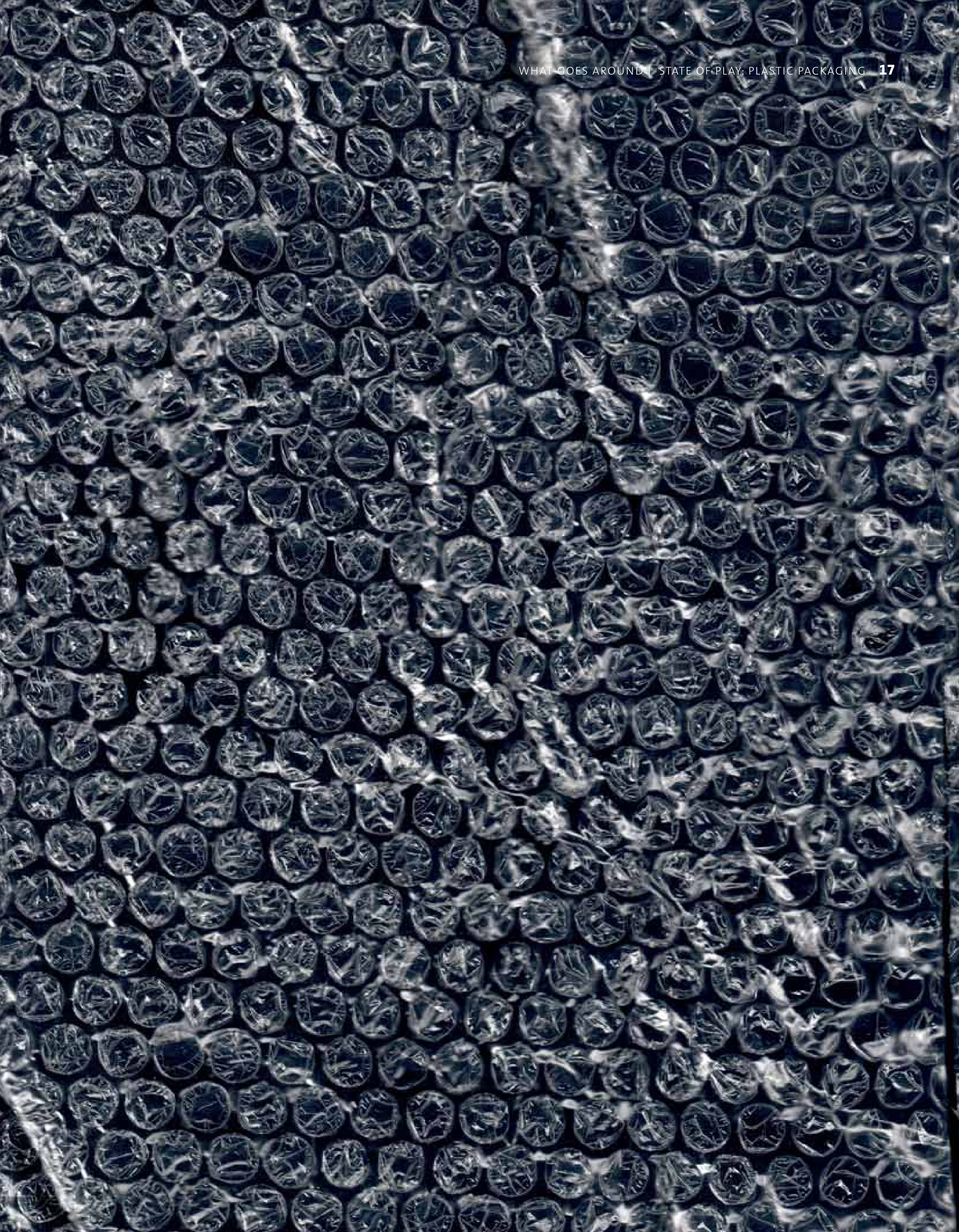
State of Play:
Plastic Packaging

Since their industrial-scale introduction in the 1950s, plastics have grown to a more than 370 million-ton market.[30] Plastics can range from highly specialised small-volume materials to cheap bulk materials. Almost every industry and product category in the world relies on plastics for some functions.



Due to the diversity of properties, function and scale, it is hard to discuss plastics as a single material or material group. This report looks primarily at plastics used in packaging, since plastic packaging makes up a large part of all waste, and the majority of plastics collected for recycling comes from packaging.

A versatile and challenging material

Plastics have numerous benefits: durability, low cost, low weight and low gas permeability. As a group – consisting of polymers of variable configuration, with a wide range of additives – plastics are almost infinitely variable, and can be designed and engineered in a very precise way to fulfil specific functions.

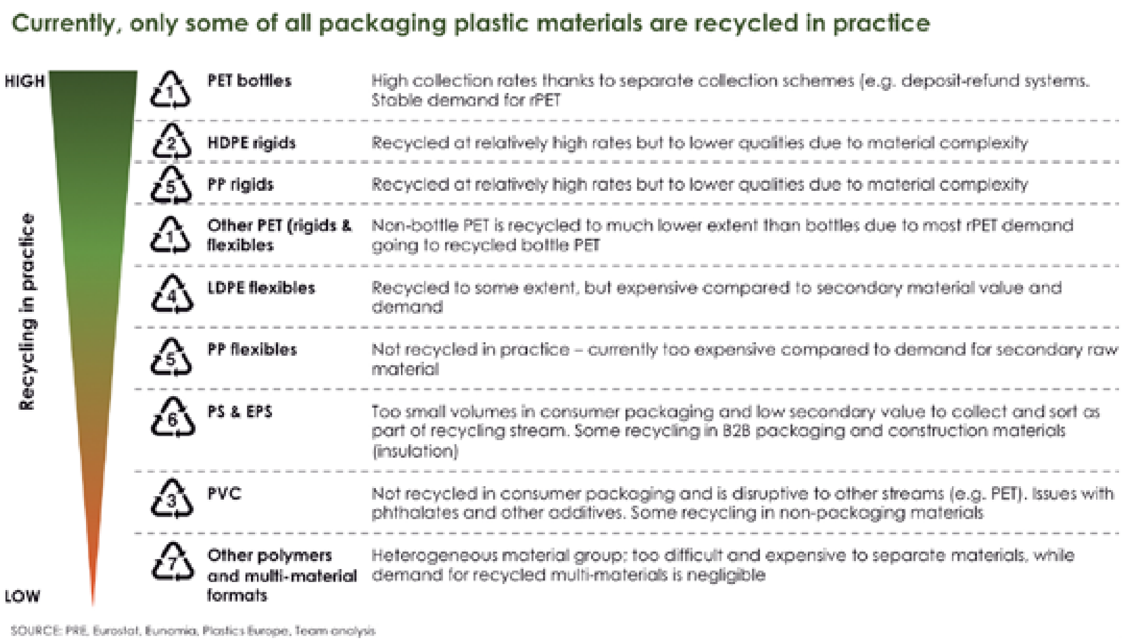
However, the versatility of plastics is also the root cause of the challenges faced in recycling these materials. To be recycled into a material of value, plastics first need to be separated into different polymer types and preferably even polymer grades. Even the most common polymers come in different molecular lengths and structures, and therefore have different properties. In addition, the chemical additives cannot easily be removed from the polymers. All these factors make the recycling of plastics more complex compared to many other materials.

The most common plastic resins are assigned 'resin identification codes' to help consumers and recyclers identify them (Figure 4). It looks simple, but this system hides an extreme complexity.

The negative impacts of plastics on society and the environment are now widely acknowledged. The environmental negative externalities generated by plastic packaging have been valued to at least EUR 36 billion by UNEP (the UN Environment Programme). [31]

Nevertheless, global plastics production continues to increase steadily. In 2019, 368 million tonnes of plastics were produced globally, including 57.9 million tonnes in the EU, out of which 40% is used for packaging.[32] It cannot be ignored that plastics will still play an important role in the foreseeable future.

Figure 4. Recycling in practice of the most common plastic resins.



Plastic packaging has a relatively short life-span compared to other plastic products. Currently, approximately 60% of plastic packaging is used for food and beverages, with the rest being used mainly for non-food contact applications.[33]

Much to improve when it comes to plastic packaging recycling

The current plastic packaging value chain is mostly linear, with only 11% of the material value remaining after a single use cycle.[34] Despite decades of effort to build an efficient recycling system, most plastic packaging is still not recycled in practice and at scale; about 14% of plastic packaging is currently collected for recycling globally, of which 10% is actually recycled, with only 2% in a closed loop.[35] In the EU, 16.7 million tonnes of plastic packaging waste were produced in 2017, of which 42% was collected for recycling – with much less being recycled as new materials.[36] The rest is mainly either landfilled, incinerated or leaked into the environment.

PET is currently the resin with the highest recycling rates and value preservation potential, being a relatively "clean stream" In 2018, 45% of the available PET was collected and sorted for recycling globally, and 52% of the PET bottles. However, only 18% of PET bottles are recycled recycled as new bottles for food and drink.[37]

Mechanical recycling is the only recycling method for plastic packaging currently operational on an industrial scale. A number of barriers hinder the upscaling of plastic packaging recycling.

- The plastic packaging value chain is highly fragmented.[38] There is very little standardisation around formats, materials or additives, along with lack of data about actual material flows.
- Common packaging types are difficult to recycle in practice, such as multilayer packaging and packaging containing certain pigments, inks, glues, or packaging contaminated by food or hazardous substances.
- It is difficult to compete with the low cost of virgin material. Sorting out specific materials from a mixed waste stream is costly and there is also a lack of interest in small volumes of secondary raw material. Recycling is therefore, on average, less economical than landfill or incineration.[39]

Several initiatives for improvement in the making

A number of voluntary, cross-stakeholder initiatives and legislations currently underway that intend to improve various aspects of the plastics system, aiming for further alignment and concerted action between the different stakeholders in the plastics sector.

Some notable initiatives include the New Plastics Economy, led by the Ellen MacArthur Foundation[40], the Global Plastics Action Partnership (GPAP)[41], led by the World Economic Forum, and the Alliance to End Plastic Waste[42], led by a coalition of plastic producers and brands.

In recent decades, efforts have been focused on expanding and improving the infrastructure for recycling, since a basic waste management system is still lacking in large parts of the world. The EU Plastics Strategy[43] also sends a clear signal to the industry to increase the recyclability of plastics.

Potentially thousands of hazardous chemicals in plastic packaging

There are currently more than 4,000 known chemicals that are probably or possibly used in the manufacturing of plastic packaging, or present in the final packaging articles.[44] Chemical additives are used in plastics to improve the characteristics and functionality of the polymer. There are also non-intentionally added substances (NIAS) found in plastics. These are reaction by-products, breakdown products and contaminants.[45]

Hazardous chemicals, and restricted chemicals, are routinely found in all types of plastics, from food contact articles and materials (coatings, adhesives, printing inks, and so on) to non-food contact plastic packaging.[46, 47, 48, 49, 50]

The presence of hazardous substances makes plastic packaging even more difficult to recycle[51], potentially inducing a cocktail of chemicals which can undergo chemical reactions during manufacture and use.[52] The presence of restricted or phased-out chemicals has also been found to possibly last for decades in recycled plastics, long after these substances have been prohibited by EU legislation.[53] Naturally, producers are reluctant to use recycled plastics if the content cannot be properly verified.

To date, there is no systematic listing of chemicals in plastics; it is difficult to identify the most problematic chemicals, but some examples are listed below:[54]

- Plastic polymers are built from smaller MONOMERS, several of which are hazardous. Whether monomers leak from the polymers in the plastic material varies, depending on the material and conditions, such as heat or acidic content. *Bisphenol A, S and F, melamine, acrylamide, styrene and vinyl chloride* are some examples of hazardous monomers.

- PLASTICISERS, also called softeners, are added to the polymer to increase flexibility, mainly for PVC. *Phthalates* are widely used softeners, many of which are known to be hazardous. The amount of plasticiser in a plastic material can be high, up to 30-40% by weight. As the phthalates are not bound in the polymer, they leak out over time. Nevertheless, large amounts can remain after recycling.

- STABILISERS are used to preserve the material from degradation due to light, for example. Toxic heavy metals such as *lead and cadmium* can be used, as well as UV filters such as *benzophenones*, which are hazardous.

- SURFACTANTS are used to change surface properties. Common surfactants include the problematic family of *PFAS* chemicals. Different *alkyphenols* are also used.

There is currently insufficient transparency and a lack of publicly available information on the actual use and levels of chemicals in plastic packaging. Some hazardous chemicals are well known and debated, driven by increasing public awareness and access to data, and their regulation is at least being discussed, such as BPA, phthalates and PFAS. Other chemicals may be hazardous, but are currently not considered as such, due to a lack of data to confirm their hazardous properties through toxicity testing.[55] Many chemicals used in the manufacture of food contact plastic packaging have not been tested for toxicity, or the toxicity data available is limited, so the hazard level remains uncertain or unknown.[56]

Product manufacturers often don't know themselves exactly which chemicals their packaging contains, and are not required to disclose the information even if they have it.[57] Although initiatives to increase transparency and identify substances of concern have emerged, such as the plastic additives initiative[58] (a joint industry project with ECHA) or the Proactive Alliance industry group, there is a clear need to go beyond voluntary measures, towards further regulation at EU level.[59] The SCIP (Substances of Concern In Products) database by ECHA is a good start.[60]

Looking ahead: Less single-use, less virgin materials – and less hazardous chemicals?

Based on the current trends, we can expect a significant increase in global plastics production and use by 2040, with a similar growth in plastic pollution. If we continue business-as-usual, the amount of single-use plastics is expected to double, followed by a four-fold increase in ocean plastics. As a consequence, the amount of chemicals used – including hazardous ones – will naturally also increase.

However, recent regulations and voluntary industry commitments are aimed towards a circular economy for plastics. The 2018 EU Plastics Strategy and Single-Use Plastics directive (SUP) aim to move towards reusable and recyclable products, with a four-fold increase in plastics sorting and recycling capacity between 2015 and 2030.[61]

The "New Plastics Economy Global Commitment" from the Ellen McArthur Foundation unites 850+ organisations behind the common vision of a circular economy for plastics. Signatories have committed to reduce virgin plastics consumption and design out hazardous chemicals, among other actions, to allow for plastics to be recycled in practice and at scale by 2025.[62] However, it is important to note that these recycled content commitments are made without specifying how to address chemicals in recycled plastics.

So far, commitments made on designing out hazardous chemicals have often been limited to phasing out entire materials such as PVC, PVDC and – to some extent – polystyrene. This is efficient, as it also deals with the numerous hazardous chemicals associated with these polymers. However, the larger majority of chemical additives or contaminants are rarely explicitly addressed.

One trend, showing a possible increase in awareness of the problem of hazardous chemicals in recycled materials, is that more and more companies are moving from setting targets on the use of recycled contents in their products to setting targets for sustainable content instead.

Safe-by-design and new business models are primary interventions necessary to drive a clean, circular economy for plastics over the next decade.

Although the Covid-19 pandemic may induce short-term impacts – some of which could dampen the progress made in tackling plastic pollution and chemical hazards in plastics – it is still difficult to evaluate the long-term impact and predict which of these changes will be significant or lasting at this stage.

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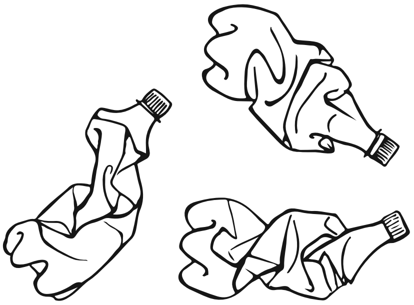
Corporate Case Study
Serving up circularity on PET trays

When you see or hear the acronym "PET", the first word that pops into your head is probably "bottles". However, that instinctive association may soon include other everyday items, as Coop Denmark has taken the concept further by introducing meat trays made from 90% recycled PET – so far saving 900 tonnes of virgin plastic material.

– It all began with Coop's new packaging strategy, focusing on recycling and circular economy. We noticed that the meat trays we were using weren't recyclable. So we started looking for alternatives and decided on PET, since it's safe and easy to recycle, says Mathias Hvam, CSR Project Manager at Coop Denmark and responsible for the PET meat tray project.



Return to sender

The project, which has just concluded in Copenhagen and will be rolled out in the rest of Denmark shortly, involved 7 tonnes of PET, or roughly 400.000 recyclable trays.

– The first step was to make sure the trays consisted of just one kind of plastic, to enable recycling, while the second step was to make sure the trays were made from as much recycled PET as possible, says Mathias.

Coop eventually succeeded in their goal of reaching "tray to tray" recycling, copying the established "bottle to bottle" concept. But since the PET bottle infrastructure – dedicated machines offering money in return for bottles – doesn't exist for PET trays, Coop first had to raise public awareness about the importance of recycling the coveted polymer.

– A lot of PET was basically thrown in the household waste in Denmark, so we realized that we needed to change that behaviour. We communicate a lot around sustainability and recycling in general, so we simply stressed the importance of keeping circularity in mind and putting the trays in the plastic recycling bins, Mathias explains.

Mathias Hvam,
CSR Project Manager at Coop Denmark

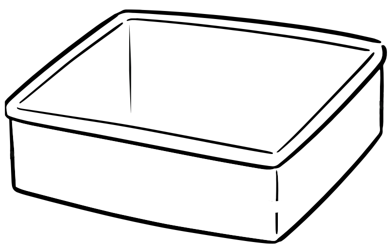
Recognition technology facilitates – and restricts

The sorting of the recycled trays was done manually at first, but as the project progressed, the team developed an automatic sorting function, using recognition technology to identify and sort out their trays.

– One thing that made trays so great for this project is that they are very characteristic, which makes them easy to sort out. Ideally, we would like to use food grade PET for all kinds of packaging, not just trays. But unfortunately, there are several things that restrict us. For example, we would need even more advanced recognition technology, says Mathias.

He is open to substituting other non-recyclable materials in Coop Denmark's supply with recyclable plastics – not just with PET, but other white-listed, plastic monomaterial as well.

– As it stands now, PET is the only plastic type we can take from household waste, and turn food grade again. There are options for the PE fraction, but for non-food grade – not for food grade. So we are looking into turning more household waste, and sorted waste in general, into packaging and new applications, says Mathias.



Does it matter if it's black or white?

Acceptable colours of recycled plastics is a much debated issue. Black plastic is difficult to scan, and thereby sort, which causes recycling challenges. In addition, the dark colour could signal that the plastic consists of a mix of polymers – and additives – from different unknown sources, potentially rendering it undesirable. But with new, more sophisticated lasers in combination with the recognition technology, Coop and their partners have been able to get past these issues and make sure that it's only their own safe, food-grade PET that is selected for recycling.

– Today, PET is generally sorted into three colour categories: transparent, white and coloured. If you demand only clear plastics, you're actually hindering circular economy, since you're only using a fraction of the recycling stream. And clear plastic doesn't stay clear when you recycle it; it turns yellow and foggy, due to different types of contamination. So either you take what you get, and produce from a "jazz mix" of colours based on what input you have for recycling that day or week. Or you colour the mix you have darker – often black – to get a streamlined and similar looking batch. Our meat trays are black, but we also work with clear, white and other coloured PET, says Mathias.

"As it stands now, PET is the only plastic type we can take from household waste, and turn food grade again."

It takes a village

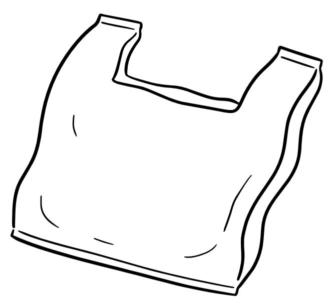
Of course, Coop could not have carried out the meat tray project all on their own. For PET production and testing, they rely on their partner and packaging supplier Faerch. Collaboration with the Municipality of Copenhagen, recyclers, other retailers and consumers has also been vital, according to Mathias Hvam.

– The beauty and the struggle of circular economy is that you need everyone on board for it to work. You have to make sure that the municipalities create the infrastructure for recycling, you need the citizens to recycle the materials and then you need companies like Coop to demand the material back and put it to use again. This project would not have been possible, were it not for the cooperation in the Partnership for circular food grade trays.

Looking back on the successful project, Mathias and the rest of the team have gained many valuable insights to carry into their continued work of expanding and further developing the initiative.

– 900 tonnes... That's a lot of virgin plastic material saved – and that's just Coop's meat trays in Copenhagen. Imagine the volumes if there were similar tray loops all over Europe! I think that circular economy needs these kinds of initiatives in order to move forward. Recycling is an international matter – not a national one. Sharing experiences and take-aways from projects like these is very important, Mathias concludes.

"The beauty and the struggle of circular economy is that you need everyone on board for it to work."



State of Play: **Textiles**

The textile industry is vast, and includes clothing, industrial/technical textiles and home furnishings. The number of garments produced has increased 400% since 2000, and new clothes arrive in stores 6 to 12 times a year to support quickly moving fashion trends. In 2020, approximately 115 million tons of textile fibre were produced. The average American throws away 36 kg of clothes each year. In the EU, the corresponding figure is 11 kg – while less than 1% of all apparel is recycled into new clothing.[63, 64]

Between 60 and 75 million people around the world are employed in the textile, clothing and footwear industry. The global textile industry was estimated at EUR 778 billion in 2018 and is projected to grow by 4.4% per year from 2019 to 2024.

China is the leading producer and exporter of raw textiles and garments. The US is the leading producer and exporter of raw cotton, and the top importer of raw textiles and garments. The textile industry of the EU comprises Germany, Spain, France, Italy, and Portugal, with a value of more than one fifth of the global textile industry. India is the third-largest textile manufacturer, responsible for more than 6% of global textile production.[65]

What are textiles?

Textiles can be loosely split into woven, knitted and non-woven forms. Woven and knitted fabrics are used to make clothes, sheets and towels, whereas non-woven textiles are used in wipes, diapers, insulation and geotextiles for road reinforcement. The scope of this report is textiles that are used to makes clothes and home furnishings.

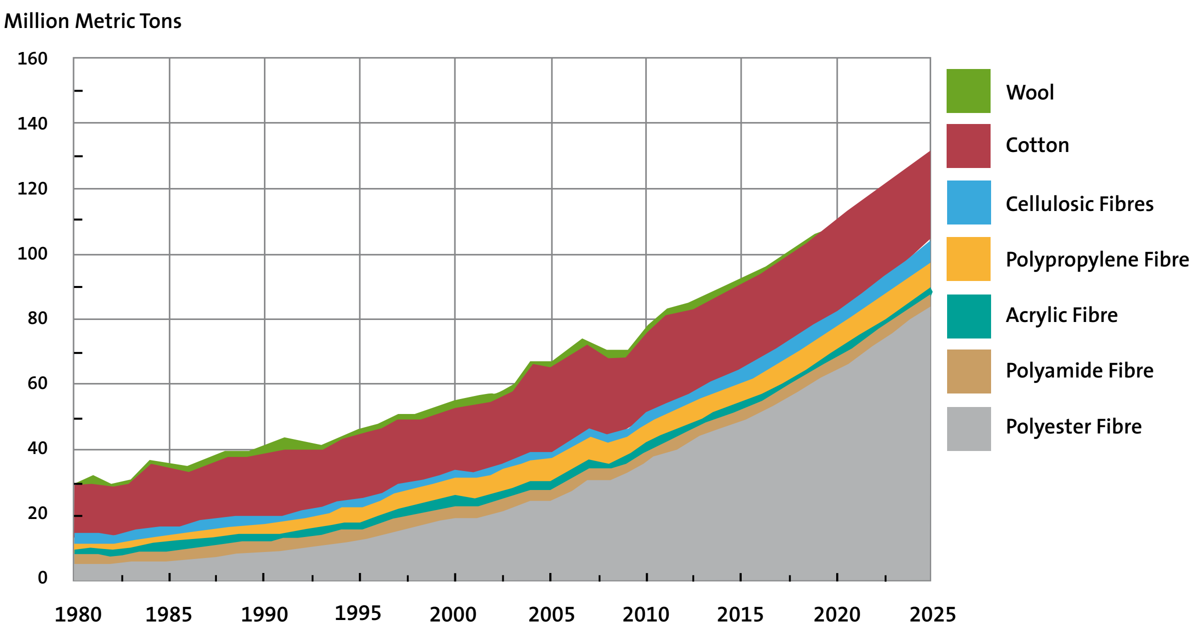
Textiles can be made from synthetic fibres, natural fibres or man-made fibres derived from cellulosic wood pulp. These are spun into yarns and either knitted or woven into fabrics. Many steps are required to transform a fibre into a finished textile article, and each step requires chemicals, usually in the presence of water.

Global fibre production is expected to increase annually, with the predominant fibre being polyester. In 2020, approximately 115 million tonnes of fibre will be produced, of which 60 million is expected to be polyester and 30 million cotton. A subset of these numbers is applicable to the apparel and home furnishings industry.[66]

Supply chain status: It's complicated

The textile supply chain is large, complex and fragmented. For example, cotton may be grown in the US and shipped to Pakistan for spinning, weaving and dyeing. The finished fabric could be sent to Bangladesh, Cambodia, or Lesotho for cutting and sewing into garments, which are then distributed globally.

Figure 5. Historic and projected global production of various textile fibres. Source: Tecnon Orbichem. [67]



Some factories are vertical, which means they may spin, weave, cut, sew and finish, or a subset of these, within the same organisation or factory complex. Other factories may specialise in one step of the supply chain, such as spinning, knitting, weaving, dyeing, or finishing.

Textile supply chains are often regionalised. For example, products destined for Europe may be mostly produced in the European region and north Africa, rather than Asia. However, many products destined for Europe are sourced from Asian countries.

Some geographical regions provide expertise and high volume for a certain type of product or process. For example, the Prato region in northern Italy is known for wool production and wool recycling, whereas Hazaribagh in Bangladesh is known for tanning leather.

The lifespan of apparel and textiles varies enormously, depending on many factors, including consumer behaviour – how we treat, use and discard our clothes. Home furnishings, such as towels and sheets, may have a longer lifespan than fashion items, which may be replaced after only being worn a few times.

Approximately 80 billion garments [68] are made every year, which is a 400% increase since the year 2000. This is due to an increasing middle class, as well as a growing population. In addition, the ongoing "fast fashion" segment, which refers to low cost garments made quickly and cheaply to maximise on current trends, continues to escalate in size and scope. Fast fashion has reduced supply chain lead-times, and garments are now dropped in stores 6 to 12 times a year, to support quickly moving fashion trends. Between 1996 and 2018, clothing prices in the EU dropped by more than 30%.[69]

According to the EMF New Textiles Economy Report, world-wide clothing utilisation – the average number of times a garment is worn before it ceases to be used – has decreased by 36% in the last 15 years.[70]

Recycling in the textile industry – a last chance resort

The average European throws away 11 kg of textiles[71] each year, while the average American[72] throws away 36 kg of clothes per year. In the EU, less than 1% of all apparel is recycled into new clothing.

The apparel industry is starting to look at new business models to keep clothes in use longer. Take-back programmes, renting, re-selling, repairing, and swapping increase clothing utilisation and delay the disposal of garments. Recycling textiles should be a last resort to keep clothes out of landfills or incineration.

Some of the challenges associated with recycling textiles are:

- **A lack of infrastructure to take back, sort and bale textiles prior to recycling.**
- **Lack of consistency in the waste source. Different fabric weights, blends, and colours all contribute to challenges such as sorting, baling, and – ultimately – recycling.**
- **Virgin material is often cheaper than its recycled counterpart, due to demand and mature business models already in place.**
- **Mechanically recycled natural textiles are inferior compared to virgin textiles.**
- **There are many questions regarding the possibilities of chemical recycling, as described in the recycling methodologies chapter.**

Today, most apparel products are not designed for disassembly – an important factor for recycling. Fabric blends, such as cotton/spandex denim and cotton/polyester fabrics, cannot be easily recycled by mechanical means, and zippers, buttons and other added sundries must be removed prior to fabric recycling.

Moving towards single-component fabrics, simplifying construction techniques (without compromising quality), and using the same fabric for labels will decrease product complexity and enhance deconstruction, both of which could lead to higher recycling rates.

Home furnishings, such as sheets and towels, are much less complex, because they are usually made from 100% cotton or 100% polyester and do not contain blended fabrics.

It is unclear how many textiles are recycled every year, and the amount varies widely, depending on the region. However, the majority of recycled textiles, meaning those that are deemed unwearable, are downcycled into other products, such as wipes and insulation, rather than used to make new textiles for the apparel industry.

Textiles can be recycled using both mechanical and chemicals means, although the latter is not well developed and not yet commercial.

In mechanical recycling, natural textiles such as cotton and wool are sorted by colour, and then cut and shredded into smaller pieces. Fibres are aligned and often mixed with virgin materials to improve strength, if used for apparel. A lot of recycled cotton is downcycled into wipes and wall insulation, where strength is not an issue. Some textile mills are integrating pre-consumer textiles into their fabric offering, especially in the denim industry.

Fabrics made from 100% synthetic fibres, such as nylon and polyester, can also be mechanically recycled. The fabric is sorted by colour, washed, cut, shredded, melted, and extruded into new pellets. Most recycled polyester fibres used in apparel originate from plastic bottles and not from polyester fabrics or clothing, mainly because polyester in clothes is often blended with other materials. Recycled polyester may also be downcycled into stuffing materials, insulation and even into non-woven materials.

Airing out the dirty laundry: Hazardous chemicals in textiles

Textile production processes make use of a large amount and variety of chemicals. About 3,500 substances are used in textile production. Of these, 750 have been classified as hazardous for human health and 440 as hazardous for the environment. It is estimated that about 20% of global water pollution is caused by dyeing and finishing textile products, affecting the health of workers and local communities.[73]

During textile manufacturing, chemicals are added to serve a function. After that, they are washed off prior to the next stage of processing, but traces of these chemicals remain in the product. During dyeing and finishing, chemicals are intentionally added and designed to stay on the product. These include dyes and finishing agents such as softeners, resins, coatings and surface treatments.

Many hazardous chemicals that were once used in textile processing are now either legislated or not used, due to voluntary action by brands and the chemical industry. However, they may still be present in older textiles that are collected for recycling.

The following represents a high-level overview of hazardous chemicals used in textile production. It is based on the ZDHC Manufacturing Restricted List.[74]

More research on chemical content is needed

Not much is known about the actual chemical content of recycled textiles. Research conducted by H&M and Ikea on recycled cotton-rich fabrics[75] identified APEOs, formaldehyde and chromium in some of the tested samples. This study is described in more detail from page 33.

Much more research is needed in this area, and this research must include synthetic fibres, such as polyester, as well as blended fabrics.

Table 2. High-level overview of hazardous chemicals used in textile production.

CHEMICAL CLASS	COMMENTS
APEO (Alkylphenol ethoxylates) NPEO (Nonylphenol ethoxylates) NP (Nonylphenols) OPEO (Octylphenol ethoxylates)	Used as detergents. Ubiquitous and may well be present in finished articles.
ANTIMICROBIALS	For example silver or triclosan, used for odour prevention.
CHLORINATED PARAFFINS	Fat liquoring agents in leather and occasionally used as flame retardants.
CHLOROBENZENES	Solvents and dye carriers for polyester.
CHLOROPHENOLS	Used as preservatives and pesticides.
AZO DYES THAT FORM RESTRICTED AMINES CARCINOGENIC DYES SENSITISING DISPERSE DYES	Large number of dyes fall into this category.
FLAME RETARDANTS (mostly halogenated)	May be added to furniture's, car seats, curtains, working clothes and sometimes bedlinen and clothes.
GLYCOLS	Used as solvents and adhesives.
HALOGENATED SOLVENTS	Finishing, cleaning, and printing agents.
ORGANOTIN COMPOUNDS	Antifoulants, biocides. Associated with rubber, inks, polyurethane and heat transfer materials.
PFAS (Per- and polyfluoroalkyl substances)	Provide durable water repellence (DWR) and stain management properties.
PHTHALATES	Added to soften plastic and in plastisol inks.
PAH (Polycyclic aromatic hydrocarbons)	Common in footwear and apparel, as a softener and extender. Exist as impurities in carbon black dyestuffs.
HEAVY METALS	Chromium VI is used in leather tanning and often present in leather.
UV ABSORBERS	Used in chemical formulations to provide protection against light.
VOC (Volatile organic compounds)	Many VOCs are associated with solvent-based processes, like PU coatings and adhesives.

63. *https://truecostmovie.com/learn-more/environmental-impact/*
64. *European Environmental Agency 2019. Briefing: textiles in Europe's circular economy. https://www.eea.europa.eu/themes/waste/resource-efficiency/textiles-in-europe-s-circular-economy*
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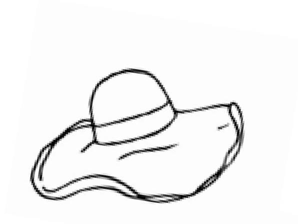
75. *H&M Group (key messages published 17th October 2019) https://hmgroup.com/media/news/general-news-2019/HMGroup-IKEA-collaborates-recycled-textiles.html*



Corporate Case Study
Working together for a smoother transition to circular economy

IKEA and H&M Group are both transforming into circular businesses, committing to only use recycled, renewable or other sustainably sourced materials by 2030. But closing the recycling loop in a circular business model for materials like textiles presents many challenges. To address the challenge around lack of knowledge about the chemical content in collected recyclable textiles, H&M Group and IKEA decided to collaborate in a large test study.

"We believe that transparency is essential to reduce the use and impact of harmful substances within the supply chain."

– The challenge of finding fact-based information about recyclable textiles on a large scale requires industry wide collaboration. We wanted to join forces with others to find innovative solutions, enabling meaningful and scalable changes, says Mirjam Luc, Project Leader for Recycled Textiles at IKEA.

She is spearheading the study together with Linn Farhadi, Project Leader for Recycled Textiles at H&M Group. Linn nods at Mirjam's reasons for collaborating and continues:

– Our two companies have worked together in different projects before and have a history of sharing experiences within chemical management. It felt like a natural step to start working together in this area too.

The chemicals of cotton

The first – and concluded – part of the study concerned cotton. All textile materials can be divided into three categories: virgin, pre-consumer and post-consumer. The IKEA/H&M Group study included pre- and post-consumer cotton samples collected from recyclers.

Pre-consumer textiles are usually waste from production and therefore easier to control in terms of chemical content, while post-consumer textiles have been worn or used by consumers or industry.

– As a brand, you can be in much better control if you only use waste from your own production streams. Challenges might increase when adding industrial production waste with unknown origin, Mirjam explains.

Chemical differences between virgin, pre-, and post-consumer cotton

The team tested the cotton samples, from unknown pre-and postconsumer sources, for 8 groups of chemical substances, such as APEO, azo dyes, formaldehyde, organotins, and PAH. They used the AFIRM RSL (Apparel and Footwear International Restricted Substances List) test matrix to make conclusions and define the probability of detection rate for the tested substances in the recycled cotton.

Linn Farhadi,
Project Leader for Recycled Textiles at H&M Group

Some substances were not detected at all, whereas others were detected at very low levels. The results indicated that there is a difference between pre- and post-consumer textiles.

Mirjam Luc,
Project Leader for Recycled Textiles at IKEA.

– For the post-consumer cotton, the test results indicated that APEO is the substance group with highest probability to be detected, while azo dyes and other allergenic and carcinogenic dyes have an almost negligible probability of being detected, says Linn.

The tests also revealed some interesting findings concerning the probability to find hazardous chemicals in recycled cotton compared to virgin.

– For example, we could see that the probability of detecting organotins is slightly higher in recycled pre-consumer cotton compared to virgin cotton, while the probability of detecting PAH and formaldehyde is potentially lower in recycled pre-consumer cotton compared to virgin, says Mirjam.

New sins can be avoided – old ones need to be remedied

The duo say that chemical management of virgin materials can be controlled in supply chains, either by audits, CoC (Code of Conduct), restricted substance lists, or "positive lists" of recommended chemicals to use and other controlling tools. However, for recycled materials – especially post-consumer waste – old sins need to be managed.

– But for azo dyes, for example, the results look very promising. We didn't detect azo dyes in any of the 166 recycled cotton samples. One reason for this might be that azo dyes have been regulated for many years, and that the samples were collected in Europe, says Linn.

Next step: Wool and polyester

Since the cotton study was such a success, the team decided to expand the scope of the study to wool and polyester, and invite more brands to participate in sharing test data.

– The feedback and interest have been incredibly positive. The work is progressing according to plan and the results and conclusions will be shared once we come further in the study, says Mirjam.

Much to gain from the results

The study has already yielded returns, providing in-depth knowledge about possible risks of finding hazardous substances in various recycled textiles.

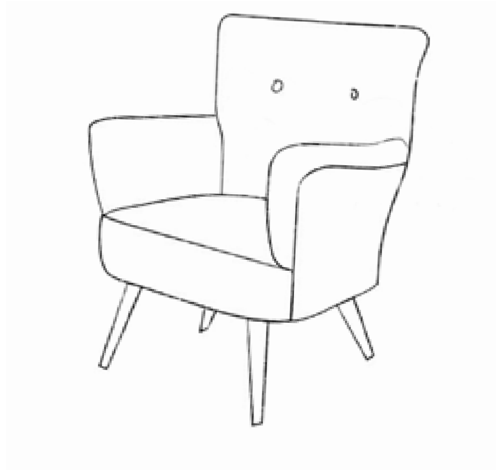
– Based on that knowledge, we can develop smarter test strategies that enable the use of recycled textiles in a safe way, says Linn.

When asked about the dream scenario when it comes to the impact of the study results in a wider perspective, the vision is clear:

– It would be fantastic if the results could be used to raise awareness around problematic substances that can be found in textile materials, but also to encourage innovation, so that we can secure that these textile materials can be recycled in safe ways, says Mirjam.

Linn agrees and continues:

– It would also be great if the results can be used by authorities in their work to align legislation, ensuring that materials are recycled in a safe way and encouraging innovation where needed, so that companies can secure safe use of recycled materials.



The fabric is only as strong as its weakest thread

This kind of collaboration is still quite unique, something that Linn and Mirjam would like to see change in the future.

– A circular economy will not be reached by individual actors. We believe that transparency is essential to reduce the use and impact of harmful substances within the supply chain. And the best way to accelerate a circular approach on how products are made is by industry wide collaboration and sharing of knowledge. Together we can make a big and lasting impact, the duo concludes.

FACT BOX: The 8 chemical groups of the cotton study.
Ikea and H&M tested the cotton samples for 8 groups of chemical substances:

- **APEO** – washing or cleaning agents
- **Allergenic and carcinogenic dyes**
- **Azo dyes** – a group of synthetic dyes
- **Formaldehyde** – used to prevent shrinking and wrinkling
- **Heavy metals** – common ingredients in dyes
- **Organotins** – used as stabilizers, catalysts and biocides
- **PAH** – used as softeners or extenders, or as impurities from dyeing
- **Phthalates** – used to increase softness and flexibility

Recycling methods

Recycling is defined as the recovery and re-processing of waste materials for use in new products. The main recycling technology today is mechanical recycling, where the material is broken down into smaller pieces, to be melted or spun into new materials. Several additional technologies are evolving under the umbrella name "chemical" recycling.

This chapter provides an overview of recycling and purification methods for plastics packaging and textiles, and a perspective on their implication for the removal of hazardous chemicals.

Current recycling methods for plastics

Today, there are various recycling methods for plastics. Their ability to extract chemical additives (for example plasticisers and stabilisers) and contaminants (for example glues and inks) from the plastic polymer differ. Here is a brief introduction to the different methods.

- **MECHANICAL RECYCLING** refers to the processing of materials into secondary raw material without significantly changing its chemical structure. After sorting and washing, plastic materials are ground and compounded into pellets or flakes, which can be reprocessed into new objects using conventional plastic manufacturing methods, such as extrusion and moulding. This is currently the main recycling method and the only one operating at industrial scale.

- **CHEMICAL RECYCLING** refers to techniques using chemicals or chemical processes to purify or break down the plastic or the polymer itself, affecting the plastic's formulation.

  There are three main types of chemical recycling methods for plastics, differing in terms of process and outputs produced:

  – **SOLVENT-BASED PURIFICATION:** Plastic materials are dissolved in a solvent. The purification steps allow additives and contaminants to be separated from the polymer. The purified polymer can subsequently be reformulated into new plastics.*

  – **CHEMICAL DEPOLYMERISATION:** A chemical reaction is used to break down plastics into their monomers, or into small polymer chains (partial depolymerisation). After purification to separate the monomers from contaminants, the monomers can then be polymerised to form new plastic polymers.

  – **THERMAL DECOMPOSITION:** Polymers are converted back to monomers, or smaller feedstock building blocks, by heating up the plastics under reducing conditions. After further refining, the output molecules can be converted back to polymers. The most common processes for thermal decomposition are:

    - **Anaerobic thermal decomposition (Pyrolysis):** An anaerobic process, where plastic is heated until it breaks down, resulting in the creation of a hydrocarbon mix in the form of a pyrolysis oil. The pyrolysis oil requires further treatment in order to separate the building blocks relevant for plastics production.

    - **Thermal decomposition with limited oxygen supply (Gasification):** Similar to pyrolysis, gasification is a controlled process, but with some oxygen, where plastic (and other carbon-based waste) is heated at high temperature to yield syngas ($CO + H_2$). Syngas is then converted into building blocks for plastic production.

Many hurdles for chemical recycling

Chemical recycling, sometimes referred to as "advanced recycling", is often presented as a promising set of technologies, allowing for the output of clean recycled material, by the removal of toxic contaminants from plastics. However, significant process challenges remain, including high energy consumption, toxic by-products and limitations on the type of waste streams that can be used.[76]

This table summarises the state of play, as well as limitations and other properties of the above-mentioned recycling methods for plastics, with hazardous chemicals in focus.

All of the recycling methods described can play a role in the transition towards a circular economy. However, as seen in the table, there are a number of limitations and/or uncertainties for all of the available methodologies.[77]

* Note that it is debated whether solvent-based purification should be counted as a chemical (since chemical agents are used) or a mechanical (since the polymer is not broken down) recycling method. In this report, we have chosen the former rationale, following the framing set out by the European Commission.

Table 3. Summary of the state of play of the main material circulation categories for plastic packaging, and how they address hazardous chemicals.

	MECHANICAL RECYCLING	SOLVENT-BASED PURIFICATION	DEPOLYMERISATION	THERMAL DECOMPOSITION
SHORT DESCRIPTION	The material is mechanically broken into smaller pieces and melted together into new materials. The polymer is preserved.	The material is dissolved in a solvent. The polymer is preserved.	A chemical reaction breaks down the polymers into monomers.	Heat is used to break down the polymer into monomers or smaller hydrocarbon building blocks.
TYPE OF PLASTIC	All	Monostreams from either PET, PE, PS or PP.	Monostreams from either PET, PU, PA, PLA, PC, PHA or PEF	Most, but not PVC.
HOW HAZARDOUS CHEMICALS ARE REMOVED	Hot-washing and de-inking methods can remove some contaminants.	Contaminants can be removed through filtration or phase extraction.	Contaminants can be removed in additional purification steps.	Contaminants can be removed by the process.
LIMITATIONS ON REMOVING HAZARDOUS CHEMICALS	Inability or difficulty to sort out and separate contaminants. Potential cumulative increase of contaminants over time. Potential formation of new contaminants through chemical reactions.	The solvents used can be hazardous. Difficult to confirm 100% removal of contaminants.	Purification steps are costly. Uncertainty about hazardous by-products	Toxins can be emitted as a by-product in the process.
ADVANTAGES	Single stream recycling can allow for high recycled material quality, e.g. rPET.	Theoretically functioning for multilayer materials, but not practically viable because of high energy and solvent costs.	The quality of the resulting material equals virgin materials. High yields demonstrated at pilot scale.	The quality of the resulting material equals virgin materials. Can work for heterogenic material streams. Outputs can be used in existing plastic manufacturing process.
OTHER LIMITATIONS	Quality is lost in every cycle.	Quality is lost in every cycle. Requires careful pre-sorting. Purification steps post-treatment are difficult and energy-demanding. Currently little information on other environmental or systemic impacts.	Only works for mono-streams. Currently little information on other environmental or systemic impacts.	Mainly used to produce fuels – not plastics. Requires very high energy input. Output heavily dependent on input waste stream. Currently little information on other environmental or systemic impacts.
ENERGY REQUIRED	LOW	HIGH	HIGH	VERY HIGH
TECHNICAL MATURITY	HIGH Industrial stage for most materials deemed to have a secondary value.	LOW Technically feasible but still at pilot stage, e.g. for EPS, where HBCD in packaging can be separated. Existing pilots also for PS, PE, PP, including multilayer packaging.	LOW Industrial pilots, e.g. for PET (including food packaging, coloured packaging).	MEDIUM There are pyrolysis pilots, e.g. for PPMA (plexiglass, inks and coatings) and PE, PP and PS (Plastic Energy). Gasification pilots also exist, mainly focused on polyolefins.
FINANCIAL FEASIBILITY	HIGH The most cost-efficient technology, linked to the maturity of the process.	LOW or NOT PROVEN Can be cost-prohibitive to recycle contaminated materials – requiring quality separation & high volumes.	LOW or NOT PROVEN Overall currently uncompetitive with virgin plastic production – need large, homogenous volumes, infrastructure and transport.	LOW or NOT PROVEN Currently uncompetitive with virgin plastic production

Mechanical – output quality depends on input

Mechanical recycling has several limitations, such as the degradation of the polymer with each cycle, high dependence on the quality and purity of the input strems to assure high quality of the output, and – most importantly – the inability to eliminate chemical contaminants from plastics.

Solvent-based purification – uncertainty on environmental impacts

Solvent-based purification preserves the polymer and could theoretically remove contaminants. The high costs of energy and solvents make it less competitive and concerns about emissions remain to be clarified.

Chemical depolymerisation – energy intensive and immature

Considering chemical depolymerisation technology, there is currently insufficient information regarding the ability of this method to handle chemical additives. This requires more understanding before the viability of chemical depolymerisation can be further investigated. Questions also remain about the overall environmental performance, including energy consumption, of all the chemical recycling technologies.[78, 79]

Even though there are plenty of examples of pilot technologies that use chemical depolymerisation, only a few have been successful – all for homogenous waste streams, and most examples are for PET or polyamides.

Thermal decomposition – mainly for fuel production

Thermal decomposition, including pyrolysis and gasification works for almost any plastic resin, but is most suitable for polyolefins. The exception is PVC, which creates corrosive and/or toxic intermediates and products. The output from thermal decomposition, "p-oil", can be fed into existing plastic manufacturing processes. However in practice, thermal decomposition has mainly been used to produce fuels, and not new plastics.

The high complexity of the output from thermal decomposition processes – a mixture of many different hydrocarbons, monomers and other small molecules – requires further purification, which can be very costly, in order to isolate the desired products. In addition, some thermal decomposition methods can release toxic chemicals through airborne emissions and toxic residues in the environment.

No breakthroughs for chemical recycling yet

Chemical recycling projects have so far been largely dependent on external funding. A report by Greenpeace[80] investigated 52 US projects set up to recover plastics through chemical recycling. According to the report, none of the projects showed promise of viable plastics recycling. Instead, the projects were largely focused on producing fuels.

Other initiatives, such as Loop Industries, which has partnered with both Coca-Cola and Nestlé, have been called out as outright frauds, raising further doubts about the abilities and performance of chemical recycling.[81]

In summary, all of the above-described chemical recycling methods require further evidence before it can be established that they can safely recycle plastics back to plastics. None of the methods can be regarded as a silver bullet for recycled content. Instead, they should be seen as potentially complementing mechanical recycling for important applications where mechanical recycling will not work, such as for degraded or contaminated plastics, or mixed fractions.

It is important to remember that chemical recycling has limited scope for tackling contaminants, and some processes may even add to pollution.

Recycling of textiles

While no clothing-to-clothing recycling operation currently exists at scale, there are a number of existing technologies for repurposing or recycling textile fibres. Mechanical or chemical methods can be used to create new materials – the latter being the only one that allows the removal of hazardous chemicals from garments.

It is clear that most known textile recycling methods remain economically and technologically immature, and thus do not allow textiles to be recyclable in practice and at scale.[82]

- **FABRIC RECYCLING** (also referred to as remanufacturing): Fabric pieces including factory offcuts, leftover materials, post-use clothing parts etc, are collected and reused in a new garments while keeping the fabric intact).[83]

- **YARN RECYCLING:** Yarns used in knitted garments are unravelled (only for knitted textiles) and then knitted to new textiles.

- **FIBRE RECYCLING** (also referred to as "mechanical recycling"): Fabrics made from natural textiles, such as cotton and wool, are sorted by colour and cut and shredded into smaller pieces, to be processed back into fibres. Fibres are aligned and often mixed with virgin materials of higher-quality fibres to improve strength, if used for apparel. Some textile mills are integrating pre-consumer textiles into their fabric offering, especially in the denim industry.

- **POLYMER RECYCLING:** There are two types of polymer recycling methods, which differ in terms of process and quality of outputs produced:

  – **MECHANICAL POLYMER RECYCLING, WHERE FABRICS MADE FROM 100% SYNTHETIC FIBRES**, such as nylon and polyester, are sorted by colour, washed, cut, shredded, melted and extruded into new pellets. Most recycled polyester fibres used in apparel actually originate from plastic bottles – not polyester fabrics or clothing.

  – **CHEMICAL POLYMER RECYCLING:** Processes involving some form of fibre dissolution and purification, using a solvent without changing the polymers. The polymer can then be re-precipitated to create new fibres (for example from cellulose) or go through additional treatment to achieve new, virgin-equivalent quality materials (for example polyester or nylon).

  The textiles are first de-buttoned, de-zipped and shredded. Depending on what method is used, different types of purification can be accomplished:

    - **Separate blended fabrics** into different streams. For example, cotton and polyester blends may be separated into a cellulosic pulp and polyethylene terephthalate (PET) polymer. Worn Again uses a dissolution process to separate cotton/PE blends, whereas Tyton Biosciences uses water to create pulp and PET monomers.

    - **Remove colourants** and other valuable chemicals that can be captured and reused. Worn Again can remove and recover dyes during their process.

    - **Treat cotton to make a cellulosic pulp**. Evrnu and Renewcell both create cellulose pulp from textiles using proprietary techniques. The pulp can then be used to make new manmade cellulosic materials, such as viscose.

- **DEPOLYMERISATION:** Process used to break down synthetic polymers back to monomers, or other constituent building blocks. The output can be re-assembled to produce new virgin-quality polymers.

  It works in the same way as depolymerisation for PET packaging (PET is the same polymer as "polyester" used in textiles), and can thus create a link between the two value chains, by providing a bridge for PET packaging to be recycled into polyester fibre, and vice versa.

  Examples of technologies include Carbios, which uses enzymes, and Gr3n, which uses microwave radiation.

– **Feedstock "recycling":** Analogous to feedstock recycling of plastics. Since textile fibres (natural and synthetic) contain a significant amount of oxygen, they are a less optimal feedstock for pyrolysis than polyolefins, but could in principle be used in gasification. Besides, textile-to-fuel is not what is commonly thought of as recycling.

As the focus of this report is on recyclability, compostable options for biodegradable garments are not mentioned, although this is an alternative treatment option. Further information on textile recycling methods in a circular economy can be found in the Ellen MacArthur Foundation's report.[84]

Table 4. Summary of the state of play of the main material circulation categories for textiles, and how they address hazardous chemicals.

	FIBRE RECYCLING (MECHANICAL RECYCLING)	POLYMER RECYCLING	DEPOLYMERISATION
SHORT DESCRIPTION	Process where fabrics are sorted by colour and cut and shredded into smaller pieces, to be processed back into fibres.	Processes involving some form of fibre dissolution and purification using a solvent without changing the polymers. The polymer can then be re-precipitated to create new fibres or go through additional treatment to achieve new materials.	Breaks down synthetic polymers into monomers.
TYPE OF MATERIAL	Cotton and wool.	Works with blended fabrics, i.e. lower-grade blended fabric input can be turned into higher-grade output.	PET packaging can be recycled into polyester fibre, and vice versa.
HOW HAZARDOUS CHEMICALS ARE REMOVED	Does not remove additives/contaminants.	Contaminants can be removed through filtration or phase extraction.	Some additives and contaminants are addressed.
LIMITATIONS IN REMOVING HAZARDOUS CHEMICALS	Potentially increasing toxicity load in recycled garments, when further treating the recycled material.	The solvents used can be hazardous. Not a 100% removal of contaminants.	Purification steps are costly. Uncertainty about hazardous by-products
OTHER ADVANTAGES	Saves some of the most resource- and chemical-intensive steps in the production value chain. Can produce new textiles even with blends.	High fibre quality.	High fibre quality.
OTHER LIMITATIONS	Fibre quality is lost, requires blending with virgin-grade fibre to retain quality.	Quality of "reformed" or "regenerated" fibre is different from the original fibre.	Currently little information on other environmental or systemic impacts.
ENERGY REQUIRED	LOW	HIGH	HIGH
TECHNICAL MATURITY	MEDIUM Spinning mills often develop their own technologies for shredding and re-spinning of pre-consumer textile waste. Various businesses use it for a relevant share of their production and sell it at scale.	LOW Still a very limited amount of infrastructure in place. Small plants are operating for both cellulosic and plastic-based fibres. Only pilot collections have been set up for these technologies.	LOW Currently not rolled-out in practice and at scale. A few companies are operating commercially.
ECONOMIC FEASIBILITY	MEDIUM A few companies are operating commercially.	LOW or NOT PROVEN A few companies are operating commercially, but currently not widely economically mature.	LOW or NOT PROVEN Currently not economically mature.

Toxins remain in mechanically recycled textiles

While mechanical recycling remains the main recycling option for the foreseeable future, the process faces several challenges in its ability to separate and eliminate toxic contaminants from materials – which could potentially accumulate in recycled materials.

In spite of industry promises of emerging recycling methods to eliminate toxic chemicals from materials, main limitations remain.

Let's not include them in the first place

As recycling alone cannot be seen as the ultimate solution for addressing chemicals in the system, there is a clear need to design out toxic chemicals upstream, eliminating the need for chemicals to enter the material system in the first place, or substituting safer alternatives where possible.

Designing out chemicals from upstream materials should be addressed as the first priority for multiple reasons, including energy savings, cost savings and the fact that it's the most efficient way to tackle the problem.

76. *Enomia, CHEMTrust 2020. Chemical Recycling: State of play. https://chemtrust.org/wp-content/uploads/Chemical-Recycling-Eunomia.pdf*
77. *Enomia, CHEMTrust 2020. Chemical Recycling: State of play. https://chemtrust.org/wp-content/uploads/Chemical-Recycling-Eunomia.pdf*
78. *Enomia, CHEMTrust 2020. Chemical Recycling: State of play. https://chemtrust.org/wp-content/uploads/Chemical-Recycling-Eunomia.pdf*
79. *Global Alliance for Incinerator Alternatives (GAIA), Chemical Recycling: Status, Sustainability, and Environmental Impacts (2020); GAIA, Chemical Recycling: Distraction, not Solution (2020)*
80. *https://www.greenpeace.org/usa/research/deception-by-the-numbers/*
81. *Plastics Today 14 October 2020. Advanced recycling company Loop industries called a fraud. https://www.plasticstoday.com/advanced-recycling/advanced-recycling-company-loop-industries-called-fraud*
82. *Ellen MacArthur Foundation, A New Textiles Economy, ibid.*
83. *Ibid.*
84. *Ellen MacArthur Foundation, ibid.*

Focus:
Meeting demand for recycled content – chain of custody models

There is great demand for post-consumer recycled materials from companies and brands that want to use them in their products. Corporate commitments based on initiatives such as the Ellen MacArthur Foundation have helped drive this development. To meet this demand, and in order for brands to fulfil their commitments to become more sustainable, the production of recycled material needs to increase drastically.

To face this challenge, many companies – both brands and chemical producers – have invested in technologies for recycling, including chemical recycling. Brands need to secure a future supply of recycled content, and chemical producers – especially plastics producers – see an opportunity to develop their existing processes to meet the demand.

What do we mean by "recycled materials" and how do we quantify it?

As the number of new technologies and processes grow, there is a need to formalise and create standards for defining recycled materials and quantifying output from recycling processes. As described in the chapter on recycling methodologies, the term "chemical recycling" can include many applications – even the production of fuels.

A common understanding of the input and output limitations, as well as how to handle different types of output and process yields, is sorely needed. One way to standardise the production and traceability of a product is by defining a chain of custody model.

Traceability throughout the value chain

Chain of custody models aim to provide means to trace the flow of materials through the value chain. In other words, to provide a connection between sustainability information or claims regarding raw materials, intermediate and final products.

There are several different models, such as segregation, mass balance, and book & claim. They vary in terms of knowledge of the source of the product. Here is a short description of each of the models:

Segregation

The goods are equivalent, regardless of origin, within the standard. Goods can be mixed within a category, but different categories are separated, for example organic and non-organic.

Mass balance

When the separation of equivalent goods from different categories cannot be achieved, for reasons such as process design, the mass balance approach can be utilised. This is designed to trace the total amount of specific goods, for example renewably sourced material, through the processes, to ensure correct allocation.

Due to complex processes, and production yields and losses, the calculation of the amount of output goods must be done in an auditable manner.

Book & claim

The book & claim model is the use of certification employed when there is no physical connection between the final product and the certified input goods. This system is used for renewable electricity, where the certified green electricity has no physical connection to the produced green electricity.

Mass balance has been suggested for plastics

Recently, the mass balance method has been proposed to be applied to recycled plastics, especially by the chemical industry. In order for today's plastic producers to be able to use the existing setup, where fossil raw material is processed, the recycled material needs to be suitable for this process.

One method to achieve this is through pyrolysis (described in the chapter about recycling methods) where the product – pyrolysis oil – can be fed into existing plastic processes.

By using the mass balance method, and mixing fossil and recycled raw material, the output will be plastics with a recycled content that is inseparable from the non-recycled content. However, the ratio of recycled content can be calculated in an auditable way, and that amount can be claimed to be purely recycled content.

For example: 100 tonnes of plastic materials are produced, and the auditable calculations show that 5 tonnes originate from recycled raw materials. These 5 tonnes can be sold as 100% recycled content, even though they do not contain purely recycled content. The remaining 95 tonnes cannot have any claim to be recycled material.

Imbalances of mass balance

Using this method gives rise to several issues. First, as mentioned previously, the output material will be a mix of fossil and recycled raw materials, meaning that any claim of 100% recycled content is incorrect.

And – most importantly – the processes still rely on fossil fuels as the major source of feedstock. This means that the mass balance method supports the continuous use of large amounts of fossil-based plastic material, instead of ending the dependence on fossil raw material.

Book & claim also considered for plastics recycling

The book & claim model has also been proposed for plastics recycling. The setup for this scheme is similar to the mass balance one, with the addition of the possibility to sell a certificate of recycled content.

In other words, the "plastic worth" of the intermediate product, for example the pyrolysis oil, can be sold and used to certify other plastic goods, without any physical connection to the recycled plastic raw material. This method also requires auditable schemes and standards.

Book & lose?

In addition to the drawbacks listed for mass balance, the lack of physical connection gives rise to new problems. For example, the calculations of "plastic worth", as well as the fate of the pyrolysis oil from the recycled plastics, need to be considered.

When the certificate has been issued, the pyrolysis oil might be used as fuel or for low-grade plastic products, inhibiting circularity.

Tracking of chemical content

There is great demand for post-consumer recycled materials from companies and brands that want to use them in their products. Corporate commitments based on initiatives such as the Ellen MacArthur Foundation have helped drive this development. To meet this demand, and in order for brands to fulfil their commitments to become more sustainable, the production of recycled material needs to increase drastically.

While it is evident that the potential risks of chemicals in recycled plastics cannot be addressed without unprecedented transparency, there is at present a lack of infrastructure capable of tracing back the chemical content of an item that ends up at a recycling facility.

But what if we could identify the material composition of every plastic item? While such information would not reduce the material complexity or chemical hazards, it would provide the data needed to optimise material recycling, suggest potential design improvements and take stock of the actual chemical hazard exposure, and how to address it.

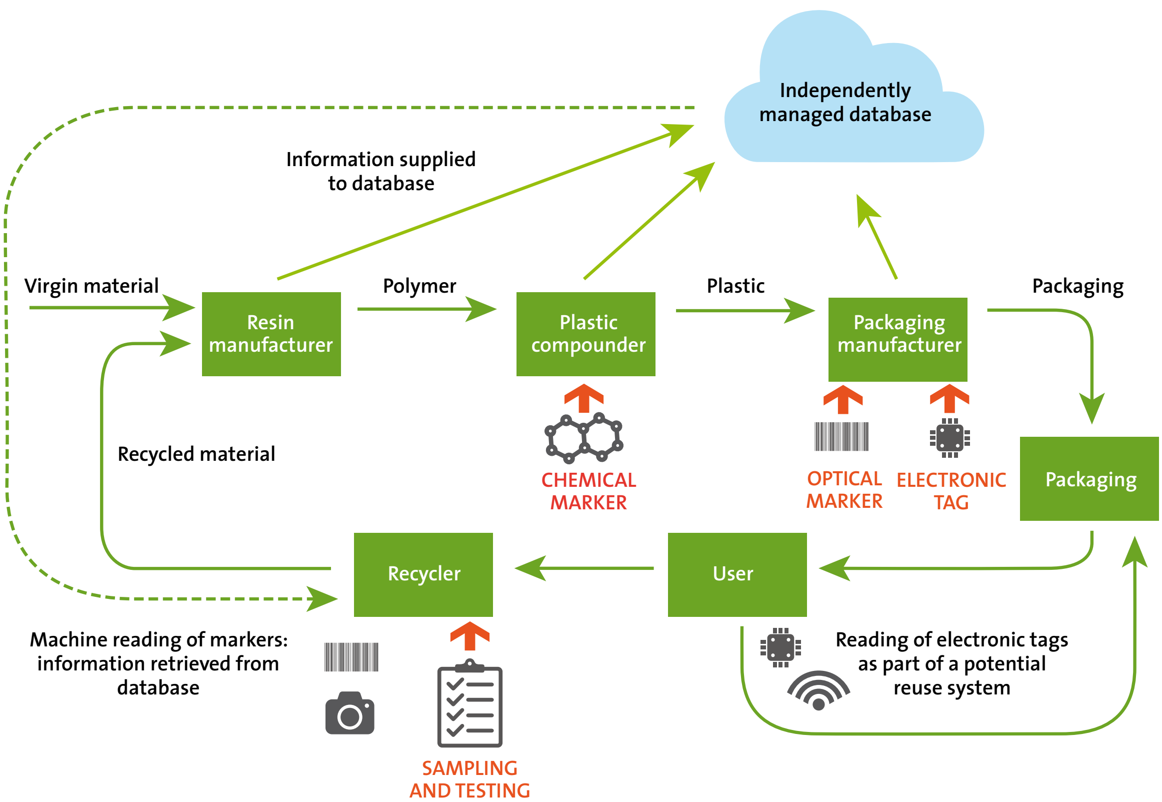
Waste needs to be sorted for recycling

All plastic recycling systems begin with collection, either with plastics separated into their own fraction, or mixed with other material, such as paper and board. In some densely populated urban areas, they are even co-mingled with general waste. This is done through either curb-side collection, collection points, or some form of informal system, as is common in developing markets.

With some notable exceptions, such as deposit-refund systems for PET bottles, different plastic materials become mixed during collection and therefore need to be sorted into homogenous waste streams. This is done either manually or with automated sorting based on some physical property, such as density, infrared absorption, or a combination of several properties.

In either case, variations within one material type – for example polyethylene – are not detectable using current sorting methods. That means that all intentionally added chemicals (additives) as well as unintentional contaminants cannot be screened for, and information about their presence is lost unless some other analysis is performed.

Figure 6. *Overview of the possible methods described to track chemical content through the life cycle of plastics.*



Improved tracking and tracing systems that provide transparency, not only about material types, but also the identity and composition of individual plastic items, would create numerous opportunities to improve both the safety and the market value of recycled plastics.

The wonders of technology offer many possible methods

Technology is not the fundamental limitation for improving material and chemical transparency in the recycling stream. There are several possible technologies available inthat are in different development stages, as outlined below and in Figure 6.

However, none of these methods can uniquely identify the full chemical content of a piece of recycled material. Therefore, any technology that becomes widely accepted and implemented should ideally be combined with a "material passport" – a database of information on material inventory.

For plastics, such an inventory would identify the polymer resin(s), any additives, as well as known non-intentionally added substances (NIAS), such as monomers, catalysts, or solvent molecules that are known to remain in the material.

One of the sectors that is actively pursuing the material passport is the construction industry, through the project BAMB (Buildings As Material Banks). Driven by 15 partners from 7 European countries that are committed to develop more circular economy models in the building sector, BAMB provides an electronic material passport, and platform, and aims to become a "one-stop shop" for material information.[85]

Chemical markers – identifying unique physical properties

A chemical marker is a machine-readable chemical embedded in the plastic resin or label, which generates an additional physical property that can set it apart from other materials that are difficult to distinguish. For example, a fluorescent chemical marker emits light when hit by UV-rays, which can be detected by a UV-VIS detector.

Chemical markers have been extensively tested to detect and sort food-grade PET from a mixture of difficult-to-sort bottles. Promising examples include the EU-funded PRISM project that concluded in 2018 and demonstrated a 90-98% sorting yield, with 95-99% purity under industrial conditions[86], as well as the Polymark project, which produced similar results.[87]

Chemical marker technology consists of three parts: the chemical marker (such as a fluorescent molecule), a spectral identification technology (for example UV-VIS) and an industrial-scale sorting machine. It is relatively easy to implement, since the marker can be added to the plastic masterbatch and the identification technology retrofitted to most industrial plants. There are, however, two key challenges:

1. To avoid adding to the chemical complexity and avoid accumulation, the markers need to be removed after each cycle. Considering that many fluorescent markers are based on hazardous transition metals, even at low concentrations, this is a clear need if the chemical marker technology is to operate at large scale over a long period of time.

While it would be easier to remove the marker if it was confined to the packaging label instead of embedded in the plastic resin, it is still a challenging and expensive operation, which might not be economically viable, considering the low material value of plastics.

2. The "bandwidth" of a tracking and transparency system based on chemical markers is limited to the number of markers used in the system. Thus, in order to drastically increase the information resolution, compared to the current state of play, several distinguishable markers would need to be employed, with added cost and complexity challenges (see 1 above).

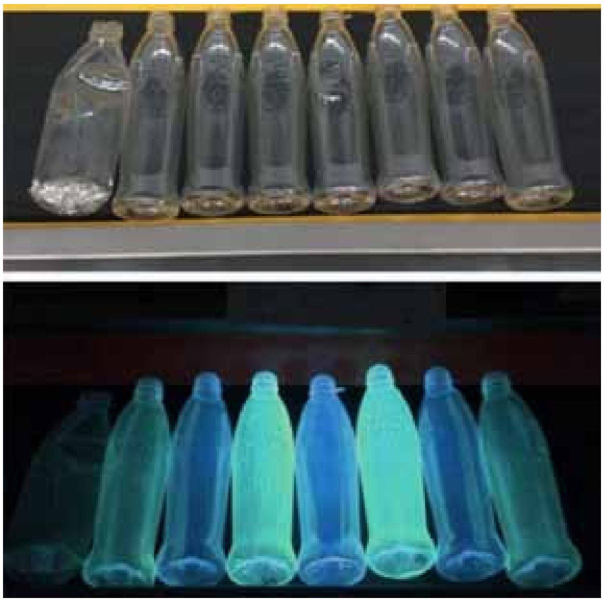


Figure 7. *Images from Polymark trials 2017. PET bottles with a UV light off and on respectively. Marked bottles appear greenish and fluorescent. Non-marked PET bottles are less bright and appear bluish.*[88]

For the reasons described above, chemical markers may be well-suited for separating one, pre-defined group of plastics from another in a well-defined system, such as food-grade PET bottles from non-food grade bottles, but are less suited to carry the bandwidth required to make information about chemicals in plastics more transparent.

Optical markers – artificial "fingerprints" all over the material

Optical markers are also known as digital watermarks. This technology puts a visual "tag" onto a packaging item, embedded in a label's artwork or in the mould itself. A helpful analogy is that optical markers can be seen as barcodes or QR codes, only smaller. The codes are pixel-sized and therefore virtually invisible to the eye, but can be read by a digital camera, provided the right software is installed.[89]

In addition, since they are invisible to the eye, they can cover an entire item of packaging without altering the appearance, which makes detection at any angle easier – even when part of the packaging is damaged.

Just like the chemical marker technology, this technology would be relatively affordable to implement, since it only requires retrofitting of some additional detection equipment. However, it also provides two key advantages over chemical markers:

- It is **non-invasive,** as the digital watermarking technology does not require any alteration to the material, and hence does not add to the complexity of the system; the tag is graphic in nature and disappears when the material is reprocessed.

- A very **large number of available codes**, and the opportunity to link the marker to a database with additional information. This means that in theory, every unique stock-keeping unit can have its own detectable code in the recycling system, providing any information made available through the link to such a database.

This is particularly interesting, since it offers an option to detect and track chemical content without having to measure chemicals directly, and even link chemical content to a particular product brand or manufacturing location.

Optical markers are not yet applied at scale in the recycling system. The most high-profiled project working to introduce them is Project "Holy Grail", a collaborative effort led by P&G, with the ambition to "devise a more consistent and scalable tagging system across all packages".

Figure 8. *Images from P&G / Digimarc to illustrate how the digital watermarking technology works.*

Electronic tags – more expensive, suitable for durable items

Chips that employ radio signals, such as RFID (Radio Frequency Identification) and NFC (Near Field Communication) are another technology for tracking chemical content. One advantage is that the NFC technology is "native", meaning that it is compatible and readable with all modern smartphones.

Because of its relatively high cost, this technology is not suitable for single-use plastics, but could be relevant for textiles, and certainly durable goods. Going forward, new innovations – such as Flex-ICs, which provides a more flexible and cost-competitive chip [90] – could make this technology applicable to a wider range of items.

However, it is questionable whether this technology is suitable for creating chemical transparency in the high-throughput, granular system of plastics packaging.

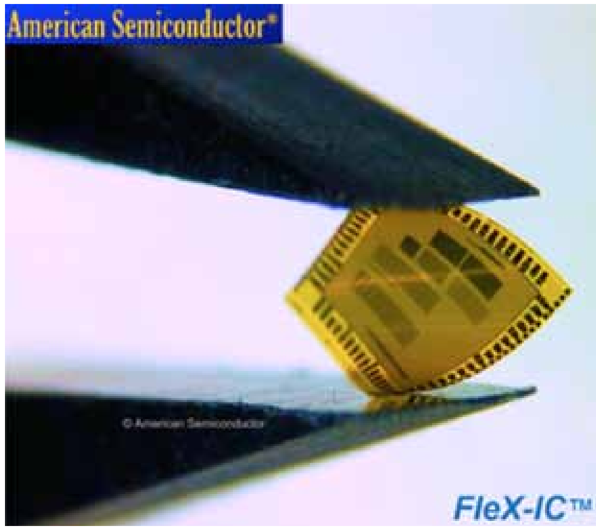


Figure 9. *Image from American Semiconductor, demonstrating the flexibility of the Flex-IC.*

Four main challenges towards chemical transparency

As stated above, several different technologies exist to increase chemical transparency in the plastic system, but neither the infrastructure nor incentive to support their large-scale implementation exist as yet. Key hurdles that need to be addressed include:

- **Infrastructure.** Recycling capabilities are unevenly distributed globally, and recycling plants need to be retrofitted to support any available commercial technology to increase material sorting.

  In the example of added information carriers (chemical or optical markers), such retrofitting is best suited for automated plants, which are most densely located in Europe. The investment needed for a full-scale implementation is significant, but limited.

  In regions with little to no automated sorting, implementation of marker technology is likely to require much larger investments in basic collection and sorting infrastructure.

  This relatively high-end technology aspect of the recycling system will be difficult to prioritise, but there may be some leapfrogging opportunities to install a full "system that works" without having to do retrofitting at a later stage.

- **Lack of data sharing incentives.** Information transparency between different players in the value chain – for example from resin manufacturer to compounder to packaging manufacturer – is notoriously bad.

  Specific material composition is typically considered to be intellectual property (IP) and provides a competitive advantage. New systems need to be put in place to safely share, store and use information without infringing IP, if tracing chemical content in individual products is to become a reality.[91]

  A first and important step in this direction is the ECHA SCIP database[92], which requires companies to register any products they supply that contain a substance on the REACH Candidate List, with the aim of making this information traceable through the product's lifecycle.

- **Standardisation.** The need for "everyone" to adopt the same technology and implementation protocol raises the barrier to get a system for chemical transparency off the ground.

An instructive example is the implementation of the barcode system, rolled-out by IBM in the 1970s, which required a large number of retailers to adopt expensive scanners, while manufacturers simultaneously needed to produce standardised barcode labels.[93]

- **Demand.** Ultimately, there needs to be demand for the type of information transparency enabled by marker technology to justify the extra investment.

  The recycling industry is not actively supporting any transparency method at the moment, and the value to recyclers of knowing the chemical baseload of one batch of granulated resin from another, is yet to be proven.

Solving these challenges is a massive undertaking, which requires broad harmonisation, (ideally global) consensus in the market, and/or regulation.

The road ahead is tricky – but not uncharted

While the task seems daunting, history shows that several successful examples of new technology standards exist. From simple technology standards, such as the USB stick, to broader system standards such as the implementation of the barcode, which the inventor drew in the sand on Miami Beach decades before it became widely accepted.[94]

There is also the example of the European pallet for shipping, which – when standardised – was commissioned by the European railways in 1961 and slashed the loading times by 90%.[95] And finally, international building standards, which strived to eliminate technical obstacles to trade and harmonise technical specifications.[96]

Adopting these standards was invariably a lengthy and complicated process, but added unprecedented value once established. The Montreal protocol to preserve the ozone layer is another often-cited example of how large stakeholders can come together to adopt a new standard when they have to.[97]

85. https://www.bamb2020.eu/topics/materials-passports/
86. EU Commission, A circular economy for plastics, 2019 (p 102)
87. NEXTEK PRISM Intelligent Sorting of Packaging Using Fluorescent Markers. Retrieved June 2, 2020, from https://www.slideshare.net/CircularEconomyAsia/nextek-prism-intelligent-sorting-of-packaging-using-fluorescent-markers
88. http://polymark.org/sites/default/files/uploads/3.%20Hans%20Eder_Polymark%20Industrial%20Scale%20Sorting%20System.pdf (Visited May 27, 2020)
89. EU Commission, A circular economy for plastics, 2019 (p 103-104)
90. https://www.pragmatic.tech/ (visited May 27, 2020)
91. EU Commission, A circular economy for plastics, 2019
92. ECHA database on Substances of Concern in articles as such or in complex objects (products). https://echa.europa.eu/scip
93. https://www.ibm.com/ibm/history/ibm100/us/en/icons/upc/ (visited May 28, 2020)
94. https://www.smithsonianmag.com/innovation/history-bar-code-180956704/ (visited June 8, 2020)
95. https://www.zeit.de/2011/19/Europalette (visited June 8, 2020)
96. https://eurocodes.jrc.ec.europa.eu/showpage.php?id=12 (visited June 8, 2020)
97. Encyclopedia Britannica, Montreal Protocol, https://www.britannica.com/event/Montreal-Protocol (visited June 5, 2020)

Regulations and Policies

In general, recycled materials must meet the same legal requirements concerning chemical content as virgin materials. There are a number of EU regulations relevant to recycled materials and many of them are expected to be adapted in line with EU policies on the circular economy. To prepare for upcoming changes in regulation, it is therefore important to look at the overarching policies from the EU Commission, since they indicate the direction and level of ambition to be expected in specific EU regulations.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In 2018, the EU Commission published a European Strategy for Plastics in a Circular Economy.[98] In this strategy, the Commission – among other things – addresses problematic substances by saying that substances that hamper recycling processes should be phased out.

The same year, the Commission also presented the ***Circular Economy Package*** [99], containing four directives, of which the Waste Framework Directive (2008/98/EC), the Landfill Directive (1999/31/EC), and the Packaging Waste Directive (94/62/EC) are relevant to packaging.

In December 2019, the EU Commission announced the ***Green Deal*** [100], ambitious not only on climate issues, but also on chemicals and circularity. It was followed by the ***Circular Economy Action Plan*** [101] (CEAP) in March 2020, accompanied by a timeline of ***key actions***.[102] The CEAP highlights seven key product value chains, which include packaging, plastics and textiles.

Same chemical limit values for virgin and recycled

Later in 2020, the Commission also presented a ***Chemicals Strategy for Sustainability*** [103], with a focus on non-toxic material cycles. One of the most important messages related to recycled material is that – as a principle – the same limit value for hazardous substances should apply to both virgin and recycled materials. There is also a strong push to ensure availability of information on chemical content and safe use.

Here are summaries of the regulations and policies of special relevance to chemicals in the circular economy:

REACH – applies to all chemical substances

The most rigorous EU chemicals regulation is Registration, Evaluation and Authorisation of Chemicals, REACH (EC No 1907/2006): In principle, REACH applies to all chemical substances; not only those used in industrial processes, but also in our day-to-day lives, for example in cleaning products and paints, as well as in articles such as clothing, furniture and electrical appliances. Therefore, the regulation has an impact on most companies across the EU, and the production of secondary raw materials must comply with REACH.

REACH places the burden of proof on producing companies to demonstrate that their substances can be safely used, and to communicate risk management measures to users. If risks cannot be managed, authorities can restrict the use of substances through either Annex XIV (authorisation) or Annex XVII (restriction). When a Substance of Very High Concern (SVHC) is placed on REACH Annex XIV, authorisation is required for continued use within the EU.

An authorisation will only be granted if the risks can be controlled, or if there are no alternatives and the socio-economic benefits are higher than the costs of using the specific substances. The authorisation is time-limited and granted to a specific company for a specific use. Authorisations can apply to substances in recycled materials. However, the procedure does not address imported articles.

Restrictions in REACH apply to all companies and products produced within the EU, as well as products imported into the EU. A restriction is set for a specific use of a specific chemical. Derogations (exceptions) from the restriction might be included in the decision, for example for recycled materials. These are time-limited.

REACH may be subject to a review, scheduled for 2022.

Waste framework directive (WFD) – clarifies the distinction between waste and materials

Directive (EU) 2018/851[104]: The WFD sets the basic concepts and definitions related to waste management and lays down some basic waste management principles.

One such element is the end-of-waste criteria, which specify when waste is no longer to be seen as waste, but obtains the status of a product or secondary raw material.

However, the existing criteria are only set for three categories:

- Iron, steel and aluminium scrap
- Glass cullet
- Copper scrap

The Commission is to prepare a set of end-of-waste criteria for additional priority waste streams. However, this work has been ongoing for a long time and it has proved to be very difficult to reach agreements on the criteria for materials such as plastic.

Chemical, product and waste interface – fills in the gaps

In the absence of appropriate end-of-waste criteria for materials such as plastics, the Commission has redirected the focus to the space between the points of waste and product, commonly referred to as the chemical, product and waste interface.

Under the Waste Framework Directive (WFD), there is a requirement to disclose all "complex objects", as well as components that contain more than 0.1 % of a Substance of Very High Concern (SVHC). This information must be reported to the SCIP database – short for "the database for information on Substances of Concern In articles as such or in complex objects (Products)" – hosted by the European Chemicals Agency ECHA.

This requirement is intended to increase the information available to recyclers, but also drive substitution. The legal obligation to provide this information took effect in January 2021.

Packaging waste directive – making producers responsible

This directive covers all packaging placed on the European market and all packaging waste, regardless of the material used. EU member states must ensure that all packaging placed on the EU market meets the essential requirements defined in Annex II of the Directive, which entails:

1. The manufacturing and composition of packaging;
2. the reusable nature of packaging; and
3. the recoverable nature of packaging (through material recycling, energy recovery, composting or biodegradation)

By the end of 2024, EU countries should ensure that producer responsibility schemes are established for all packaging. These schemes should help incentivise design of packaging in a way that promotes high quality recycling and minimises the impact of packaging and packaging waste on the environment.

This directive has been revised several times, for example to include requirements that PET bottles will need to contain at least 25% recycled plastic as from 2025. From 2030, the target will be 30% for any plastic bottle placed on the market.

Sustainable Product Initiative – made for the circular economy

Under the Circular Economy Action Plan, the Commission intends to introduce the Sustainable Product Initiative to make products fit for a climate-neutral, resource-efficient and circular economy. It aims to reduce waste and ensure that the performance of frontrunners in sustainability progressively becomes the norm.

This upcoming legislative initiative could entail a revision of the Ecodesign Directive, widening its scope beyond energy-related products, and propose additional legislative measures. It is also foreseen to address the presence of harmful chemicals in products. One of the current problems that the initiative sets out to remedy, is that many products break too quickly, cannot be easily and safely reused, repaired or recycled, and are made for single use only.

In addition, the Commission has announced that they will address some key product value chains specifically by presenting strategies. The textile sector is one of the areas where policy documents are expected.

In conclusion: Chemicals need to be central in legislation on recycled materials

There are also many additional policy initiatives, EU regulations, international directives and non-EU legislation relevant to recycled material in products. However, the regulations and policy papers mentioned above give an overview of the general state of play, as well as an indication of the direction and level of ambition ahead.

Much of the regulation that is relevant for recycled material is either outdated, in the making, or open to exceptions that could compromise the content. If the use of recycled material is to increase, there needs to be a shift in the regulatory baseline, applying both the precautionary principle and recognising the need for toxic-free material cycles in all regulatory measures.

98. *European Commission 2018. A European Strategy for plastics in a circular economy.*
https://ec.europa.eu/environment/circular-economy/pdf/plastics-strategy-brochure.pdf

99. *Latham And Watkins 2018. The EU adopts four directives to solidify Europe's leading position in waste management.*
https://www.globalelr.com/2018/07/the-eu-adopts-four-directives-to-solidify-europes-leading-position-in-waste-management/

100. *European Commission 2019. The European Green Deal COM/2019/640 final*
https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1588580774040&uri=CELEX:52019^{32}*0640*

101. *European Commission 2020. Factsheet. Circular economy action plan.*
https://ec.europa.eu/commission/presscorner/detail/en/fs_20_437

102. *European Commission 2020. Annex. A new Circular Economy Action Plan for a cleaner and more competitive Europe.*
https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan_annex.pdf

103. *European Commission 2020. Chemical strategy for sustainability towards a toxic-free environment.*
https://ec.europa.eu/environment/pdf/chemicals/2020/10/Strategy.pdf

104. *Directive (EU) 2018/851 of the European Parliament and the Council of 30 May 2018 amending Directive 2008/98/EC on waste*
https://eur-lex.europa.eu/legal-content/ES/TXT/?uri=uriserv%3AOJ.L_.2018.150.01.0109.01.ENG&toc=OJ%3AL%3A2018%3A150%3ATOC

Focus:
How do bio-based materials fit in the Circular Economy?

Chemicals will soon be the largest driver of world oil demand, surpassing cars, trucks and aviation, according to a study conducted by the International Energy Agency.[105] These petrochemicals are set to account for more than a third of the growth in world oil demand by 2030, and nearly half of the growth by 2050.

In 2018, 12%[106] of the oil was used to produce chemicals. Petrochemicals are used to make plastics, electronics, clothing and other goods, and the demand for these chemicals is increasing.

The switch from fossil to sustainable is accelerating

Chemists have long tried to find alternative feedstocks to oil, and have developed methods to derive similar molecules from renewable sources, mainly plants. These molecules, and the resulting materials that are made from them, are therefore known as bio-based.

The demand for sustainably-sourced materials has led to rapid growth in the production of bio-based materials, and this increase is expected to continue. This is especially true for bioplastics.

The potential, and opportunities connected to bio-based materials are huge, and many exciting solutions are already on the market. One example of bio-based materials are new plastics, such as polyhydroxy acids (PHA) and polylactic acid (PLA), which can be produced using bacteria, and are both biodegradable and compostable in industrial conditions.

But what about recycling?

When it comes to recyclability of bio-based materials, it is the material and not the origin of that material that matters. Most bioplastics, such as PE and PET, are chemically and physically identical to existing plastics produced from oil and can therefore be recycled in the same way. [107]

The story is different for bio-based and biodegradable materials, such as PHA and PLA, which are created to be composted and not recycled. For this to work, these materials of course need to be identified in existing waste streams and treated accordingly.

Are bio-based chemicals the answer?

Biomaterials will certainly be part of the solution for a less fossil-fuel dependent society. However, there are issues to be considered if the use of bio-based materials is to become truly sustainable:

1. How sustainable are the sources?

Bio-based building blocks can come from a wide array of raw materials, including corn, sugar cane and wood. There have been concerns about what the impact of a shift towards growing crops for bio-based chemicals – instead of food – would be on society and the environment, and how sustainable such a shift would be.

At the moment, there seems to be no immediate threat to global food production, nevertheless, aspects such as where a crop has been cultivated and harvested play a vital role in determining overall sustainability. In conclusion, the source and supply chain of the raw material must be understood and considered when evaluating bio-based alternatives.

2. Bio-based chemicals can still be hazardous

When it comes to chemicals, hazardous properties are hazardous properties – no matter where they come from. In other words, chemicals are not inherently safe just because they are produced from bio-based building blocks.

DEHP or BPA are, for example, just as hazardous to human health and the environment when produced from biomass as they are when produced from fossil sources because they are ultimately the same substance.

3. The plastic waste burden won't be reduced

In line with the previous issue, bio-based plastics are still plastics. Producing bio-based versions of, for example, PE or PET will not decrease the production of plastics, nor reduce the plastic waste burden.

Even if a plastic bag is produced from sugar cane, it does not mean it is compostable. Bioplastics, as well as petroplastics, break down into microplastic particles that end up in waterways and oceans, which is a huge environmental problem found all over the world.

105. *IEA 2018, The future of petrochemicals. Towards a more sustainable chemical industry. https://www.iea.org/reports/the-future-of-petrochemicals*
106. *IEA 2018, The future of petrochemicals. Towards a more sustainable chemical industry. https://www.iea.org/reports/the-future-of-petrochemicals*
107. *https://docs.european-bioplastics.org/publications/pp/EUBP_PP_End-of-life.pdf*

The financial aspects of hazardous chemicals in the circular economy

The focus of this chapter is an often-overlooked topic, the potential financial opportunities for EU businesses from the upfront removal of chemicals of concern from products eventually entering the waste streams. Again, we look specifically at plastic packaging and textiles.

This chapter seeks to explore the scale of market opportunities that may arise from early action on hazardous chemicals. To support the analysis, interviews with a limited number of stakeholders in plastics, textiles and corresponding recycling industries were carried out. The information from the interviews was used to provide context and support assumptions for the analysis.

The data used in the analysis was derived from publicly available resources. It is however clear, from both data mining and interviews, that key quantitative data on e.g. the volumes of recyclable materials discarded due to hazardous chemicals, is not accessible. The analysis in this chapter therefore presents a number of scenarios to illustrate the potential scale of the market opportunities.

The financial opportunity for recycling of cleaner plastic packaging

This section attempts to evaluate the financial opportunity that could accrue to EU-based plastic packaging recycling industry, if hazardous chemicals are removed from future production of plastic packaging. The analysis is done in three steps:

- The first step is an overview of the current plastics market in the EU with a focus on the plastic packaging market.
- In the second step we explore data on volumes of plastic waste, with a focus on plastic packaging.
- Lastly, we explore the future market potential for plastic recycling in the EU through the development of market projections with and without removal of hazardous chemicals from the plastic waste stream.

1. CURRENT AND FUTURE MARKET FOR PLASTIC PACKAGING

Global production of virgin plastics in 2019 was reported to be 368 million tonnes (Mt) and EU production was reported at 57.9 Mt. Historic trends shows that globally the market has been steadily increasing by around 4% per year between 2012 and 2018.[108] The EU market, on the other hand, oscillates between growth and reduction, with an average annual growth of 1% over the same period.[109] The EU plastics industry had an annual turnover of more than €350 billion [110] in 2019, across 55,000 companies.

Around 40% [111, 112] of all plastics is used for packaging, both in the EU and globally – making this the end use with the highest market share.[113, 114] The global plastic packaging market was valued at €171[115] billion in 2019, comprising 36.5% of the total market value for all plastics worldwide.[116] It was estimated that the virgin plastic packaging sold in the EU in 2019 had a material value of around €36 billion.[117]

The plastics markets see a number of future uncertainties due to upcoming government policies, changing consumer preferences and oil prices, making it challenging to accurately predict future material value. However, in the short term, the global plastic packaging market has been projected to grow by 3.5% [118] per year up until 2025.

To capture the uncertainties associated with the plastic packaging market, three different baseline growth projections were used in this analysis. The ***high-use baseline*** assumes that the EU plastic packaging market grows at the same pace as the global market during 2021-2026, after which the growth rate is reduced to 2% per year. In the ***low-use baseline*** the growth until 2026 is 25% of the high-use baseline, after which it is assumed to be negative: -2%. This baseline is intended to capture EU ambitions as well as consumer preferences to reduce plastics packaging. The impact of Covid-19 has not explicitly been included in the analysis, but it is partially accounted for by assuming no net growth between 2018 and 2020.

According to these projections the material value of virgin plastics is expected to reach €23 billion – €71 billion by 2050.

2. CURRENT AND FUTURE MARKET FOR THE RECYCLING OF PLASTIC PACKAGING

Around 250 Mt of plastic waste was generated globally in 2018, of which 70% was collected. It is unknown what happens to the remaining 30%. The global plastic recycling market was valued in 2017 at around €29 billion.[119]

Annual growth between 2018 and 2025 was predicted to be 5.0-7.9%, which means that the global plastic recycling may reach €55 billion by 2025.

What is collected for recycling does not all end up as recycled material. Material Economics [120] suggest that only 8-10% of the end-of-life plastics is actually recycled.[121]

It is reasonable to assume the share of plastic packaging that will be recycled will continue to grow over time, due to several policy drivers. For example, the EU Directive on Packaging and Packaging Waste which sets recycling targets of 50% for 2025 and 55% by 2030. A ban on land-filling of recyclable materials will enter into force by 2025, which may also encourage further recycling.[122]

For the development of the baseline for the recycled plastic packaging market it is assumed that the above-mentioned recycling targets are met for 2025 (50%) and 2030 (55%), and that the share of waste collected for recycling will reach 80% by 2050. It is further assumed that 50% of the waste collected for recycling will actually be recycled.

The price of recycled plastic packaging is even more uncertain than that of virgin material, as it depends on the virgin prices (and thereby inherits these uncertainties) but is also more sensitive to environmental policies and consumer preferences for sustainable goods. To capture these uncertainties, different material prices have been used to create the baseline scenarios. At the lower end, the price for recycled plastics cited in Material Economics (2020) has been used (~€1/kg), whilst for the upper bound price, this is assumed equal to the virgin price (~€1.9/kg), and the central baseline is the average of these. It is assumed that this price range is representative for the average, inflation-adjusted price for recycled plastics between 2021 and 2050.

By combining the estimated waste collected, the growing recycling rates and the price estimates, we project three baselines for the material value of recycled plastics. This shows, that despite the significant decline in the use of plastics packaging in the *low-use baseline*, the market for recycled plastics will still grow due to the increasing recycling rates during 2021-2050.

The best estimate for the material value of recycled plastic packaging in 2050 is between €4.6 billion and €25.3 billion, while the annual average for the period 2021-2050 is expected to be €4.7– €15.3 billion.

3. THE MARKET OPPORTUNITY TO BE REALISED IF HAZARDOUS CHEMICALS ARE REMOVED

Phasing out hazardous substances may enable even higher growth in actual recycling rates over time, and thereby increase the market opportunities for recyclers. In the absence of data, it was chosen to construct three scenarios to exemplify potential market opportunities that might be partially or fully realised by early action on phasing out the use of hazardous chemicals in plastic packaging.

Table 5. *Estimated plastics and plastic packaging recycling in 2019. Based on information from Conversio Market & Strategy GmbH (2020) and PlasticsEurope (2020).*

MARKET SEGMENT	PLASTICS (MT/YEAR)	PLASTIC PACKAGING (MT/YEAR)
EU DEMAND	50.7	20.1
TOTAL WASTE COLLECTED	29.1	17.8
WASTE COLLECTED FOR RECYCLING	9.5	7.5
WASTE ACTUALLY RECYCLED	4.7	3.7

- **Scenario 1:** 5 percentage point increase in actual recycling rate by 2025 as compared to the central baseline.
- **Scenario 2:** 15 percentage point increase in actual recycling rate by 2025 as compared to the central baseline.
- **Scenario 3:** 30 percentage point increase in actual recycling rate by 2025 as compared to the central baseline.

The figure below shows the estimated development of the recycling market under the three scenarios, as well as the central baseline scenario (without removal of hazardous chemicals). By 2050, the most conservative scenario (Scenario 1) results in an estimated material value for recycled plastic packaging of €12.4 billion, Scenario 2 yields 15.2 billion, while Scenario 3 reaches €19.3 billion.

The unrealised market opportunities associated with the example scenarios are given by the difference between the market size estimated for the scenarios and the market size estimated for the baseline.

The results indicate that there are sizable unrealised market opportunities under all three scenarios, falling within €1.3 billion – €7.7 billion per year in the EU. Due to data gaps, it is not possible to conclude whether the actual market potential opportunity falls within this range. The analysis does, however, show that even if only a small increase in recycling rates (e.g. 5% as shown in Scenario 1) can be attributed to removing hazardous substances, there are sizeable market opportunities that could be realised. (Table 6.)

Note that the market opportunities exemplified by scenarios 1-3 do not represent socio-economic benefits. They do not account for investment costs for new technologies, neither do they include benefits from reduced environmental and human health costs, avoided disposal costs, savings for downstream users, avoided risk management measures and PPE, regulatory costs, reputational costs, avoided greenhouse gas emissions, landfill space, and avoided landfill leaching. If the technological and economic barriers to faster textile recycling can be addressed, then this may evolve into a further financial opportunity for European businesses.

Figure 10. *The € billion opportunity of recycled plastics*
Estimated annual value in the EU i 2050, without and with removal of hazardous chemicals – three scenarios

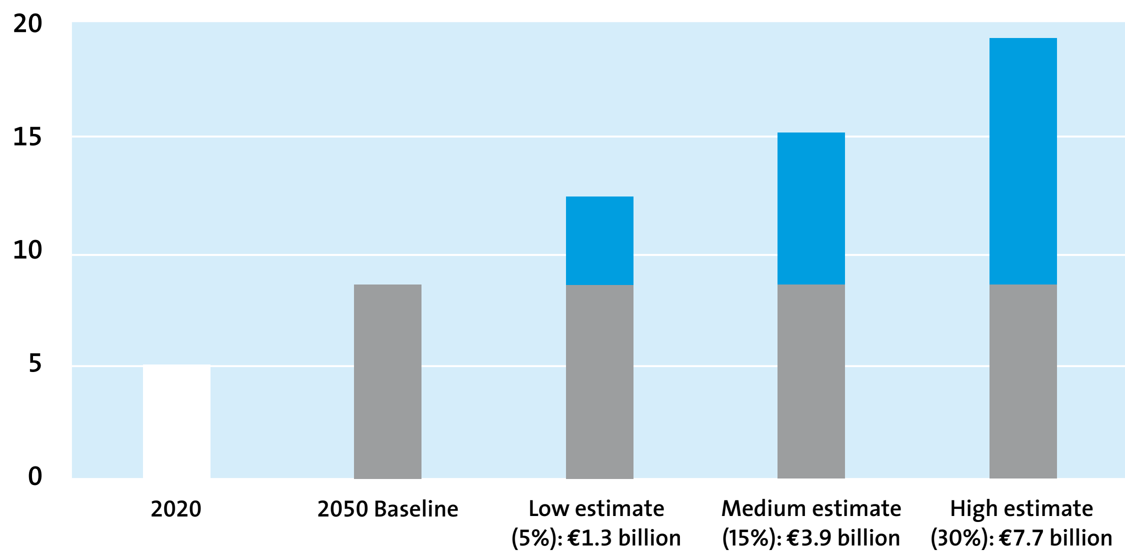

Table 6. *Unrealised market opportunities within the plastic packaging recycling sector, average 2021-2050.*

MARKET SEGMENT	CENTRAL BASELINE	SCENARIO 1	SCENARIO 2	SCENARIO 2
AVERAGE ANNUAL DEMAND FOR PLASTIC PACKAGING (MT)	22.1			
AVERAGE ANNUAL PLASTIC PACKAGING WASTE COLLECTED (MT)	19.6			
AVERAGE ACTUAL RECYCLING RATE (% OF WASTE COLLECTED)	31%	36%	45%	59%
AVERAGE ANNUAL ACTUAL RECYCLING (MT)	6.1	7.0	8.8	11.6
AVERAGE ANNUAL MATERIAL VALUE (€ BILLION)	8.5	9.8	12.4	16.2
AVERAGE ANNUAL MARKET OPPORTUNITY (€ BILLION)	-	1.3	3.9	7.7

The financial opportunity from recycling of cleaner textiles

In this section we aimed at evaluating the financial opportunity that could accrue to the EU-based textile recycling industry, if hazardous chemicals could be removed from waste streams. However, this proved to be a too uncertain analysis to follow-through. Instead, we present key data on the current textiles' market in the EU and possible future projections.

"Textiles" here are defined broadly; they include all fibres: knitted and woven fabrics destined for use in various types of clothing, home and office furnishings, bed linen, towels, furniture, and carpets and in transportation, such as car, train, and aircraft interiors. There is however much more data for clothing than for these other uses, so the analysis focuses on this area.

We present data on waste arising from textiles, including the ultimate disposal method for that waste.

While we were not able to quantify the financial opportunity, it is clear that if a coherent policy package can be implemented – supporting safe-by-design, circular business models and technologies, alongside the removal of hazardous chemicals from waste streams – to accelerate growth in the sector, that this could represent a sizable financial and commercial opportunity, and help to reduce the environmental and health costs from chemicals exposure whilst supporting a transition to a circular economy.

1. CURRENT AND FUTURE MARKET FOR TEXTILES

In 2019, around 3 million tonnes of fibres and woven material were produced in the EU.[123] However, European textile production comprises a small share of European textile consumption. Textile imports to the EU in 2018 were around 14.5 million tonnes, worth €139 billion. Exports comprised around 5.7 million tonnes with a value of €61 billion; some of which are re-exported products. The total volume of European textile consumption is over 10 million tonnes per year with most imported from outside the EU.[124] In 2018, there were about 170,000 companies in the EU's textile and clothing industry, with a collective turnover of €178 billion.[125]

Global fibre and textile production are growing quickly. In 2017, global production was around 99 million tonnes, which is around twice the volume produced 15 years ago and equivalent to an average growth of 5% per year. While the economic disruption of the Covid-19 lockdowns will significantly affect short-term trends, before the pandemic it was predicted that global fibre consumption would increase to 145 million tonnes by 2025, an annual average growth rate of 2.5%.[126]

This is driven by a range of factors, but ultimately by consumer demand and changing fashion trends. This is reflected in increasing volumes of clothing purchased, with garments worn fewer times, on average. The average price of clothing has decreased, as has the typical share of income consumers spend on them.

While these trends are global, they are reflected in Europe. The value of European clothing purchases increased by 40% between 1996 and 2019.[127] Longer term, the Ellen MacArthur Foundation assumed annual average growth in textile fibre demand of 3.5% per year to 2050.[128]

2. CURRENT AND FUTURE MARKET FOR THE RECYCLING OF TEXTILES

It has been estimated that EU consumers discard about 5.8 million tonnes of textiles per year, corresponding to 11.3 kg per person of which 2.15 million tonnes (4.2 kg per person) are identified as waste. The rest is either stored, re-used or exported.[129, 130]

Textile collection rates are around 15-20% across EU countries; the remaining 80-85% of volumes are incinerated or landfilled. Of the collected textiles about half is recycled, and half is reused. Most re-use involves exporting clothing outside of the EU. Textile waste volumes comprise a small share (< 0.1%) of the total EU waste.

More than 99% of global clothing recycling involves *"downcycling"* [131], where the value of the recycled material is lower than the original material. The lower material value is a result of inferior quality or functionality, which limits the uses of the materials, e.g. for production of insulation felts and cleaning wipes. Closed-loop recycling comprises a small share of the total volume of recycled clothing (<1%), and most of this is sourced from factory cut-offs. (Table 7)

Table 7. *Textile waste and recycling volumes.*

MARKET SEGMENT	VOLUMES
TOTAL EU TEXTILE WASTE	2.15 million tonnes/year
INCINERATED OR LANDFILLED TEXTILE WASTE	1.7-1.8 million tonnes/year
COLLECTED TEXTILE WASTE	320,000-430,000 tonnes/year
DOWNCYCLED TEXTILE WASTE	160,000-215,000 tonnes/year
REUSED TEXTILES TYPICALLY VIA EXPORTS [132]	160,000-215,000 tonnes/year
TOTAL VOLUME RECYCLED, DOWNCYCLING AND CLOSED-LOOP	165,000-235,000 tonnes/year
ESTIMATES OF CLOSED-LOOP RECYCLING OF CLOTHING, INCLUDING FACTORY CUT-OFFS (HIGH UNCERTAINTY)	~20,000 tonnes/year
ESTIMATES OF CLOSED-LOOP RECYCLING OF CLOTHING, EXCLUDING FACTORY CUT-OFFS (HIGH UNCERTAINTY)	~2,000 tonnes/year

There is very little data on the overall size and economic characteristics of the textile recycling market in Europe. However, data is available on the wider waste treatment, disposal and recovery sector. This provides some indication of economic characteristics and trends. While the data implies that only a small proportion of EU recycling involves textile recycling, the stakeholder consultation indicated that companies are involved in several related activities. Data from Eurostat, below, was used in the development of the future growth scenarios below, including:

- In 2018 there were just under 46,000 companies in the EU undertaking recycling; the number of companies had grown by 8% between 2014 and 2018, around 1.6% per year.
- Turnover (i.e. total revenue) associated with recycling in general (not specifically textiles) had grown strongly, particularly after 2016, and stood at €165 billion in 2018. This has increased by just over 25% between 2014 and 2018, or 6.2% per year.
- Total production value (i.e. the economic value all recycling and waste recovery activity) also grew by just over 25% in the same period (6.1% per year); the value in 2018 stood at €158 billion.[133]

Three baselines show possible evolutions in the textile recycling market to 2050:

- The low baseline assume that the size of the textile recycling market is €12 million in 2018 and grows in line with demand for textiles as a whole, at 2.5% per year. The low baseline thus implies that the recycling rate and material quality/value remain at the 2018 level up until 2050.
- The medium baseline assumes that the textiles recycling market grows at the same rate as recent growth in the wider recycling market, at 6%, indicating a moderate increase in the recycling rate between 2018 and 2050. The 2018 recycling rate (0.01%) is very low compared to other materials, which reflects the immaturity of this market. If more market barriers are resolved this could lead to a significant increase in the recycling rates and/or price premiums, putting the market in a rapid growth phase. Such a scenario is not unlikely considering the increasing focus on recycling in the EU.
- The high baseline is thus derived using a growth rate that is twice the recent growth rate for the overall recycling market, i.e. 12.4%.

The adverse effects of Covid-19 on demand are not accounted for in either baseline and are considered to be within the overall uncertainties. This suggests that the textile recycling annual market turnover may grow to €25 million – €559 million by 2050. (Table 8, next page)

Table 8. *Baselines – key variables and assumptions.*

INPUT	DATA ASSUMPTION LOW, CENTRAL AND HIGH BASELINE			SOURCES AND NOTES
CURRENT TEXTILE WASTE AND RECYCLING MARKET ESTIMATES				
TONNES OF TEXTILE WASTE IN THE EU	2 million tonnes			Based on Eurostat data
CLOSED LOOP RECYCLING AND DOWN-CYCLING (TONNES PER YEAR)	165,000	235,000	235,000	Derived using GiZ (2017) estimates of downcycling market share, estimates of closed-loop recycling and Eurostat data on waste volumes.
MARKET TRENDS IN TEXTILE DEMAND AND RECYCLING				
ANNUAL AVERAGE GROWTH RATES – TURNOVER IN EU RECYCLING SECTOR	6.2% per year (2014 -2018)			Eurostat (2020a). Annual enterprise statistics, special aggregates of activities (NACE Rev. 2).
BUSINESS AS USUAL (BAU) – ANNUAL INCREASE IN TEXTILE DEMAND	2.5% per year	6.2% per year	12.4% per year	The low rate is based on forecasts of future textile demand from GiZ and Ellen MacArthur Foundation study. The central rate is based on growth in the overall recycling sector. The high rate assumes twice the growth of the overall recycling market.
PRICE PREMIUM FOR RECYCLED MATERIAL FREE FROM HAZARDOUS CHEMICALS	Not quantified			Consultees indicated there is a price premium (for certain applications, at least). This could be as much as 100%.
DERIVING TEXTILE RECYCLING MARKET ESTIMATES				
ANNUAL TURNOVER IN EU WASTE COLLECTION TREATMENT, DISPOSAL ACTIVITIES, MATERIAL RECOVERY) SECTOR	~€165 billion/year			Current revenue generated in the wider recycling and waste disposal sector (Eurostat, 2020a). Annual enterprise statistics for special aggregates of activities (NACE Rev. 2).
TOTAL EU WASTE FROM ALL SOURCES	~2.3 billion tonnes/year			Eurostat (2020c). Generation of waste-by category, hazardousness, and NACE Rev. 2 activity, 2018 data.
TEXTILE RECYCLING (CLOSED LOOP AND DOWNCYCLING) AS A SHARE OF TOTAL EU WASTE	~0.01%			Derived using above inputs.
ESTIMATE OF TEXTILE RECYCLING MARKET SIZE IN 2018	€17 million			Derived using above inputs.
ESTIMATE OF TEXTILE RECYCLING MARKET SIZE IN 2050	€25 million	€102 million	€559 million	Derived using above inputs.

3. THE MARKET OPPORTUNITY TO BE REALISED IF HAZARDOUS CHEMICALS ARE REMOVED

As set out in the "State of play – Textiles" section, the textile recycling market faces several economic and technological barriers. These mirror those in the wider transition to a circular economy and have been discussed at length in other studies.[134]

Based on the very scarce information available, and the immaturity of the textile recycling market, it is not possible to estimate how much the market for textile recycling will increase as a whole, and therefore not either as a result of the removal of hazardous substances from textile waste streams. The three hypothetical scenarios in table 8 illustrate the uncertainty in extrapolating economic growth when no data is available, with an estimate of the textile recycling market in 2050 ranging from €25 millions to €559 millions.

Due to data gaps and the large uncertainties on market development, it is not possible to conclude on the actual market potential opportunity. Considering that textile recycling is currently in its infancy, the emergence of ground-breaking new technologies is highly probable, this could lead to high acceleration in the market growth.

Whilst the market opportunity examples do not consider investment costs for new technologies, neither do they include benefits from reduced environmental and human health costs, avoided disposal costs, savings for downstream users, avoided risk management measures and PPE, regulatory costs, reputational costs, avoided greenhouse gas emissions, landfill space and avoided landfill leaching. If the technological and economic barriers to faster textile recycling can be addressed, then this may evolve into a further financial opportunity for European businesses.

While the figures are uncertain, the opportunity is definitely there

There is too little available information to properly assess the market opportunity that is currently constrained by the issue of hazardous chemicals. There are also large uncertainties regarding the overall development of the market for plastic packaging and textiles, due to upcoming changes in policies and public perception. For the immature industry of recycled textiles, we found the uncertainties being too many to make projections.

However, available data could be used to make a number of qualified assumptions for plastic packaging, showing the scale of the business opportunity if hazardous chemicals no longer constrained the market for recycled materials.

The average annual value of the EU market for recycled plastic packaging, without further action, is estimated at €8.5 billion per year between 2021 and 2050. If actual recycling rates can be increased by 5-30 percentage points, additional market opportunities in the order of €1.3-7.7 billion could be realised.

108. *PlasticsEurope (2019). Plastics – the Facts 2019. An analysis of European plastics production, demand and waste data. Available at: https://www.plasticseurope.org/application/files/1115/7236/4388/FINAL_web_version_Plastics_the_facts*2019_14102019
109. *PlasticsEurope* (2020). *Plastics – the Facts 2020. An analysis of European plastics production, demand and waste data. Available at: https://www.plasticseurope.org/download_file/view/4261/179*
110. *PlasticsEurope (2020). Plastics – the Facts 2020. An analysis of European plastics production, demand and waste data. Available at: https://www.plasticseurope.org/download_file/view/4261/179*
111. *PlasticsEurope (2020). Plastics – the Facts 2020. An analysis of European plastics production, demand and waste data. Available at: https://www.plasticseurope.org/download_file/view/4261/179*
112. *Conversio Market & Strategy (2020). Global plastics flow. Available at: https://www.conversio-gmbh.com/res/Global_Plastics_Flow_Feb10_2020.pdf*
113. *PlasticsEurope (2020). Plastics – the Facts 2020. An analysis of European plastics production, demand and waste data. Available at: https://www.plasticseurope.org/download_file/view/4261/179*
114. *Conversio Market & Strategy (2020). Global plastics flow. Available at: https://www.conversio-gmbh.com/res/Global_Plastics_Flow_Feb10_2020.pdf*
115. *Note that the methodology used to calculate the market value likely differs from that of PlasticsEurope, which means that the value for the EU and globally cannot be directly compared.*
116. *Grand View Research (2020). Plastic Market Size, Share & Trends Analysis. Available at: https://www.grandviewresearch.com/industry-analysis/global-plastics-market*
117. *Material Economics (2020). Preserving value in EU industrial materials – A value perspective on the use of steel, plastics, and aluminium. Available at: https://resource-sip.se/content/uploads/2020/11/material-economics-preserving-value-in-eu-industrial-materials-2020.pdf*
118. *Mordor Intelligence (2020). Plastic Packaging Market – Growth, Trends, Forecasts (2020-2025). Available at: https://www.mordorintelligence.com/industry-reports/plastic-packaging-market*
119. *USD 34.8 billion, converted using xe.com, 11/12/20*
120. *Material Economics (2020). Preserving value in EU industrial materials – A value perspective on the use of steel, plastics, and aluminium. Available at: https://resource-sip.se/content/uploads/2020/11/material-economics-preserving-value-in-eu-industrial-materials-2020.pdf*
121. *Material Economics (2020). Preserving value in EU industrial materials – A value perspective on the use of steel, plastics, and aluminium. Available at: https://resource-sip.se/content/uploads/2020/11/material-economics-preserving-value-in-eu-industrial-materials-2020.pdf*
122. *CSIRO (2017). The recycled plastics market: global analysis and trends. Available at: https://www.csiro.au/en/Research/MF/Areas/Chemicals-and-fibres/plastic-recycling-analysis*
123. *Source: https://ec.europa.eu/eurostat/web/prodcom The estimate is approximate – some data are only available by length of material, rather than weight so assumptions have been made – see table notes. However it is in good agreement with EEA data from 2017 of 3 million tonnes – also based on Eurostat: https://www.eionet.europa.eu/etcs/etc-wmge/products/etc-reports/textiles-and-the-environment-in-a-circular-economy*
124. *This is based on applying the average per person figures together with the EU population in 2017 of 445,500,000. Source: Eurostat Population and population change statistics https://ec.europa.eu/eurostat/statistics-explained/index.php/Population_and_population_change_statistics#EU-27_population_continues_to_grow Other sources are in broad agreement with this figure, although some are within a large range (between 9 to 27 kg per person. A 2014 JRC study estimated 19.1 kg (see EEA 2019).*
125. *Turnover of EUR 171 billion for 2016 was noted in the GiZ (2019) report, GiZ (2019). Circular Economy in the Textile sector Study for the German Federal Ministry for Economic Cooperation and Development (BMZ).*
126. *GiZ (2019). Circular Economy in the Textile sector Study for the German Federal Ministry for Economic Cooperation and Development (BMZ).*
127. *GiZ (2019). Circular Economy in the Textile sector Study for the German Federal Ministry for Economic Cooperation and Development (BMZ).*
128. *Ellen MacArthur Foundation (2017) A new textiles economy: Redesigning fashion's future. Available at: http://www.ellenmacarthurfoundation.org/publications*
129. *EEA (2019). Textiles and the Environment in a Circular Economy. Available at:https://www.eea.europa.eu/themes/waste/resource-efficiency/textiles-in-europe-s-circular-economy*
130. *GiZ (2019). Circular Economy in the Textile sector. Study for the German Federal Ministry for Economic Cooperation and Development (BMZ).*
131. *Ellen MacArthur Foundation (2017). A new textiles economy: Redesigning fashion's future. Available at: http://www.ellenmacarthurfoundation.org/publications*
132. *Note this is significantly less than the total volumes of textile exports by EEA (2019) as noted in Figure 1.1. The difference is likely to be represented by a range of intermediate products, such as non-wovens, fibres and technical textiles and high-quality fabrics.*
133. *Data in this subsection is from Eurostat (2020d). Annual enterprise statistics for special aggregates of activities (NACE Rev. 2) – "Waste collection, treatment, and disposal activities; materials recovery sector" EU27. Available at: https://ec.europa.eu/eurostat/databrowser/view/SBS_NA_SCA_R2__custom_365370/default/table?lang=en*
134. *For example, https://op.europa.eu/en/publication-detail/-/publication/2d7fc4d1–96f6–11e9–9369–01aa75ed71a1*

Main conclusions

This report shows how chemicals of concern are preventing the growth of circular economy. To a large extent, current materials contain chemicals that make them unusable for production of new products. At present, and for the foreseeable future, there are no viable technologies to remove problematic chemicals from waste. Instead, the phaseout of chemicals of concern must be considered at the design and manufacturing stages.

Business-as-usual is not an option

Chemicals production and the production of virgin materials are predicted to increase dramatically in the future. As 73% of the chemicals in the EU market are classified as hazardous to human health or the environment, a corresponding rise in human and environmental health problems are expected.

In early 2021, the EU chemicals agency – ECHA – launched a new database called SCIP (substances of concern in products), which aims to increase transparency regarding the presence of the most hazardous chemicals, meaning Substances of Very High Concern (SVHCs), in products on the European market. In the first week alone, more than five million notifications from companies were made for products containing SVHCs.

Randomised chemical tests on products prove the grave reality. An investigation of food packaging in Sweden showed that 80% contained DEHP, an extremely hazardous phthalate. In addition, PFOS and PFOA, which provide oil repellence on paper packaging, were also frequently identified.

Most sustainability challenges, including the issue of hazardous chemicals, would improve with new business models based on less consumption. Reducing, reusing and recycling must guide future production, but recycling is only feasible if the materials (waste streams) are made from non-toxic materials.

Recycling levels are lower than you probably think

Recycling levels are still very low, in spite of decades of ambitious initiatives to raise them. In 2019, "circular material use" in the EU was 11.7%, and global levels were even lower.

Even a small increase of 10% in the recycling of plastic packaging would correspond to an annual increase in EU market value of €2.6 billion.

In this report, we have taken a closer look at plastic packaging, where EU recycling rates are 8-10%. For the other material of focus in this report – textiles – recycling rates are not as well developed and figures are therefore uncertain. However, it is estimated that only 1% of textiles globally are recycled into new clothing.

There are many reasons why recycling levels are still so low. These include:

- Lack of infrastructure for collection and sorting.
- Lack of predictability of which materials will be available, and when.
- Products are not designed to be disassembled into individual materials.
- The sheer number of different materials on the market.
- Blends and multilayer materials are difficult – or impossible – to recycle with currently available technologies. Different colours also complicate recycling.
- Material quality can be impaired in the recycling process, which means that virgin material often needs to be blended in.
- Due to lack of transparency and traceability, the chemical content of recycled materials cannot be known until tested, or unless only specific and well-known input waste is used. Materials with unknown content have very limited market value.

Considering all the above, it is hard for recycled materials to compete with virgin materials in terms of both price and quality. Since companies are liable for the chemical content of their products, it is currently challenging for them to increase the use of recycled materials in the production of new products.

At present it is often difficult or impossible to use recycled materials in the manufacture of some consumer products. Similarly, there is little interest in recycling materials such as electronics that are known to commonly contain hazardous chemicals. Progressive companies with strict requirements on material safety find it challenging to use recycled materials for other products too.

Our analysis shows that if chemicals of concern were more efficiently addressed, this would increase the market for recycled materials. Even a small increase of 10% in the recycling of plastic packaging would correspond to an annual increase in EU market value of €2.6 billion.

We can't just wait for theory to become reality

Mechanical recycling is the only economically large-scale viable recycling method today and for the foreseeable future.

Chemical recycling could potentially be used to remove hazardous legacy substances from materials. However, the methodologies presented to date are at non-commercial level and have not been proven to work on a large scale. They are energy intensive, expensive, limited to certain types of materials and may – ironically enough – generate hazardous chemicals.

The only way to break this vicious circle is to stop using hazardous chemicals in the production of new materials and products.

What needs to be done?

Recommendations for companies

It is an exciting, but also challenging journey for a company to become more circular. No matter whether virgin or recycled material is used, the company is responsible for the chemical content of its products – legally and due to corporate commitments and expectations from consumers.

When considering circularity, much of the focus tends to be on the use of recycled materials in new products. However, it is also important to consider that what is produced and sold by a company will eventually become waste. A circular product must therefore be a product without chemicals of concern, designed for disassembly, so that the materials can be easily separated and recycled.

WHAT COMPANIES CAN DO TO KICK OFF A SAFE AND CIRCULAR ECONOMY

- Produce only what can be recycled safely; consider recycling when choosing materials and during the design phase.
- Avoid using chemicals of concern.
- Ensure that information on chemical content is available throughout the supply chain and be sure to include recyclers.
- Buy only clean and non-toxic recycled materials; ask for information on chemical content.
- Establish common industry standards for materials and chemical content. If fewer materials, blends and multilayer materials are used, the recycling potential will increase.
- Establish close collaborations with recycling companies to better understand how to facilitate each other's work.
- Recognise that the price of recycled materials with known content may be higher than virgin materials and less well characterised recycled materials.

Recommendations for recyclers

Making valuable materials from waste is an important task for the future, and there are unrealised market opportunities ahead. Lack of transparency and uncertainty regarding chemical content are currently seen as the main barriers for many companies to increase their use of recycled materials.

HOW RECYCLERS CAN INCREASE PRODUCTION OF SAFER MATERIALS

- Use separate streams and avoid mixing waste of known and unknown chemical content.
- Be transparent on what is known about the chemical content of the recycled material – and also if it is not known.
- Share information on how to design products to make them more recyclable: dos and don’ts.
- Establish close collaborations with manufacturing companies to better understand how you can facilitate each other’s work.
- Be prepared for increased demand and stricter regulations for recycled materials.

Recommendations for policymakers

Regulation is a very strong incentive for innovation and market transition. It is crucial that policy actions that aim to increase circularity do not compromise targets for chemical safety. The requirements must be the same for recycled virgin materials.

Legal requirements for transparency on chemical content are important to drive development and level the playfield. Frontrunners need to be rewarded. As regulatory processes are slow, it is important that legal ambitions are clear to stakeholders, so that they have the opportunity to adapt upfront.

A level playing field between mechanical and different types of chemical recycling needs to be obtained. Therefore, policy makers should clearly define system boundaries preserving a physical connection (between input and output) and regulate how mass balance allocation is used in order to reflect the quantity originating from waste which has been chemically recycled.

It also clear that much information is missing to assess the market opportunity for recycled materials, that can arise from stricter chemical requirements in new production. Such a study would be a valuable part of upcoming impact studies under the chemical strategy.

WHAT POLICYMAKERS NEED TO DO TO SET THE STAGE

- Speed up all legal processes to phase out substances of concern.
- Make sure that the same requirements apply to virgin and recycled materials, and do not approve derogations in chemical regulations for recycled materials.
- Introduce regulation to ensure that the same requirements apply to both imported and domestic articles.
- Consider the recycling phase of products and materials in all socioeconomic and impact assessments.
- Enforce transparency and information requirements on substances of concern in products.
- Introduce requirements for circular design, including chemical criteria.
- Agree on end-of-life criteria that are aligned with REACH and product directives, as well as the principles in the EU Chemical Strategy for Sustainability.
- Review EU waste legislation to introduce definitions of chemical recycling technologies, to increase clarity and exclude fuel production.
- Be careful when it comes to definitions! "Recycled" goods should be made of materials derived from waste, and a physical link should be proven.
- Create level playing fields by implementing bonus/malus systems to balance the cost premium for frontrunners, including recycling companies.
- Similarly, use bonus/malus systems to tip the balance in favour of recycling over incineration and landfill.
- Explore legal paths to achieve harmonisation in waste regulation, considering efforts made by Member States to go beyond regulation.

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