HOW CIRCULAR IS PET?

A report on the circularity of PET bottles, using Europe as a case study

February 2022

Contents

Definitions

Collection Rate: Is the weight of packages collected versus the weight of the same packages placed on the market.

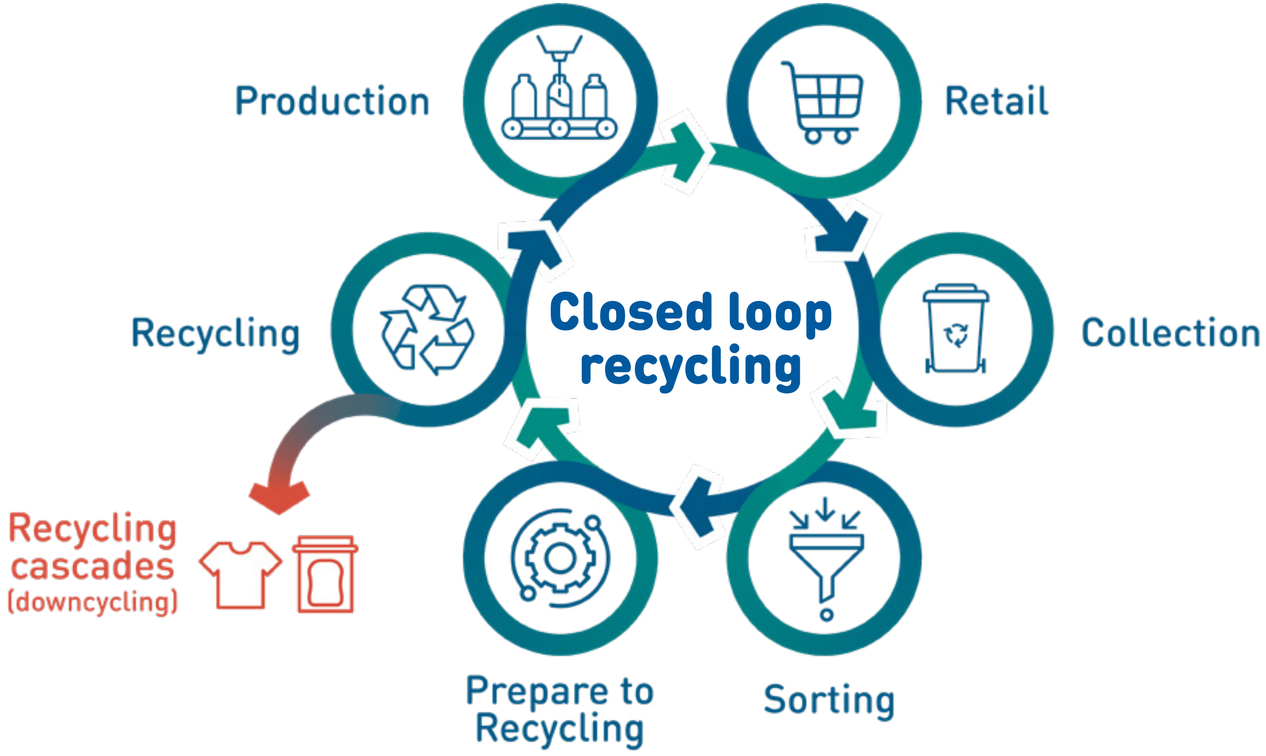
Recycling Rate: The weight of packages entering the recycling operation versus the weight of packages placed on the market. In this report unless otherwise stated this is assumed to be the equivalent of the new EU measurement method for recycling.

Recycled content: The weight of recycled PET versus the weight of virgin PET in packaging.

1.0 Introduction

A circular economy is one in which end-of-life products provide the materials for manufacturing new products. In this way, a circular economy maintains the value of products, materials and resources, while reducing the need for virgin resources and minimizing waste generation. When focusing on supply chain sustainability, closed loop recycling decreases emissions and preserves natural resources by reducing the use of virgin materials. In closed loop systems all the materials in manufactured goods can be recycled back into the same type of product, without significant quality losses. This prevents materials from being "downcycled" through recycling cascades into, for example, a lower grade product application, which then results materials being lost from higher quality applications. The materials flowing through recycling cascades are caught in a one-way stream, which means that even if a lower quality product can be recycled, then in the best case the recyclate from this product can stay within the same product group but cannot be used in a higher-grade application again.

Figure 1.1: Closed loop recycling



For example, there are cases of closed loop recycling with aluminium beverage cans. A closed loop aluminium recycling cycle is where beverage cans are collected, sorted, and then processed into aluminium ingots which are then sent to manufacturing into aluminium beverage cans. In the case of many other packaging applications, material might be recycled for the use in alternative applications with lower quality requirements. An example that we will explore further in this report is polyethylene terephthalate (PET) used in beverage bottles. If the recyclate from beverage bottles is not used in to make new beverage bottles, but instead used in other PET product applications such as trays, the material cascades into a lower grade application from which it cannot be recovered back into bottles due to its change in material properties.

In this report, we are investigating the circularity of PET, a polymer used extensively in single-use packaging, but also in other industries such as textiles. To answer the question "how circular is PET?", we will explore the material flows of the different product applications and what happens at the end of each product category's lifecycle, e.g., if material gets recycled and where the recyclate is used. We are measuring circularity by looking at the proportion of virgin PET (vPET) required to manufacture PET products, and the corollary which is the amount of PET that can be kept within the circular PET manufacturing model. On a fully circular PET model, and with no growth in production, there would be no requirement for vPET at all.

We note that this issue is commonly thought of by how many times a specific packaging item can be recycled but, in this report, we explain that this is a simplification of what is likely to happen in a circular model for PET and argue that this is not a useful way of explaining the potential for circularity.

Examining the extent to which PET has been used in circular manufacturing in recent years provides an evaluation of the **current** state of circularity. We also examine the potential circularity and its upper limits in a **future** scenario (estimated around 2030) to answer what degree of circularity could be achieved in the short-term. Importantly, this potential scenario involves mechanical recycling techniques. We also consider the **further potential** for circularity if currently hard to recycle PET streams such as trays and fibres were to be treated in a closed loop mechanical recycling process, and if chemical recycling techniques were also employed.

This report is predominately focused on PET as used in beverage bottles, but to gain a holistic view we also touch on PET use in other single use packaging and other applications such as textiles and fibres. We have found it useful to consider the circularity of PET through three manufacturing scopes:

PET Bottles

47% of overall EU PET demand

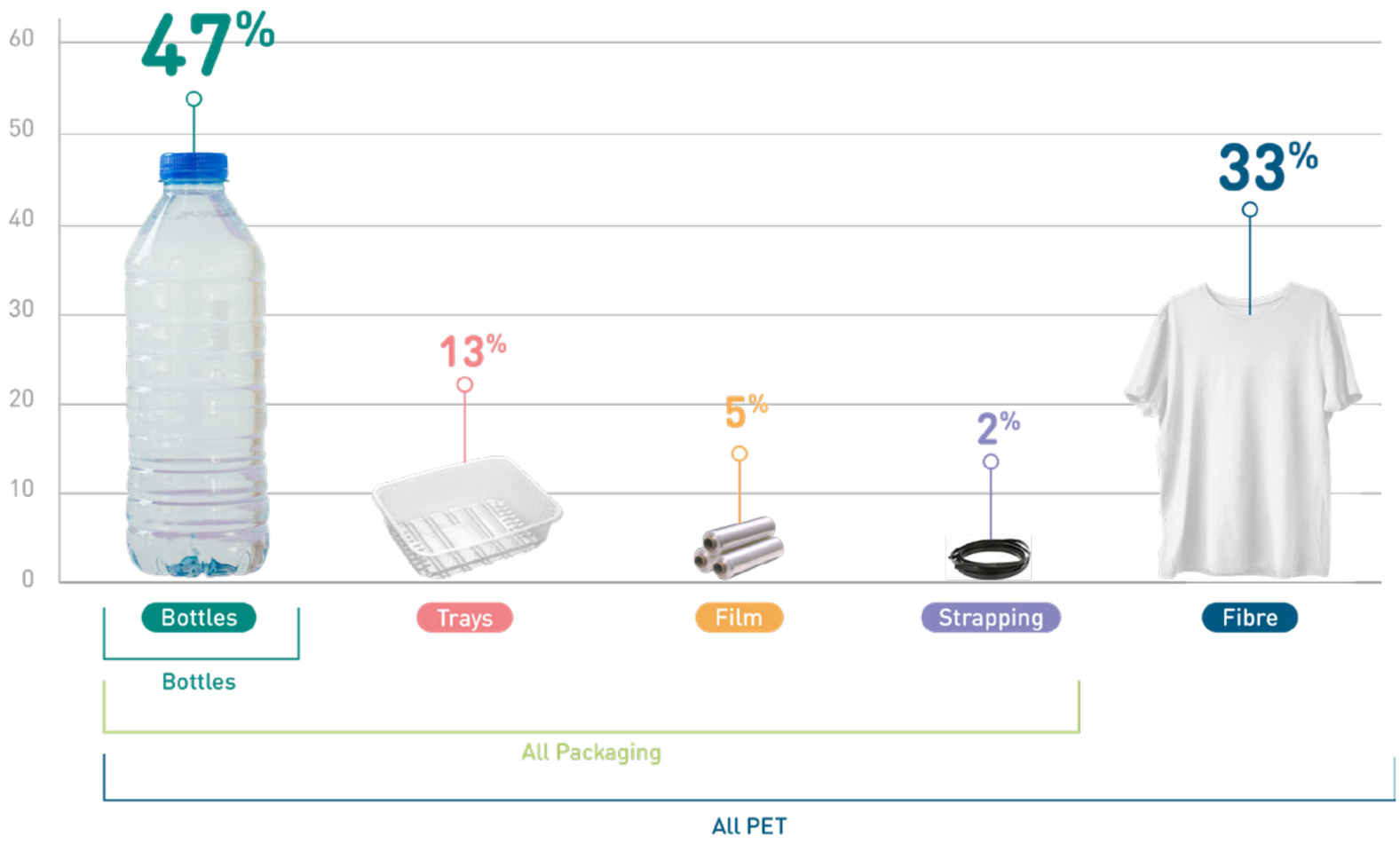
All PET Packaging

Including other PET packaging, such as trays, flexibles and strapping, adds **20%** to overall PET EU demand

All PET Packaging and Polyester textiles/fibre manufacturing

Adding **33%** to the overall European PET demand

Figure 1.2: Market shares of PET placed on market by manufacturing scope



Where relevant, we differentiate between food contact and non-food contact packaging and different colour applications. We have assumed that all food contact bottles are beverage bottles. Furthermore, it is important to note that our assessment does not consider other PET products on the market, such as photographic films and electrical insulation (estimated to account for only 2.6% of the market). This report uses data from Europe, but we would suggest that similar themes apply to the global circularity of PET.

2.0

Current state of the PET circularity

In this section, we explore the current circularity of PET. Our findings demonstrate that the majority of PET is not currently managed in a circular model and leakage from the system is high. The holistic model of PET circularity is much more complex than one singular circular PET product model. In fact, the different PET products have different manufacturing requirements of recycled PET (rPET) feedstock. There are several potential limitations which influence the current circularity of PET. These are broadly categorised in Table 2.1.

Limitation	Current Situation
Collections	**Bottles:** capture from (deposit return systems) DRS is generally higher than from separate collections; in Europe the Collection Rate[1] for beverage bottles is only 60%[2] with the majority (74%) being collected through separate collections. **Trays/Flexibles:** schemes vary across Europe; where schemes exist the capture rates into recycling collections are lower than for bottles. **Others:** Strapping is generally not targeted in collections; where collections for textiles exist, captures are typically low. 
Availability of recyclers	**Bottles:** well developed infrastructure and mechanical technologies; **Trays/Flexibles:** early stages of development. **Textiles:** early stages of development. 
Contaminants from collections	Collections of bottles and other PET applications in separate collections introduce contaminants such as organics, metals, glass and non-PET polymers; DRS will likely provide cleaner stream than separate collections at a lower cost; while sorting technologies have advanced, contaminants can cause issues to the quality of rPET.
Product design and material quality	• EFSA standards for the production of rPET suitable for food contact applications such as beverage bottles and food trays mean feedstock may not exceed 5% of used PET from non-food contact applications[3]. • Bottle production (blow moulding) requires a higher intrinsic viscosity (i.e., longer polymer chains) of PET than the production of other PET applications such as trays; rPET from trays or other applications therefore will unlikely, at reasonable cost, ever be mechanically recycled into bottles. • Problematic materials such as additives, certain labels and inks limit recyclability; voluntary design guides are informing the market; many brands have made changes eliminating problematic materials, but further improvements need to be made. • Coloured/opaque and multi-material packaging continues to be an issue; polyester fibres are often blended with other materials and additives[4].
rPET economics	Supply and demand as well as processing technologies and steps influence the price which thereby influences usage for end markets.

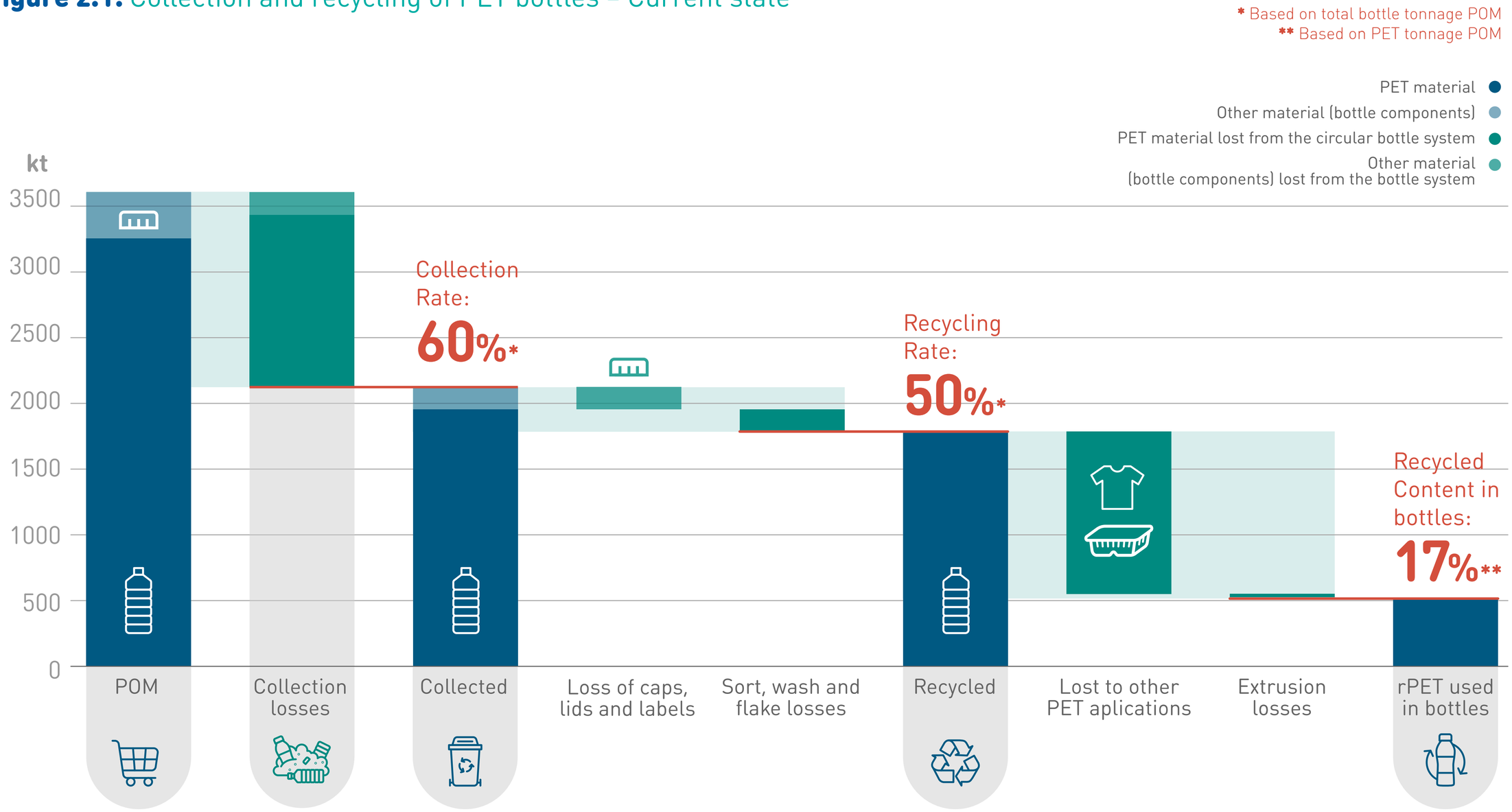
Due to the uncertainty of data and arguably small quantities recycled from non-bottle PET applications, as noted under "availability of recyclers" in Table 2.1, we have not considered their recycling loops within our calculations for the current state of PET circularity.

2.1 Current circularity within the PET bottle stream

Of the entire PET family, bottle recycling has the most developed technology and infrastructure. In Europe, the average Collection Rate[5] of PET bottles is estimated at 96%[6] for countries operating DRS and 48% in countries without DRS[7]. This provides an overall Collection Rate for beverage and non-beverage PET bottles of 60%, as can be seen in Figure 2.1. Low Collection Rates mean that a large proportion of PET bottles POM (40%) are lost for recycling (i.e., leakage) and end up in landfills, incineration or lost to the environment; this constitutes a linear model of production, use and disposal, as opposed to a circular one.

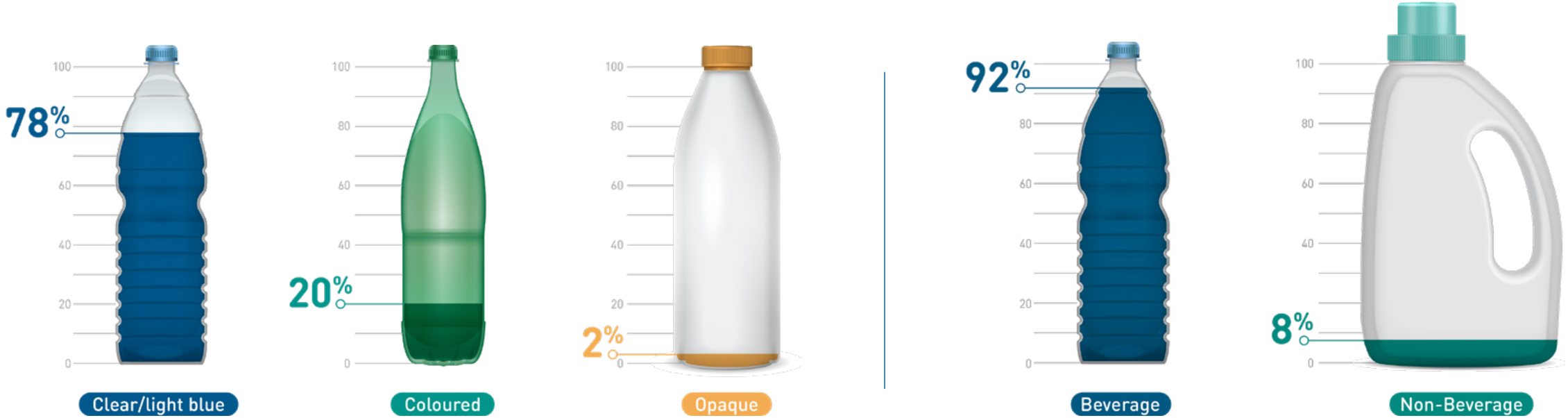
Further losses from the removal of caps, lids, and labels as well as pure PET material occur at the recycling stage (wash and flake) as well as the extrusion of rPET flakes to pellets, a step needed to produce new bottles from rPET flakes. Reaching an accurate estimate of the current Recycling Rate is difficult as there are several reporting issues. In many cases the Collection Rate has been seen as the equivalent to the reported Recycling Rate and hence is often overstated. To eliminate unclear reporting, the European Commission issued and implementing decision on the calculation method to be used to identifying the Recycling Rate, which also accounts for losses during the sorting, washing and flaking processes. With minor amendments to work conducted by Plastic Recyclers Europe (PRE), we estimate that PET bottles (beverage and non-beverage combined) have a Recycling Rate of around 50%, calculated using the weight of PET material at the stage after wash and flake vs the weight of PET bottles (including caps, lids and labels) placed on the market, in accordance with the guidelines issued by the European Commission in April 2019[8]. This equates to approximately 1.8mt. If you consider the Recycling Rate of the total packaging unit, it would be slightly higher as some of the polyolefin material from lids is likely to also be recycled.

Figure 2.1: Collection and recycling of PET bottles – Current state



rPET used in bottle manufacturing needs to be derived from bottles because it is currently economically unviable to produce rPET made from other applications that can meet the bottle quality criteria, such as high intrinsic viscosity, clear flakes and food grade requirements in line with the EFSA guidance. Although an estimated 50% of PET bottles POM are recycled into rPET, on average PET bottles contain only 17% rPET content, equating to 545 kt of rPET flakes, or approximately 540 kt of rPET pellets post extrusion losses[9]. This equates to 31% of the total bottle derived rPET flakes generated each year. As we will explore in the following sections, the remainder of the rPET from bottles is used in other applications and is therefore considered a loss from the circular bottle stream.

Figure 2.2: Estimated market shares of bottle types and colours



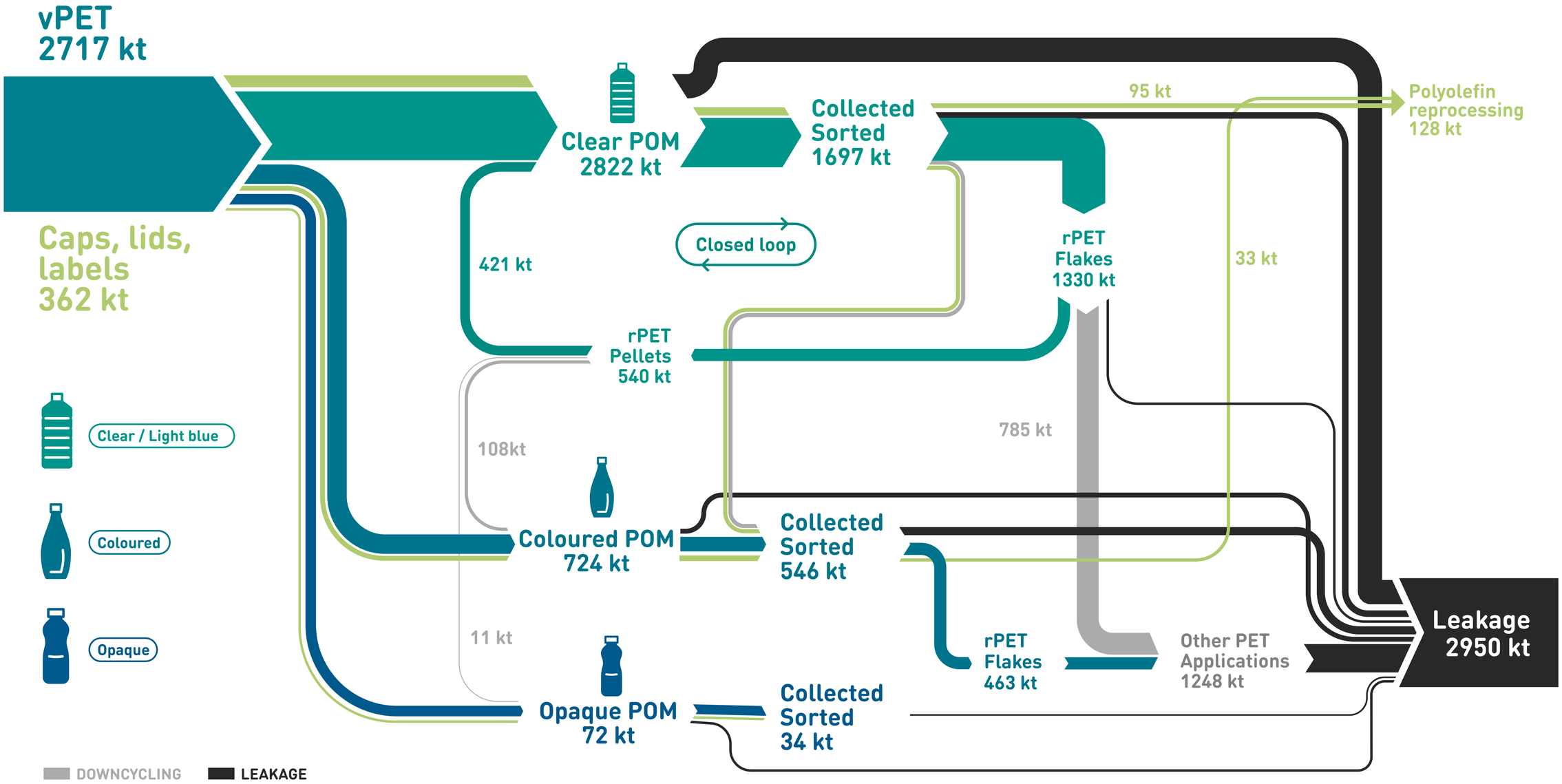
Most bottles (92%) are used in beverage applications (see Figure 2.2), and the remainder in non- beverage applications[10]. Manufactures of these bottles require rPET derived from beverage bottles that meets food safety standards. While DRS collections provide a pure beverage bottle stream, other forms of collections do not, thus potentially limiting the availability of food grade rPET feedstock.

We estimate 78% of bottles to be clear or tinted light blue PET, while the remaining 22% are variously coloured and opaque. The higher the amount of colouring, the fewer (and darker coloured) the applications for which the rPET can be used. Therefore, as colouring increases, more material is lost to successively darker coloured applications, in what we refer to as the 'colour cascade', presented in in Figure 2.3. The Sankey diagram provides mass flows and shows a lack of circularity with most material either being lost as leakage to waste or downcycled to other PET streams, which means once it is downcycled or cascaded, it does not return into its original higher quality stream system. PET from coloured bottles when downcycled into other PET applications such as trays and fibres will come to its end of life after a single additional cycle.

There is some circularity as a small quantity of rPET from clear/light blue bottles goes back into clear/light blue bottles. There are also colour cascades from one colour stream to another, e.g., from clear/light blue into transparent coloured bottles. There are two key stages where this happens: cascades during sorting, and when rPET flake enters an end market. Cascades during sorting occur as different bottle streams that are collected together require subsequent sorting into their respective colour's streams. Every time mechanical sorting occurs, material is lost from one form to another (usually down the colour and quality cascade). When entering an end market, flake from one bottle stream can also cascade to other streams (e.g., clear to coloured).

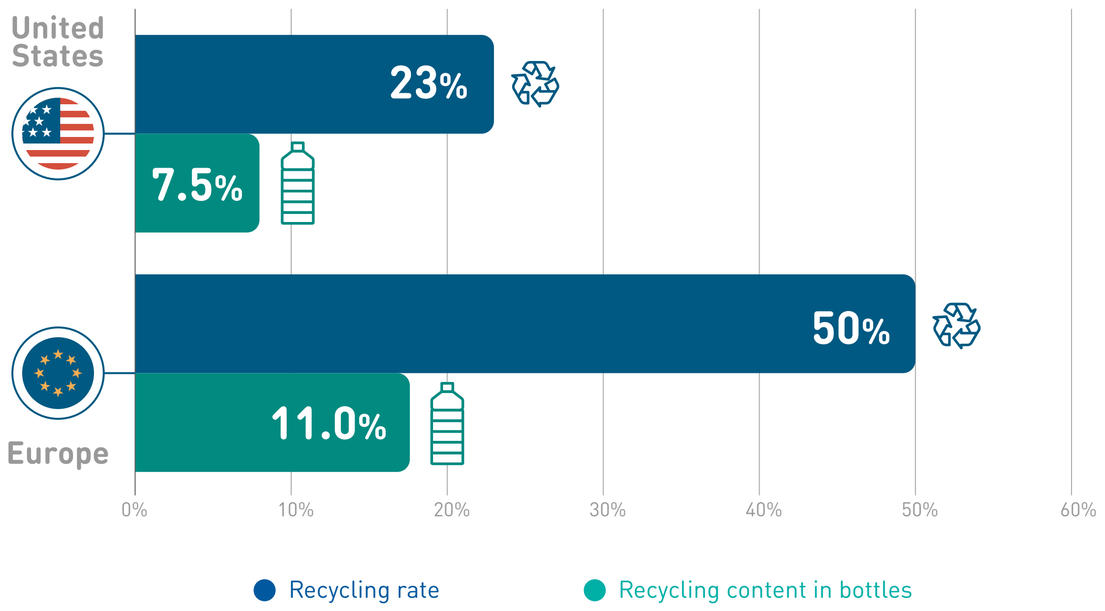
Each colour stream is assumed to prefer clear flakes over coloured. Firstly, the use of rPET from their own colour stream (e.g., green flake into green bottles) could provide difficulties relating to colour consistency – there may be variations in tint and saturation of the flakes (depending on input mix of bottles from various brands). Additionally, coloured bottles often do not get separated into individual colour streams and therefore produce flakes with mixtures of colours that can only be used in darker coloured PET applications such as coloured trays, strapping, or fibre (when bleached, which is further explained in section 2.3). While opaque bottles are collected in some separate collection schemes, they pose a risk of contaminating the clear bottle streams due to sorting facilities not being able to adequately distinguish clear from opaque bottles[11]. For this reason, opaque bottles need to be sorted out of the recycling stream and diverted to landfill or incineration, ending the use of PET in opaque bottles after a single cycle.

Figure 2.3: Circularity in PET bottles – current state



In the United States (US), the Recycling Rate for PET bottles is far lower than in Europe and only reaches just under 23%, when all losses are taken in to account. Only 28% of the US population are covered by the so-called bottle bills, the US equivalent of DRS. The current average of recycled content used in bottles in the US is unclear but was believed to be less than 7.5% in 2013[12]. In 2020 major brands are said to be using an average of 6.2% recycled content in all their packaging combined[13]. More recently NAPCOR released a report on PET recycling, claiming an increase of rPET used in bottles by 41% between 2017 and 2019[14]. It is therefore plausible that the current figure for recycled content lies around the 7.5% mark. These figures show that PET bottle circularity in the US is lagging behind the European market.

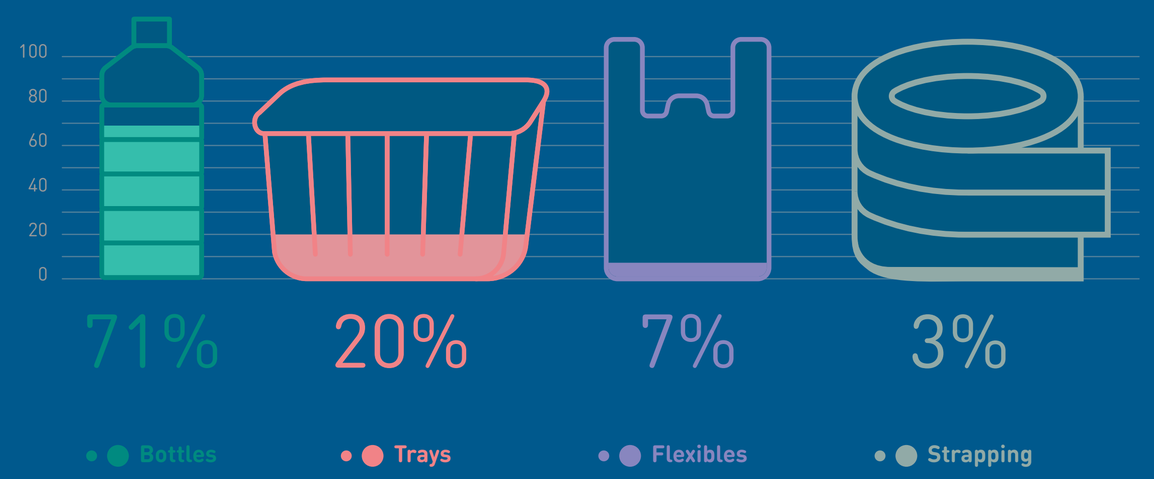
Figure 2.4: PET bottle comparison US vs Europe



2.2 Current circularity within the PET packaging stream

While bottles make up the largest share of PET packaging, most PET usage in other PET packaging applications is in single-use tray manufacturing (20%), flexibles (7%), and a relatively small amount of strapping (3%). These figures are for Europe, but they likely also reflect the manufacturing landscape in other parts of the world.

Figure 2.5: Estimated market shares of PET packaging



There are no standardised collection and sorting of trays or other PET packaging applications in Europe. In some cases, trays and flexibles are collected mixed with other plastics in separate recycling collections, while in other cases they are not collected at all. From separate collections, in some collection systems PET trays are sorted into bottle bales. rPET produced from the tray proportion of these bales is not desirable for bottle manufacturing due to the lower intrinsic viscosity and the presence of various other polymers from multi-material trays. It is likely that a high proportion of the PET reprocessed from trays in this manner is lost due to fragmentation of the PET trays in bottle orientated processing lines. Collection quantities for these PET packaging applications are therefore much lower than they are for bottles. As a product category, 'trays and other flexibles' has a Collection Rate of approximately 21% across the European countries[15]. We are not aware of any collections for strapping and assume that it is lost to residual waste.

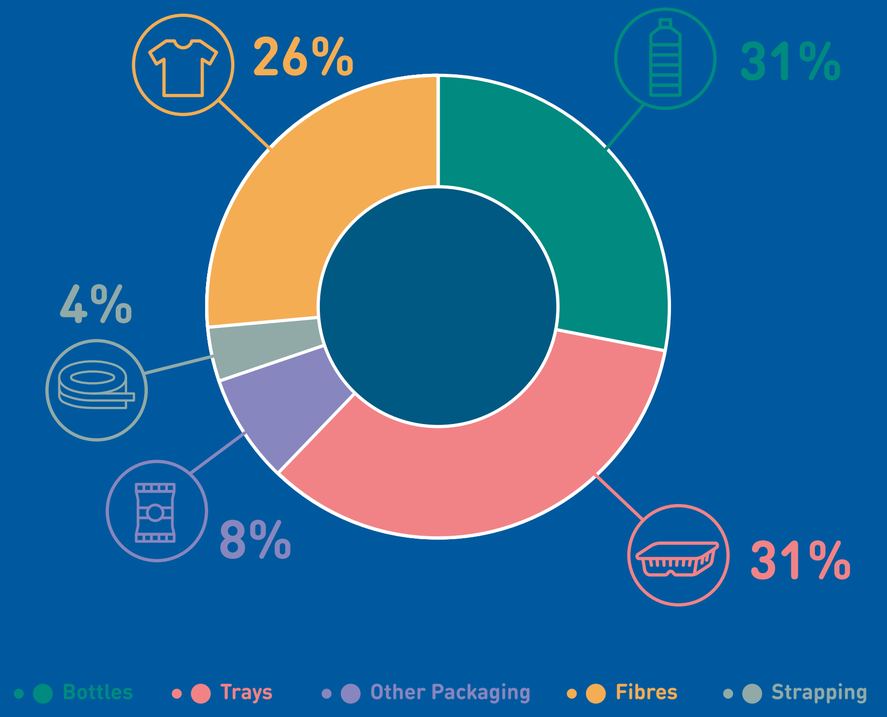
The lack of appropriate sorting and recycling technologies as well as the design of trays and film makes them currently difficult to recycle. Trays and flexibles can be made of multiple materials, e.g., laminated (i.e., PET/PE) and gas-barrier (i.e., PET/PE/EVOH). While these could be delaminated, they first need to be separated from mono-material PET trays, which is currently not a market-wide practice. Like bottles, glues and inks also cause an issue in the recycling. As with bottles, design guidelines have been developed for PET trays to ensure they are designed for recyclability[16]. However, the effectiveness of these standards in increasingly tray circularity will depend on the extent to which manufacturer's embrace designing for recyclability.

Although some tray recycling does happen on a small scale (mainly from industrial/commercial applications and where the feedstock composition is known or in pilot projects), the amount is negligible in the scale of our model. Due to variability of products and contaminations resulting from separate or residual collections, chemical depolymerisation is being explored as a means for the recovery of PET from flexibles (see section 4.3 for further details). We are unaware of any targeted collections for strapping and assume this packaging category is lost in residual waste.

In section 2.1 we estimated 1.8mt of rPET from bottles being generated each year. As no other packaging application yields additional recyclate, any rPET used in packaging applications currently comes from bottles. This means that when considering all PET packaging in Europe the overall Recycling Rate for PET packaging drops to 35%.

Of the total rPET generated from bottle recycling, trays use a similar amount of rPET flakes to bottle manufacturing (31%). In total, PET Packaging uses 57% of rPET derived from bottles. While this means that the rPET generated by bottles finds use in new packaging products, the lack of large-scale recycling for anything other than bottles means that it is eventually lost as leakage from circularity of PET packaging.

Figure 2.6: End markets of bottle derived rPET



E.2.3 Current circularity within general PET stream

Besides bottles and other packaging, one of the largest non-packaging applications (and therefore the only one considered within our estimations) is the production of polyester fibre. In this section we will consider the circularity of PET within the general PET stream (i.e., bottles, trays, film, strapping and fibre). An estimated 7.7mt of PET products are placed on the market (POM) within the general PET stream in Europe annually, with a vPET demand of just under 5.5mt.[17][18] The vast majority of PET POM is used in bottles, which we discussed in section 2.1.

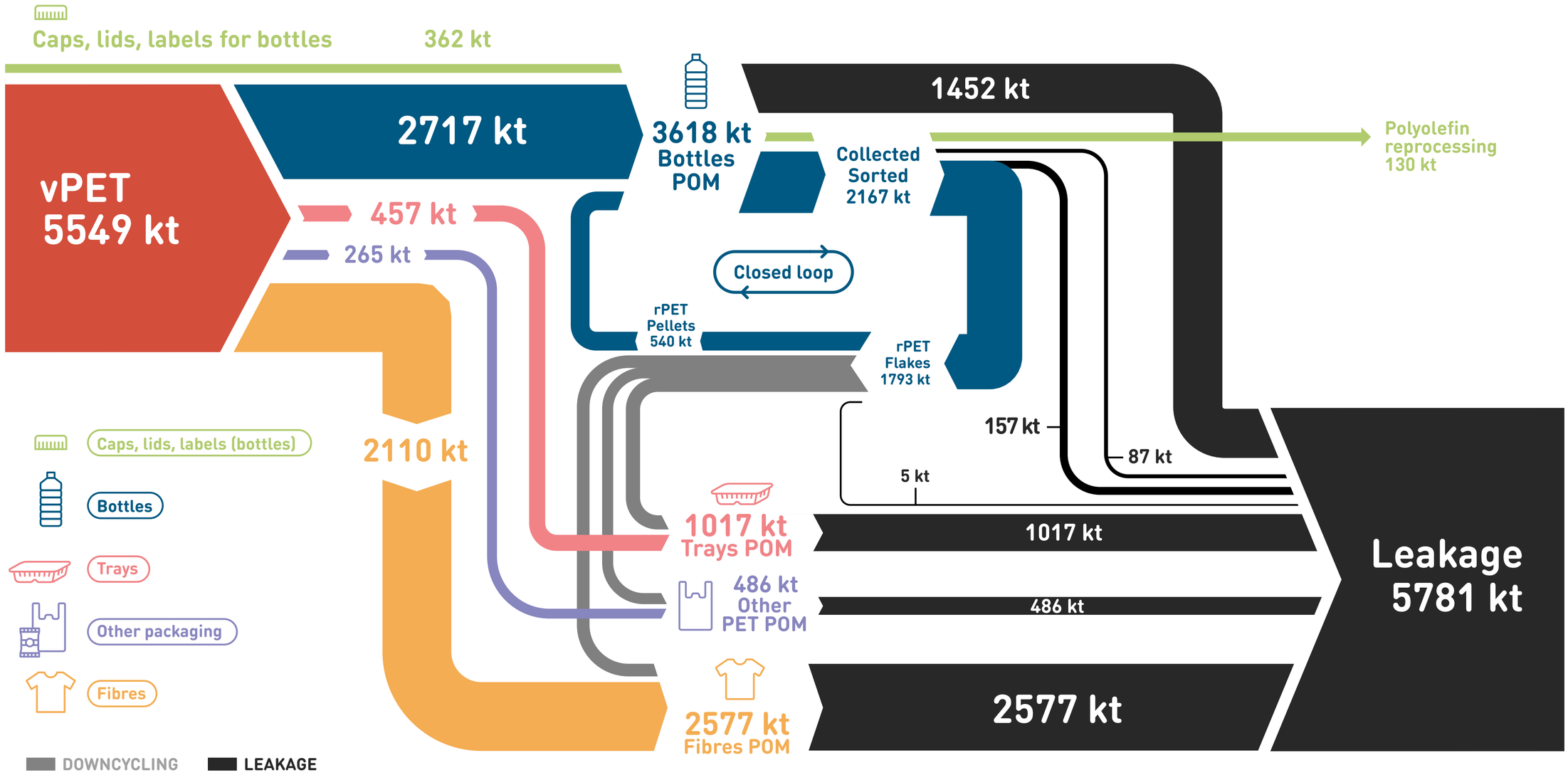
While there is considerable uncertainty concerning the quantity of polyester POM, we estimate that fibre accounts for approximately 2.6mt (26% of PET demand in the EU). Approximately 14% of the global polyester market is recycled polyester, the majority of which is produced from PET bottles.[19] While fibre can be made from coloured PET bottles, it can be discoloured, making it less desirable to textile manufacturers. Coloured fibres could be bleached, but this requires the use of bleaching agents and high levels of re-dyeing caused by colour inconsistency. Therefore, clear/light blue bottle material is typically more desirable, as this produces fibre with reduced discolouration.[20][21] This can conflict with the needs of bottle manufactures, who also require clear/light blue rPET pellets. Once PET is used in polyester production, it is ultimately lost as leakage from the PET system due to limitations within collection, sorting and recycling technologies and infrastructure for textiles.

It is both technically and economically more challenging to deliver manufacturing quality requirements from rPET than vPET. For example, in circular bottle-to-bottle recycling, to make a clear PET beverage bottle the rPET would need to be derived from feedstock with little or no colour additives. However, rPET for the manufacture of hot food trays can be derived from a wider range of coloured bottles. This introduces an important concept: the flow – or 'cascade' – of rPET from one product stream to another, usually from higher quality to lower. Once cascaded, it is unlikely to return up the cascade and, in some cases, rPET may exit the circular recycling system through the cascade.

All product categories rely on bottle rPET as this is the only product stream currently recycled on a large scale. Clear/light blue rPET is the most desirable for clear and coloured bottles, clear trays and flexibles, and fibres. For coloured bottles, this is because rPET flakes derived from coloured bottles are unlikely to exactly match the required colour input for newly produced bottles. For example, a bottler using a blue bottle for their specific beverage requires a precise blue tint to ensure all bottles POM are consistent in colour. The colour of a batch of rPET flakes depends on the input material for each batch and these can vary in tone. Therefore, dying clear rPET flakes is considered less complex than adjusting the colour variants each time. For fibres, coloured rPET could be bleached, but this is also a less desirable route than using uncoloured rPET. Coloured and CPET trays and strapping tend to use coloured rPET as this is typically cheaper.

Figure 2.7 provides a visual representation of these PET cascades, which shows that only bottles are recycled and hence recycled content for all product streams is sourced from bottles. Of the 1.8mt flake output from bottles, only 31% are made into pellets for bottles, with the rest (69%) cascading into other products, such as trays, other packaging or fibres, as we have already seen in section 2.2. The lack of recycling in some product streams provides further leakage from the total PET system. We see a high leakage from all stages of the PET lifecycle, resulting in 5.8mt (75% of the total PET POM) leaking from the total PET system.

Figure 2.7: PET Mass Flows - current state



Applying the new recycling rate calculation method issued by the European Commission in April 2019[22], measures the production of recycled plastics versus the amount placed on the market, a Recycling Rate of only ca. 23% for all PET POM would be achieved. Figure 2.8 shows the Recycling Rates across the three manufacturing scopes indicating a reduction in circularity the wider the scope.

Figure 2.9 also shows the lack of circularity of PET by looking at the recycled content of each manufacturing scope. Bottle producers use an estimated 17% average recycled content in their production.[23] The overall use of rPET in packaging is higher at 28%, due to the use of bottle derived rPET in trays and other packaging applications. This drops to 24% if the use of rPET in all PET is measured.

Figure 2.8:
Current recycling rates by manufacturing scope

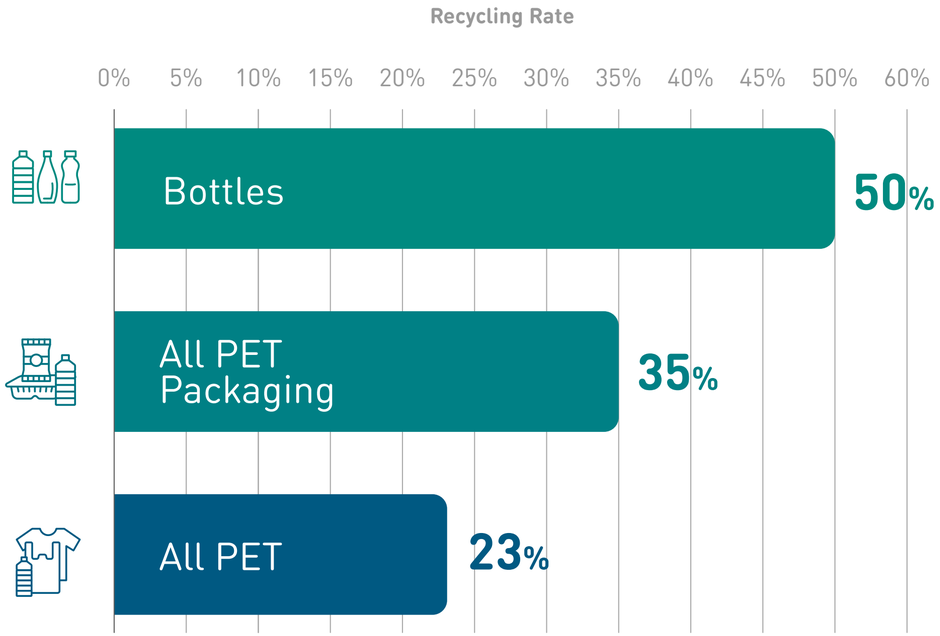
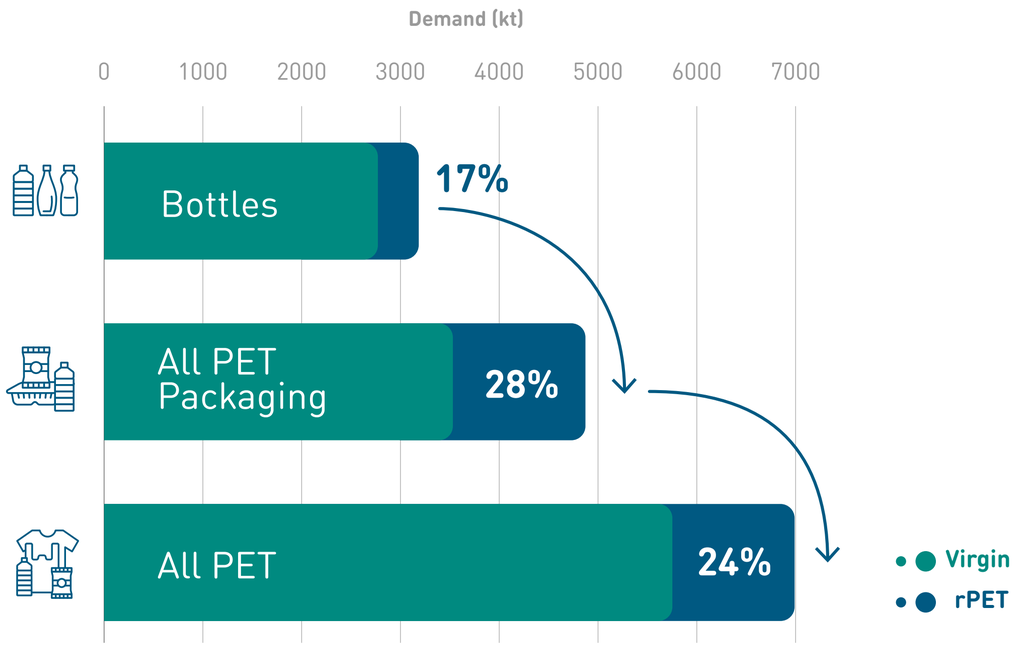


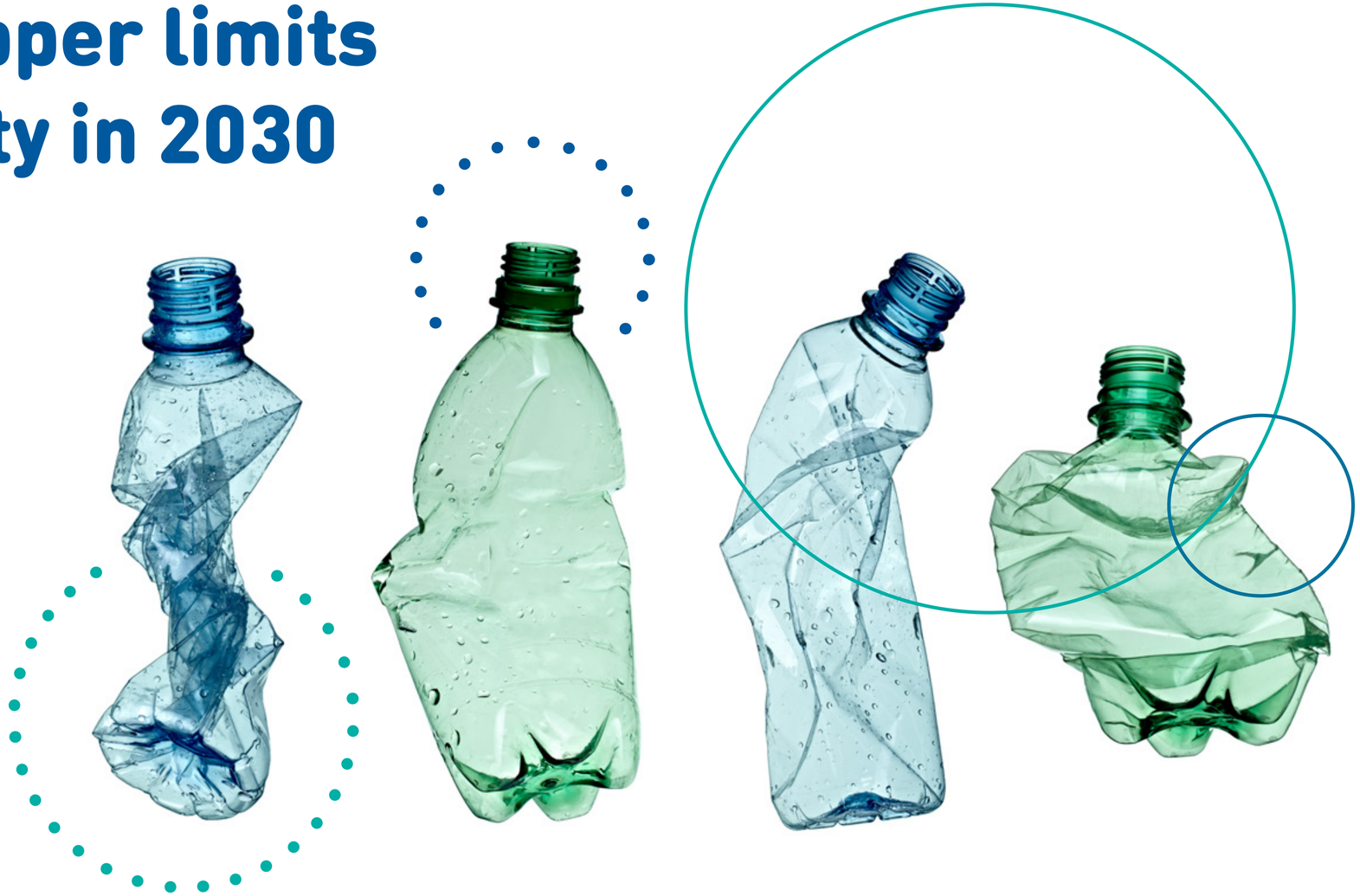
Figure 2.9:
Current PET recycled content by manufacturing scope



3.0

Potential and upper limits to PET circularity in 2030

In this section we provide a forward look to a possible scenario around 2030. The conditions and assumptions we have applied include implementation of well performing DRS across Europe and to some extent brand commitments, which are generally aligned with policy except for a few instances in which brands aim to exceed policy requirements. We also review what impact a move away from coloured and opaque PET bottles to clear bottles may have on the circularity of PET. These assumptions depict the best-case scenario, and the economic impact of competing end markets for rPET has not been assessed.



3.1 Impacts for future of PET circularity

3.1 Impacts for future of PET circularity

3.1.1 Key policy impacts

Several recent and forthcoming policy changes at the EU level impact the future outlook for PET circularity. The key policy changes are:

- Directive (EU) 2019/904 (known as the Single-Use Plastics (SUP) Directive), introduced in 2019, set a collection target for beverage bottles of 77% by 2025, rising to 90% by 2029;
- The SUP Directive also sets targets for average recycled content within PET beverage bottles of 25% by 2025 and 30% by 2030; and
- Plastic taxes on non-recycled/virgin plastics.

Changes in legislation can be seen in other parts of the world as well. In California, mandate AB793 sets out recycled content targets of all beverage containers placed on the Californian market of at least 25% by 2025, and 50% by 2030.[24]

EU Member States will likely only be able to achieve the SUP Directive's 90% collection target for plastic beverage bottles through a DRS, as only this collection method has ever proven successful in approaching such a high rate. Therefore, we can expect to see DRS become much more common across the EU and other parts of the world. This will have the additional benefit of reducing contamination in the collected material, resulting in improved rPET quality, and therefore resulting in a higher sorting efficiency rate.

In addition to the known changes in legislation, the EU are discussing additional changes to the definition of recyclability.[25] The result could see that non-recyclable packaging may no longer be placed on the market. There are many uncertainties in terms of what this might mean for the future of PET packaging which is currently considered as unrecyclable or difficult to recycle such as strapping, film and trays. Our approach has been set out in section 3.2.

In its 2018 'Strategy for Plastics in a Circular Economy', the European Commission, aimed to quadruple the sorting and recycling capacity for plastics between 2015 and 2030, and to this end inviting voluntary commitments and pledges from industry groups across the supply chain.

3.1.2 Brand commitments on increasing PCR content

In Table 3.1 we have listed the brand commitments on post-consumer resin (PCR) content of four of the largest and globally active brands. We can see that they are mainly aligned with the targets set out in European legislation but executed on a global level. More and more beverage brands are committing to higher PCR content and recyclability in their bottles, with some even investing in their own collection and recycling infrastructure. As noted above, meeting bottle collection targets will likely require implementing DRS, something that in turn requires brand support. Therefore, for ambitious brands, DRS is high on the agenda.

Earlier in 2020, research into plant-based plastics for bottles has seen backing from brands such as Danone and Coca-Cola.[26] More recently, however, Coca-Cola has made a significant shift in its sustainability strategy, seeking to switch to 100% rPET bottles for some product ranges in the US instead, explaining that plant-based plastics are still considered virgin.[27] In our calculations we have not accounted for any planned switches to plant-based plastics in the future, assuming all currently PET POM remains to be made of fossil-fuel-based PET. Hence, the change from major brands back to fossil-fuel-based bottles with PCR has not made any impact to the results.

Table 3.1: Recycled content commitments of top global beverage brands

Brand	2025	2030
The Coca-Cola Company	25% PCR content – global plastic packaging	50% PCR content – global plastic packaging
PepsiCo	25% PCR content – global plastic packaging	50% rPET content – PET bottles in the EU
Danone	50% rPET content – global PET bottles — 100% rPET content – PET water bottles in Europe	
Nestlé	30% PCR content – global plastic packaging — 50% rPET content – global PET water bottles	

Figure 3.0: Recycled content commitments of top global brands beverage

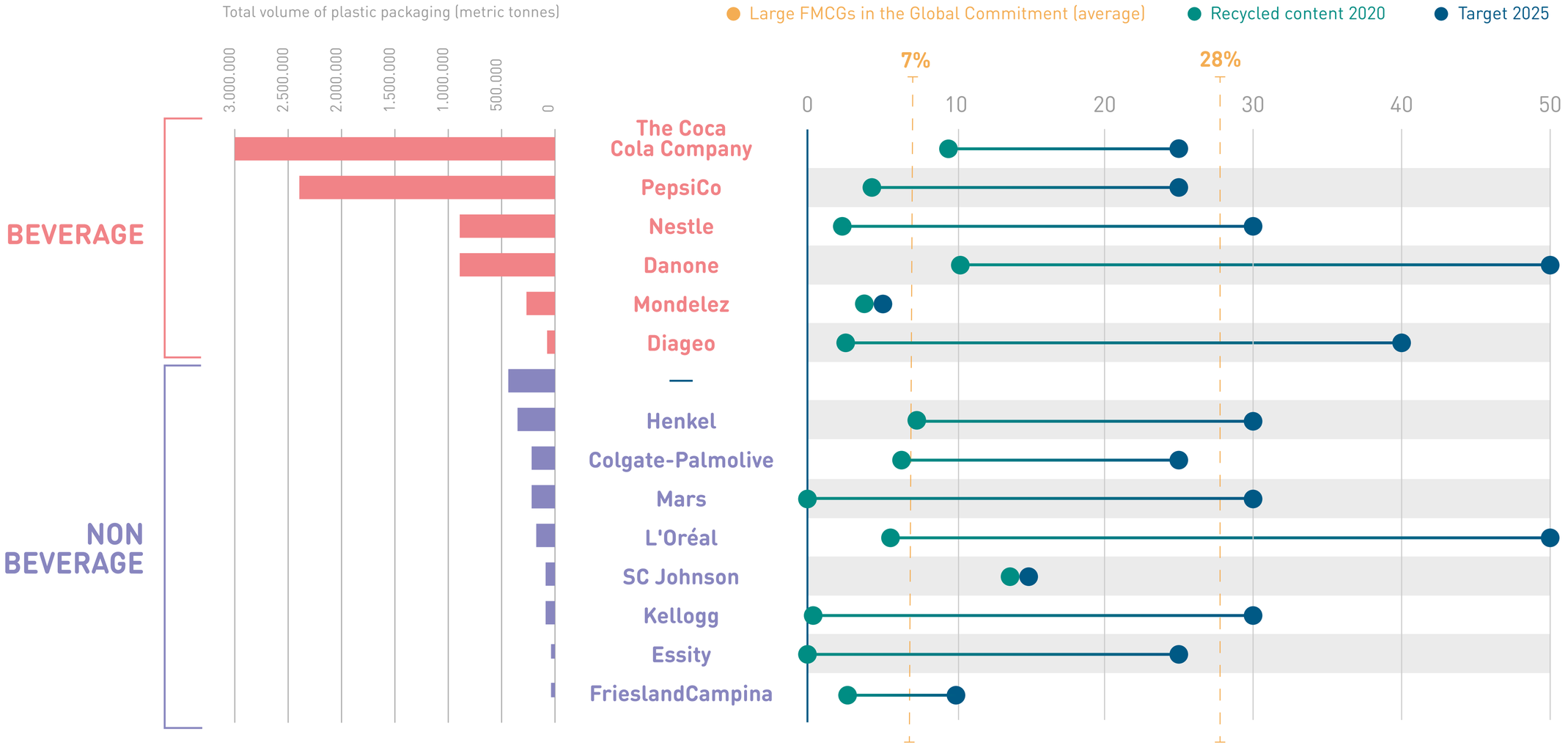
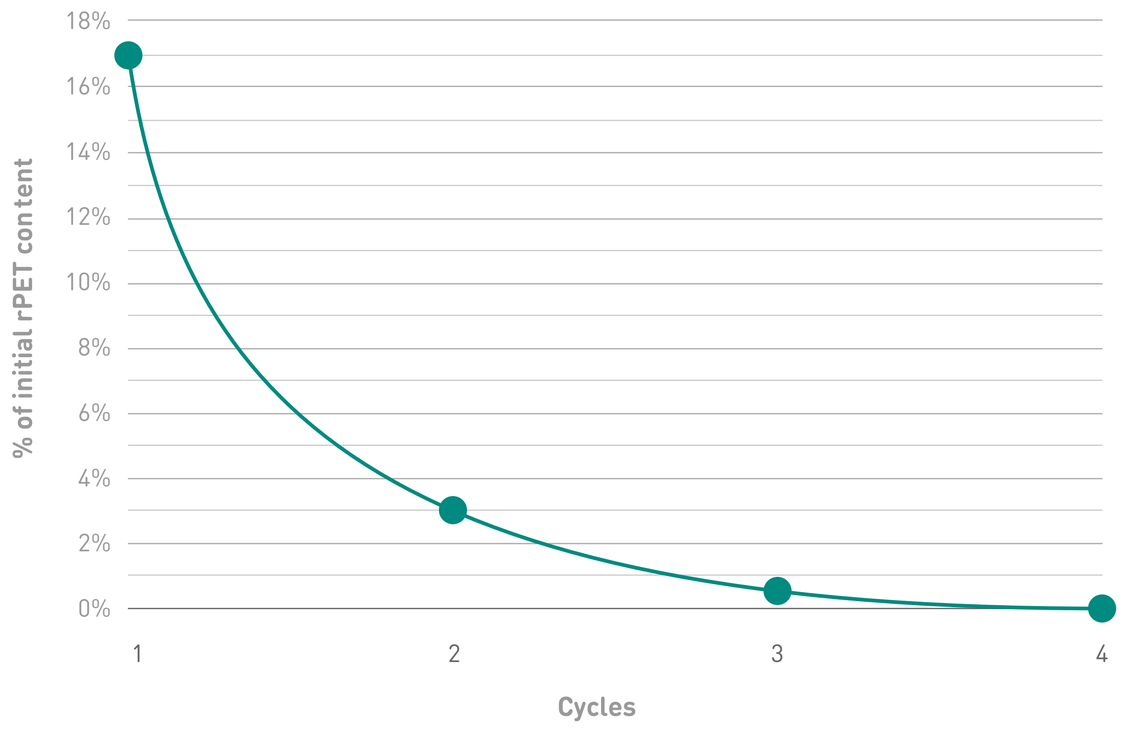


Figure 3.1: Longevity of 11% recycled content within PET bottles



3.1.3 Current high PCR case studies

In our research we have found several examples indicating that a high rPET content in bottles is achievable.

Some companies are already achieving levels as high as 100% rPET. These companies include large brand such as Nestlé,[28] which has introduced 100% rPET for several of its water brands (including Vittel, Valvert, Poland Spring Origin and Buxton), and Danone,[29] which has introduced a 100% rPET 8-litre Volvic bottles in several key markets. However, we have not seen evidence that these bottles are managed in a closed loop. Rather, these 100% rPET bottles are likely made with rPET that was produced from high virgin content bottles. Furthermore, the 100% rPET bottles will likely not be recycled back into a 100% rPET bottle but will instead be processed along with a mixture of other, lower recycled content bottles, meaning the overall rPET content in the batch will be much lower.

Overall, the lack of a closed loop system within the total European PET bottle market means that bottles POM contain on average 17% rPET. This means, only 17% will be carried over from the previous loop, equating to only 2.9% PCR material between first and second cycles, as demonstrated in Figure 3.1. As such, PCR content within the system is swiftly reduced, with any potential impacts on material quality likely being diluted in each loop. Figure 3.1 shows that the original rPET content within a PCR bottle nearly disappears after the third cycle.

100% Recycled Content Bottles

There is a recent trend of major beverage brand owners requiring their suppliers to manufacture pre-form bottles from a 100% recycled PET (rPET) to align with brand-specific commitments for '100% recycled plastic' bottles. On a superficial examination, these examples may seem to be positive developments for PET bottle circularity and, there seems little doubt, are considered positive from a brand marketing perspective. However, they do not reflect the reality of the brand owners' full portfolio of products, and criticism is increasingly being levelled at this practice by NGOs, for example on the basis that it masks the underlying overall low levels of circularity in PET bottles.

We have demonstrated in this report that average recycled content across the PET bottle production in the EU is currently a long way below 100%. We have also shown that reaching an average of 75% recycled content will be challenging and will require:

- At least a 90% Collection Rate;
- Changes to colour forms of bottles; and
- Significantly increased capacities for food content rPET production.

The examples of 100% rPET bottles almost certainly utilise rPET that has been cycled very few times and that in previous loops comprised a high proportion of virgin material. Our analysis suggests that the approach of continuously looping 75% of PET in bottles in a circular production model is likely to be far more challenging than manufacturing the 100% rPET bottle examples of today. Furthermore, if circularity does substantially increase in the future to the levels of 75% average recycled content, then making 100% recycled content bottles doesn't make sense because there will be insufficient rPET to make all bottles 100%, and therefore it is simply likely to be offset by reduced recycled content in other bottles. Achieving 100% recycled content is also likely to be far more technically challenging than it is today via mechanical recycling methods.

Our analysis suggests that brand owners wanting to contribute to the circularity of PET bottles may achieve more by focusing on investing in the necessary components of a circular model rather than showcasing 100% rPET bottles.

Case study – Petcycle

Petcycle is a German DRS, owning ~8% of the national DRS market (including plastic, glass bottles and cans) and claims a Collection Rate of 99%.[30] Petcycle sets the following bottle manufacturing standards that must be met by its members:

- Min. 75% rPET content from 2021 (55% for the previous eight years; the average rPET content in Q2 2020 was nearly 65%, with some bottlers exceeding the rPET content requirements).
- Water-soluble inks and glues for labels and, as non-water-soluble glues and inks can cause contamination.

Petcycle is mainly a closed loop system, however, not all members recycle their bottles back into their own bottles, or even into Petcycle bottles.[31] There are two types of service agreement recyclers can have with Petcycle bottlers:

- Bottle bales are sold and ownership of recyclate lies with recycler. The recyclate may be mixed with recyclate from other bottles, before being sold to whichever customer requires recyclate at the time (possibly outside the Petcycle scheme).
- Ownership of the bottles and recyclate stays with the bottler.

On the second agreement type, in some cases different Petcycle bottlers pool together, meaning that bottles with varying rPET content (>55% to prior to 2021) are recycled into a single batch of recyclate and used to produce bottles with minimum 55% recycled content (prior to 2021). Meanwhile, in very rare cases the bottles stay in a complete closed loop with one bottler only. The latter is very complex to manage, as individual batches of bottles need to be fully separated from one another in processing.

Changes in seasonal demand (e.g., higher drinks consumption in summer months) mean that recyclate might be stored before being sold; whether this impacts how bottles are managed in a closed loop is unknown.

An important consideration for this system is a successful recycling operation with a minimum 55% rPET requirement, demonstrating higher levels of PCR content can be recycled multiple times in a closed loop without quality impacts. However, while Petcycle's new target for rPET content is 75%, there has been a lack of clarity with regards to the impacts of these increased levels of rPET content.

Case study – Testing 75% PCR content

Pinter et al., tested the repeated recyclability of rPET under controlled conditions.[32] Sorted and washed post-consumer PET bottles collected through Swedish DRS was passed through 11 recycling loops, each cycle utilising material composed of 75% of the material from the previous cycle and 25% virgin material. The material was hot washed using industrial PET processing water to attempt to factor for the introduction of contaminants such as fibre, PET dust and sodium hydroxide that occur within PET recycling. Further processing impacts such as extrusion and filtration were also accounted for to simulate realistic industry conditions. Small quantities of acetaldehyde blocker were added after each loop. The extrusion and decontamination methods were equivalent to that used by bottle-to-bottle recyclers today. The experimental design assumed that, if not adapted, the recycled PET would turn yellow due to the presence of contaminants in the heat cycle. Most recyclers add a small amount of blue colourant during the process of recycling PET bottles to factor for the yellowing. Whilst this does effectively mask yellowing, it produces more of a grey colour than would be typical for a high virgin PET content "clear" bottle. The experiment followed this common practice and added small amounts of blue colourant at each cycle to combat the anticipated yellowing. rPET pellet was removed at some of the cycles (not all) and was subsequently blow moulded into bottles, as presented in Figure 3.2. It is noted that this approach means that the material was not subjected to the number of heat cycles that would be incurred in practice, though when the results were examined, it was reasonable to conclude that this does not majorly impact the results.

The experiment provided an empirical approach to evaluating mechanical, optical and chemical quality change, to test the extent to which PET can be kept within a circular economy. The results of this experiment concluded that there was no evidence of quality degradation to the material over the recycling loops that any potential quality issues could not be managed through the solid state polycondensation (SSP) extrusion process and the addition of additives.

As such, it is plausible that 75% average rPET content could be facilitated within closed loop recycling over 11 loops without impacts to quality. This is, however, likely only achievable by meeting a number of criteria, such as:

- DRS collections, which can help reduce contamination and overcome quality issues;
- Meeting product design guidelines such as water-soluble inks and glues and ideally a move to clear bottles from coloured or opaque bottles;
- Adequate recycling technology, e.g., SSP controls during the recycling process; and
- Discolouration management within the recycling process (e.g., using blue tint to reduce yellowing).

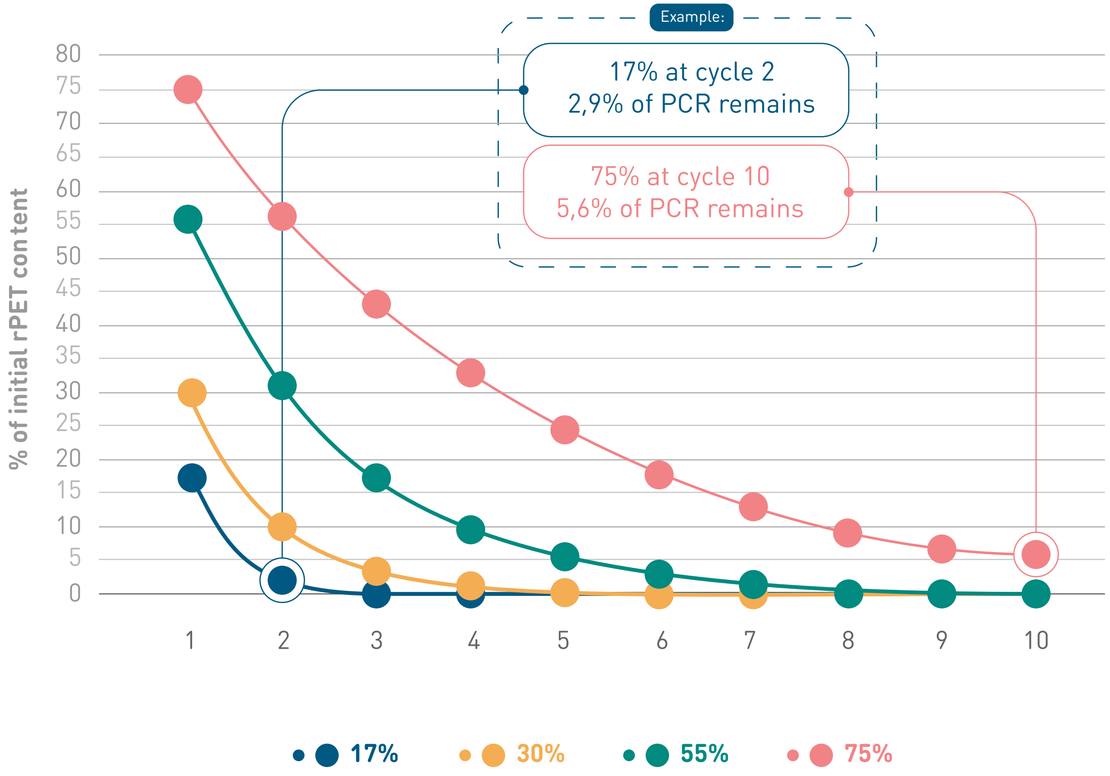
It is worth noting that this level of circularity appears to be achievable without significant further discolouration in later recycling loops but that the achieved colour, although stable, is not the same colour as a virgin "clear" bottle and therefore this change in colour would need to be acceptable to all brands using these bottles.

Figure 3.2: Colouration of the bottles blown for successive recycling loops with 75% recycled content [33]

Longevity of PET within recycling loops

Taking these case study examples into account, the impact on the longevity of PCR content is significant, as demonstrated in Figure 3.3. If the policy target for 30% rPET content in bottles are met, the longevity of the PCR content is still minimal, reducing below 1% by the 4th cycle. However, at higher quantities, as demonstrated by the reported minimum rPET content within the Petcycle system (55%) and the potential for even higher quantities of rPET as demonstrated by Pinter et al.'s[34] test for 75% rPET, the longevity of the material and circularity of the system is improved significantly.

Figure 3.3: Longevity of Recycled Content within PET bottles



3.2 Assumptions

The policy developments, brand commitments and current case studies discussed above, lead us to following changes in the assumptions between the current and future circularity scenarios.

Table 3.2: Key changes in assumptions

Assumption	Current Scenario	Future Scenario
Bottle Collection Rate [35]	96% DRS (26% of all beverage bottles POM) 48% separate collections	82%[36] DRS (100% of all beverage bottles POM) 48% separate collections
Maximum Assumed Bottle Recycled Content	17%	75%*
Other Packaging Collection Rate	21%	41%
Other Packaging Recycling Rate	0%	25%

* Provided that similar operational circumstances are achieved to those replicated by Pinter et al.[37]

Assuming the entire beverage bottle market meets the 90% collection target with a DRS scheme, while separate collections continue to achieve an average beverage bottle Collection Rate of 48%, then we estimate that DRS bottles would require an 82% Collection Rate. This estimation sits below the current average for DRS schemes in Europe, however, we assume that a lower Collection Rate for DRS can be explained with some countries implementing less efficient or only partial DRS systems. We assume that separately collected rPET from bottles is not suitable for food contact purposes in the future scenario, as the vast majority beverage bottles will be collected via a DRS and therefore, the remainder would not meet the 95% food contact packaging target as described by the EFSA guidance (see section 2.0). We have not considered any demand increases or changes to packaging formats or materials (e.g., move from PET to other materials or vice versa).

There are a number of assumptions regarding the "Potential and upper limits to PET circularity in the future" scenario that if they were to differ then the results would also differ. It is worth highlighting the major assumptions, which if they significantly differ, could result in lower levels of circularity.

- Recycling capacity capable of producing bottle grade rPET would need to expand significantly to produce sufficient rPET.
- rPET of bottle-to-bottle quality is likely to cost significantly more than the option of producing flake and it being used in tray and textile manufacturing, and producers of bottles would need to pay for that material beyond their statutory obligations and all the way to the upper limit that we have modelled.
- The modelling assumes that the additional cost of bottle grade rPET would be sufficient for bottle manufacturers to pull that rPET into the bottle loop and that textile and tray manufacturers do not pay that additional premium.

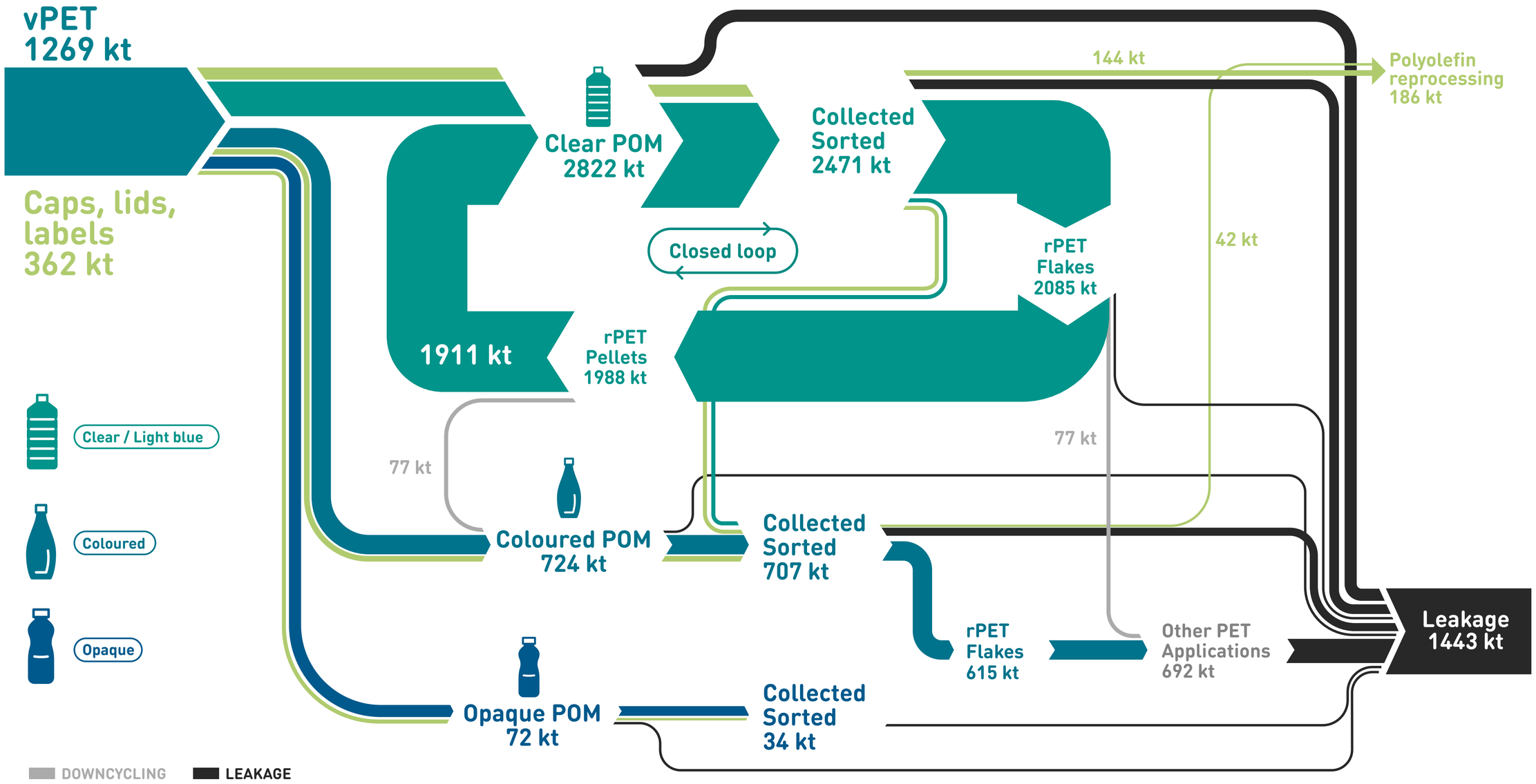
We are assuming that the recycled content across all beverage bottles increases from the current 17% to a maximum recycled content of 75% for beverage bottles. We believe this to be a reasonable assumption as a maximum value given the results from Pinter et al. and Petcycle. Considering the criteria discussed above as well as the competing demands on rPET from the various end markets, however, we believe that realistically the recycled content rate for bottles would lie somewhere between 30% and 75%.

With reference to potential changes in legislation to the definition of recyclability of packaging, as discussed in section 3.1, within the timeframe of the the next 8 to 10 years, it will become increasingly likely that packaging that does not meet recyclability tests will not be able to be placed on the market. This sets a potential challenge for all non-bottle packaging as these groups would in all probability have a low recyclability score at present. How recyclability criteria would apply with respects to individual application Recycling Rates remains unclear, but it would seem plausible that a Recycling Rate between 20% and 50% could be a criterion. For the purposes of our calculations, we have assumed a 25% Recycling Rate and with an assumed recycling yield of ca. 60% of collected trays, the new Collection Rate for this material would need to increase from currently 21% to 41%.

3.3
Upper limits to circularity within PET bottle stream in the future

Based on our assumptions set out above, a future scenario will likely see bottles being managed in a more circular way than currently is the case (see Figure 3.4). A widespread application of DRS collections systems across Europe will improve the quality of collected bottles minimising contamination levels seen in co-mingled, separately collected bottle streams. This in return leads to lower loss rates to leakage, allowing 51% more rPET flakes to be produced from bottles than in the current scenario (2.7mt compared to 1.8mt). With a high PCR content (a maximum of 75% in our example), a high amount of rPET flake is returned into bottles of the same colour, with reduced levels of cascading from bottles to lower value streams. Noticeable is also a significant reduction in loss from the bottle system, both in terms of waste and rPET flakes cascading into other, lower grade PET applications.

Figure 3.4: Circularity in PET bottles – 2030 scenario



Upon closer inspection we see that 74% (2.01mt) of bottle recyclate is used in bottle applications (see Figure 3.5). After extrusion loses this would result in a recycled content of 61% in bottles. This is lower than the 75% that we see as the upper limit in our assumptions. The variance here is because even with the increased Collection Rate for beverage bottles, not enough bottle recyclate is available to reach a recycled content of 75%. Considering the traditional mechanical recycling market, there are two potential scenarios which could increase the recycled content in bottles:

- A further improvement in Collection Rates (e.g., meeting higher Collection Rates in DRS schemes).
- A move from coloured and opaque bottles to clear bottles (this would require a ca. 91% reduction in coloured and opaque bottles).

Brands are already making design changes, and in some instances switching to clear bottles. For example, Coca-Cola has recently replaced its iconic green Sprite bottle with a clear bottle.[38] We are also seeing similar changes in the opaque bottle market, which is traditionally, used for milk packaging.

To generate 75% recycled content purely with a further increase in the DRS Collection Rate is not possible. Even if all current and future DRS systems would achieve the current Collection Rate of the highest performing DRS system (i.e., 97% reported in Germany), this would only increase the recycled content in bottles from 61% to 67%.

Therefore, manufacturers should consider changes within the design of their bottles, more specifically the colours they use for their products. Reducing the current opaque and coloured beverage bottles POM by 91% and thereby increasing the clear and light blue bottles POM by the same absolute numbers means that 75% recycled content in bottles overall could be achieved. The impact of each approach is laid out in Figure 3.6.

In addition to mechanical recycling, the development of novel technologies such as chemical depolymerising (see Section 4.3) will likely contribute to the shift in PET circularity in the future. It is assumed that by 2025[39], it would also be possible to reach 75% recycled content if chemical depolymerisation of other PET applications (e.g., coloured bottles or trays) reaches its planned input capacity (sorted and clean post-consumer PET flake) of approximately 350ktpa by 2025, and the output resins are used in the production of monomer into clear and tinted bottle manufacturing (subject to food contact regulations).

Figure 3.5: End markets of bottle derived rPET and PET recycled content in bottles

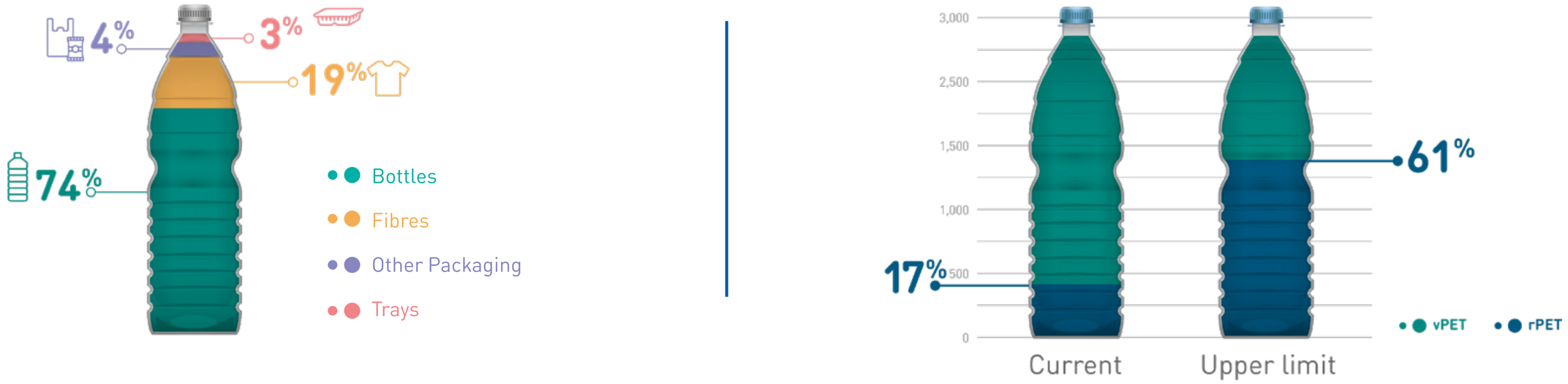
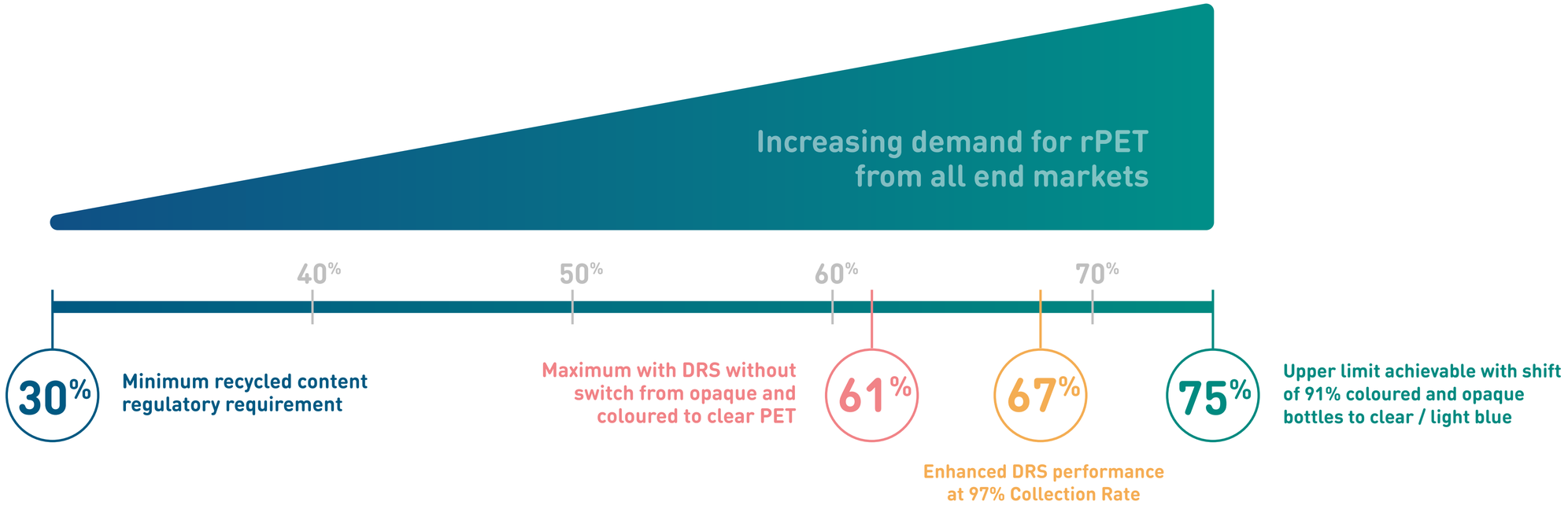


Figure 3.6: Opportunities to increase recycled content in bottles



We can therefore assume that in the future, with improved Collection Rates through the targets specified by the European Commission, a high recycled content in bottles is possible. Provided all assumptions are met, the upper limit of recycled content in bottles could lie within a range of somewhere between 61% and 75%.

Several factors will however influence this number in reality. The upcoming EU policy calls for a 30% recycled content target and so this is the minimum that brands need to meet in the EU. Policy development in most parts of the world is not as advanced, and therefore the wider global market may be lacking in incentive to increase recycled content. While major brands have voluntarily committed to meeting recycled content targets that are in line or higher than the upcoming EU policy, there is also the issue of the unknown economic developments of the rPET market and competing demands of rPET end markets.

We also note at this point that the grey discolouration caused by a high recycled content in bottles, as discussed in section 3.1.3, might be a consideration for brands when marketing their products on shelf. While this might not pose an issue for dark coloured drinks, it is yet to be seen if water and light-coloured drinks brands would accept this change in colour in favour of higher closed loop recycled content within bottles. One option brands might consider is to disguise discoloured bottles under a shrink wrap label, which would then make the bottles more challenging to recycle.

We therefore believe that in the future, the average recycled content of bottles will likely be within the range of 30% to 75%. Within the further assessment, we continue to work within the upper limits of circularity that can be achieved in Europe to demonstrate what circularity could look like if the right conditions in the market are met.

3.4

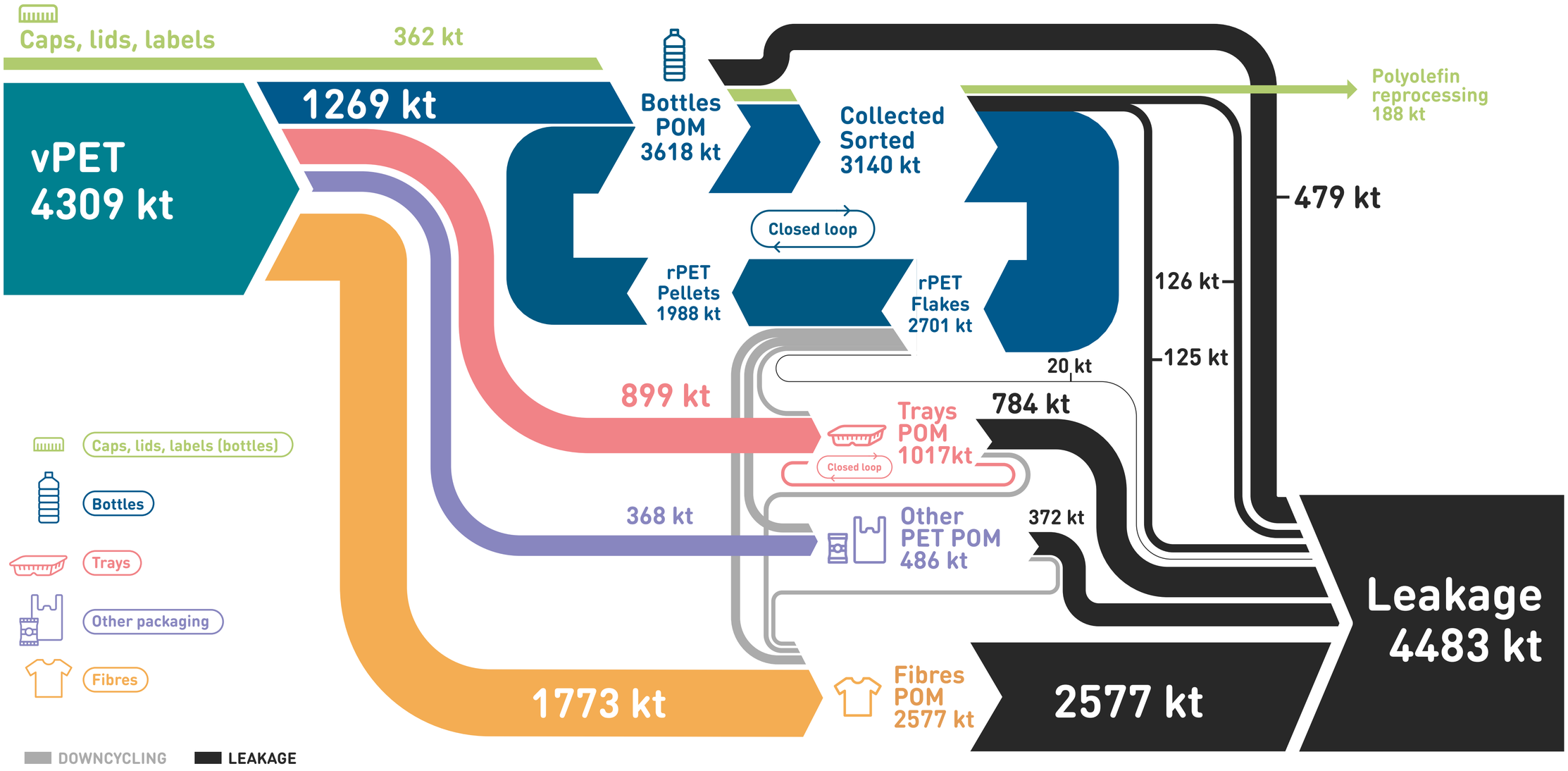
Upper limits to circularity within the general PET stream in the future

Considering all PET applications, rPET can also be managed in a more circular manner, with less cascades. Figure 3.7 presents the mass flows of PET in future scenario. Due to the cascades, this is still not a fully closed loop system for all the PET categories we have assessed, but allows for much improved circularity, particularly within the bottles streams as discussed in section 3.3.

As discussed in section 3.2, we are expecting that some additional recycling will happen in other packaging categories to potentially meet EU packaging regulations. This could provide an additional 350 kt of rPET flakes derived from trays, flexibles and strapping. Due to the challenges from material characteristics of these products, the rPET flakes from these applications cannot be used in bottle production. We have assumed a small amount of tray-to-tray recycling will take place, but most of the rPET derived from other PET packaging applications will likely be used in lower grade applications such as fibres for insulation, ultimately entering a linear system.

With the increased bottle to bottle recycling and the additional small amount of tray-to-tray recycling, the circularity for all PET packaging increases to 47%, as can be seen in Figure 3.8. This drops to 41% if the use of rPET in all PET is measured, though this is still an increase to the current scenario.

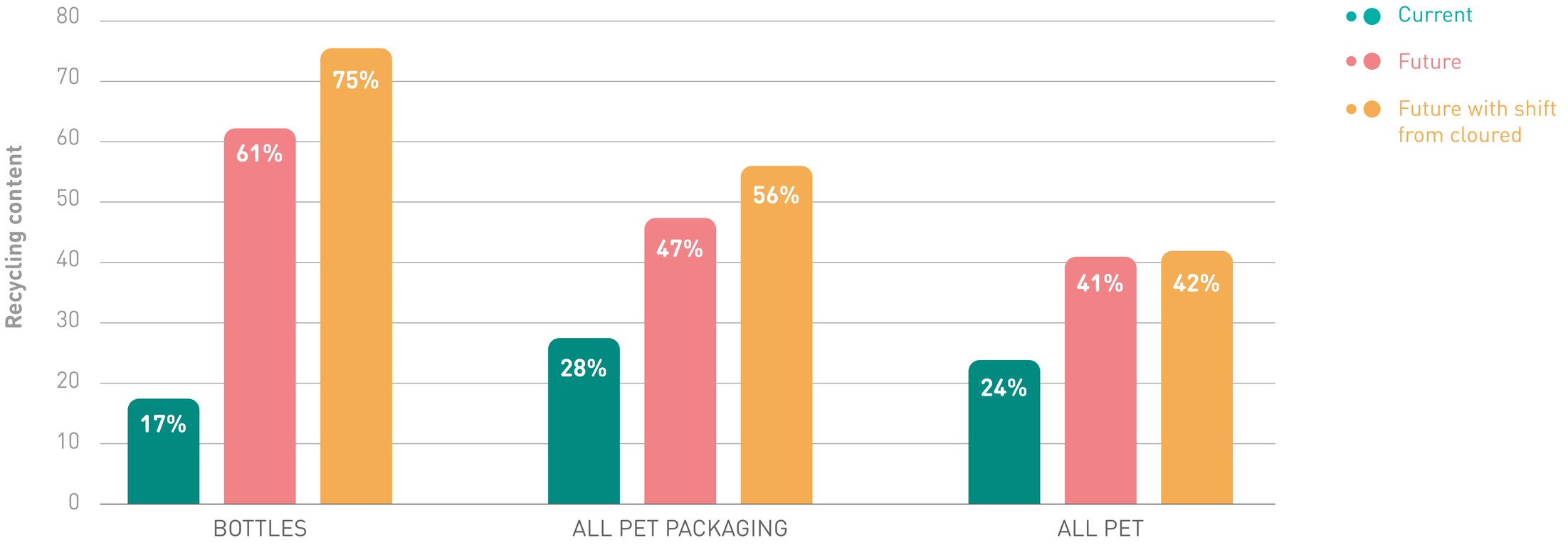
Figure 3.7: PET mass flows – future scenario - 2030



If manufacturers switch 91% of coloured and opaque bottles to clear bottles, more recyclate could remain in a closed loop and reach a 75% recycled content in bottles. This would, however, have the greatest impact on circularity of bottles and only impact the overall PET circularity minimally. Figure 3.8 shows that this would increase in the recycled content used in total PET category assessed in this report.

While circularity within the bottle stream can be improved in the future, subject to stringent process controls, many other PET categories are still displaying a predominantly linear system, or one with cascades towards a linear system at best. This shows there is further potential scope both for improvements within mechanical recycling and for the introduction of chemical recycling in the difficult or economically unviable to recycle categories such as other PET packaging and fibres.

Figure 3.8: Recycled content by manufacturing scope (upper limit scenario)



4.0

Increasing circularity of non-bottle PET applications

As previously demonstrated (see Figure 3.7), the increased demand for rPET in bottle applications is set to reduce the availability of rPET for other PET packaging applications. Given the lack of viable, large-scale methods of recycling PET thermoforms such as trays, manufacturers will require increased volumes of virgin material to meet demand.

In our model we have predominantly accounted for potential open loop recycling of other PET packaging (i.e.trays, flexibles and strapping), in which rPET flakes from these product streams cascade into other product streams. This has been assumed due to the somewhat difficult nature of these packaging streams marked by multi-layer/multi-material, colour and other limitations. However, there is evidence of mechanical closed loop recycling in these categories which may, if processes such as sorting are developed in future, increase circularity further.

4.1
Material recycling of PET packaging

Developmental work on tray end-of-life options with a reasonable yield are taking place. PETCORE Europe established the Working Group on Recycling PET Thermoforms in 2015. At time of writing, no details were available regarding material yield and loss rates for the different experimental processes and therefore its effectiveness cannot be assessed.

There are already established processes for the mechanical recycling of post-commercial, industrial and agricultural films.[40][41] While most recycling is of polyethylene or polypropylene films, PET film is suitable for mechanical recycling as it can maintain its physical and optical properties over extrusion cycles.[42] Little is however known about the extent of film recycling taking place at the moment. It is assumed that quantities are low and at best on an experimental level and feedstock would require to be from clean, mono-material sources.

We are aware of examples of small-scale recycling of industrial PET strapping, in which the material is shredded or granulated before being melted and re-formed into pellets for reuse.[43][44] There is a lack of clarity regarding the capacity and recycling efficiency of this process. Often, strapping is collected in mixed residual waste and not sorted for recycling.

4.2
Material recycling of polyester fibres

There are two main routes for the mechanical recycling and one form of physical recycling of PET fibre, which have seen implementation on an experimental level:

- Direct fibre-to-fibre (mechanical)
- Melt extrusion (mechanical)
- Solvent Purification (physical)

Direct fibre-to-fibre

Typically, homogenous or near-homogenous feedstocks are preferential for these processes, to ensure the resulting recycled fibre meets quality requirements. As such, stringent, manual sorting is typically required, which is both labour intensive and time-consuming. Another drawback of the technology is that the mechanical processing shortens the length of the fibres.[45] The resulting material is often downcycled into low-quality material[46] or blended with virgin fibre to ensure sufficient durability and quality, with studies citing the maximum possible percentage of recycled material as 20-30%.[47][48] While this method provides a means of recycling some polyester fibre, future developments are unlikely to lead to continuous closed loop recycling due to the high virgin input required.

Melt extrusion

There is a lack of clarity on the extent to which this technology can handle contamination such as coatings or dyes and whether any virgin material is required to ensure that quality is retained. Another consideration is the impact of the recycling process on the fibre, as extrusion has also been shown to induce thermal degradation of the polymer chains in PET, reducing the material's mechanical properties.[49][50]

Solvent purification

Solvent purification is a physical recycling process that separates polymers from additives and other contaminants within the waste stream through the principle of solubility.[51]

There is a lack of production and environmental performance information regarding yields and chemical/energy input requirements. While solvent purification could provide a promising route to increasing circularity within PET, as yet the long-term viability from both an economic and environmental perspective is unclear.[52] It is also important to note that the resulting polymers are subjected to thermal strain when reprocessed into new plastic, which can lead to degradation of the polymer chain.[53][54] Hence, this technology's ability to infinitely recycle plastic without the requirement for virgin material input is unknown.

4.3 Chemical Depolymerisation

In recent years, manufacturers, recyclers and policy makers have all shown increasing interest in the development of chemical recycling technologies as complimentary mechanisms alongside mechanical recycling for the recycling of plastics.[55] The output from these recycling processes can vary, depending on the precise technology utilised.[56]

Of particular interest to the PET industry is chemical depolymerisation (often referred to as monomer recycling), a category of recycling processes that break down the polymer chains using chemicals. Once this depolymerisation has occurred, the monomers are recovered from the reaction mixture and purified to leave a virgin-quality monomer which can be used directly in polymer production.[57][58]

However, in Europe this is still an emerging marketplace. There are examples of companies with pilot/demonstration plants and the depolymerisation industry is reporting that it is in the process of scaling up to full commercial scale plants. It is estimated that the current input capacity of plants that have systems proven on an operational environment or in a similar level of operation is approximately 68ktpa. The combined ambition in the industry is likely going to lead to an input capacity of collected post-consumer PET flake of approximately 350ktpa by 2025.[59] However, the performance and costs of these processes are not yet clear. Information on yields of monomers through these processes, which on the face of them look promising, is typically only found in technology patents or marketing-driven material. Minimal supporting information on the method of calculation is provided (e.g., the materials considered within the yield calculation), as opposed to a mass flows of material at plant level being detailed. As such, the resulting impact on yield where these technologies are scaled up, when considering factors such as sorting, processing and purification, remains unclear.

It is also important to note that, while companies report that these technologies are capable of processing PET waste inputs from a variety of sources, many still target beverage bottle material. Given the optimised mechanical recycling systems already in place, and the likely changes to product design previously highlighted, an increase in chemical depolymerisation could lead to direct competition for material, resulting in minimal benefit in terms of overall circularity within PET markets. However, if a synergistic approach was possible, for example utilising chemical depolymerisation for PET waste streams that are not typically targeted by mechanical recycling this could lead to overall improvements in circularity of PET. This could be particularly relevant where these technologies can provide effective contamination removal, and subsequent production of food-grade PET outputs, where mechanical recycling is not capable of achieving this.

Such a scenario will depend on a policy framework that increases incentives for improved circularity. It will ultimately also depend on market conditions where relative costs of the recycling processes and the waste streams that can be effectively processed are aligned with such a synergistic outcome.

Currently there is still significant uncertainty surrounding the long-term potential of chemical depolymerisation technologies from a financial and environmental perspective. These technologies often require significant inputs of chemicals and energy[60] and require similarly clean and homogenous waste streams to mechanical recycling, resulting in broadly similar costs and impacts at the collection, sorting and material preparation stages. A broad consensus also exists that these emerging technologies should be viewed as complementary to mechanical recycling. As such, this study focuses on the optimisation of mechanical recycling using techniques that are well proven and established at commercial scale but acknowledges that a future including chemical depolymerisation could see further improvements in PET circularity.

5.0 Conclusions

The PET system is currently not very circular and has a high level of leakage (approximately 75% of PET POM). Only bottles show some level of circularity, with an average of 17% PCR from bottles reused in bottle manufacturing in Europe. The rest of the recyclate produced from bottles 'cascades' into other product categories such as trays, other packaging or fibres. It is then lost when these products reach end-of-life, as these product types are predominantly linear with no large-scale recycling taking place.

To model the future scenario, we have assumed that all of Europe will switch to DRS collections for beverage bottles and that the 90% collection target will be reached. However, our modelling has shown that there is not sufficient material to allow for such high circularity in bottles alone, with its upper limit in this scenario met at 61%. Two potential approaches within the existing mechanical recycling market could increase the circularity of PET bottles further:

1) A further improvement in Collection Rates; and/or
2) a move from coloured and opaque bottles to clear bottles.

We estimate that in the future, we could see an increase in the upper limit of bottle-to-bottle recycling with a recycled content of somewhere between 61% and 75%, up from currently 17%. This is, however, under the assumption of prioritising closed loop recycling (i.e., using rPET from bottles in bottles as opposed to other PET applications) to ensure maximum circularity. More realistically, based on market conditions, we estimate the future use of recycled content in bottles to lie somewhere between a minimum policy driven target of 30% and the upper possible limit of 75%.

In addition to the two scenarios considered for mechanical recycling there is potential for chemical recycling technologies, such as chemical depolymerisation, to contribute to PET circularity. This industry has not reached maturity, however, and its true potential is not fully known at present, but it does appear that there is planned input capacity of approximately of 350ktpa (clean and sorted post-consumer PET flake) by 2025, that could be sufficient to achieve this 75% content in bottles if food contact regulations allow.

When considering the impact the changes might have on all PET packaging, we can see an increase of recycled content from 28% to an upper limit of somewhere in the region of 47% to 56%. For all assessed PET applications, recycled content shifts from currently 24% to an upper limit of 41% to 42% in the future.

Whether this future potential is achieved will depend on the market replicating these parameters. However, a shift towards such higher recycled content, one that will not only exceed the legislative requirements but also ensure the longevity of rPET in the recycling loops, is closely linked to price developments, public pressure and brand aspirations. These will ultimately fuel further developments in the industry.

Notes

1) Percentage of bottles (including caps, lids and labels but excluding beverage/ product) collected vs placed on the market bottles

2) Based on our own modelling

3) European Food Safety Authority (2012) PET recycling processes for food contact materials: EFSA adopts first opinions, accessed 25 June 2021

4) Hann, S., and Connock, T. Chemical Recycling: State of Play

5) Collection Rate refers to collected vs placed on the market bottles, including caps, lids and labels but excluding beverage/product.

6) Weighted average calculated from Reloop's 2020 Global Deposit Book

7) Plastics Recyclers Europe, Petcore Europe, and EFBW (2020) PET Market in Europe - State of Play: Production, Collection and Recycling Data, 2020 and confidential sources; taking into account removal of contaminants and moisture for separately collected bottles

8) COMMISSION IMPLEMENTING DECISION (EU) 2019/ 665 - of 17 April 2019 - amending Decision 2005/ 270/ EC establishing the formats relating to the database system pursuant to European Parliament and Council Directive 94/ 62/ EC on packaging and packaging waste - (notified under document C(2019) 2805)

9) Natural Mineral Waters Europe, Petcore Europe, Plastic Recyclers Europe, and Unesda (2022) PET Market in Europe: State ofPlay 2022, January 2022

10) Natural Mineral Waters Europe, Petcore Europe, Plastic Recyclers Europe, and Unesda (2022) PET Market in Europe: State ofPlay 2022, January 2022

11) Kennisinstituut Duurzaam Verpakken (2017) Factsheet - Opaque PET bottles and recycling

12) Container Recycling Institute Plastic Facts & Statistics, accessed 1 September 2021

13) Colin Staub Major packaging users hit 6.2% average recycled content - Plastics Recycling Update, accessed 2 September 2021

14) NAPCOR NAPCOR releases 2019 PET Recycling Report, accessed 1 September 2021

15) Natural Mineral Waters Europe, Petcore Europe, Plastic Recyclers Europe, and Unesda (2022) PET Market in Europe: State of Play 2022, January 2022

16) https://www.petcore-europe.org/images/pet/Design_for_Recycling_Guidelines_PET_Trays_Clear_Transparent_Jan_2020.pdf

17) Natural Mineral Waters Europe, Petcore Europe, Plastic Recyclers Europe, and Unesda (2022) PET Market in Europe: State of Play 2022, January 2022

18) European Environment Agency (2019) Textiles in Europe's circular economy, accessed 19 April 2021

19) Textile Exchange (2020) Preferred Fibre & Materials Market Report 2020

20) Interview with industry stakeholder; Nov 2020

21) http://thecircularlaboratory.com/recycled-polyester-and-the-plastic-bottle-dilemma

22) COMMISSION IMPLEMENTING DECISION (EU) 2019/ 665 - of 17 April 2019 - amending Decision 2005/ 270/ EC establishing the formats relating to the database system pursuant to European Parliament and Council Directive 94/ 62/ EC on packaging and packaging waste - (notified under document C(2019) 2805)

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