Summary

HOW CIRCULAR IS PET?

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

February 2022

1.0 Introduction and scope

Polyethylene terephthalate (PET) is a polymer used extensively in single use packaging as well as in textile manufacturing (polyester fibres). On a fully circular economic model, all PET products would be made from recycled PET (rPET), and there would be no need for virgin PET (vPET). In this report, we ask what proportion of PET placed on the market (POM) is kept within a circular manufacturing model today – and how much virgin PET (vPET) is required as a proportion of all the overall PET goods manufactured – to answer the question "how circular is PET?".

In addition to assessing the **current** circularity, we also assess potential circularity and its upper limits in the **future** involving only mechanical recycling techniques. We then consider the **further potential** for circularity if chemical recycling techniques are also employed in the future, and if the range of PET products recycled in a closed loop is increased. While our detailed assessments of PET circularity use data for Europe, similar themes and conclusions also apply globally.

This report considers the circularity of PET through three manufacturing scopes:

PET bottles

All PET packaging
(including other PET packaging, e.g., trays and strapping)

The general PET stream
(adding textiles/fibre manufacturing to the scope)

2.0 Current circularity

The majority of PET is not currently managed in a circular model since leakage from the circular system is high, with material lost at all stages of the PET lifecycle. There are several potential limitations which influence the current circularity of PET:

Key Issues

- **Ineffective collection systems leading to high losses of post-consumer PET.**
- **Lack of availability of recyclers means some collected material cannot be reprocessed.**
- **Contaminants from collection and sorting.**
- **Product design and material quality, including coloured PET and multi-material applications as well as food-grade standards for rPET.**
- **rPET economics, i.e., the market rate of rPET compared to vPET, which is dependent on many drivers including the demand by end markets.**

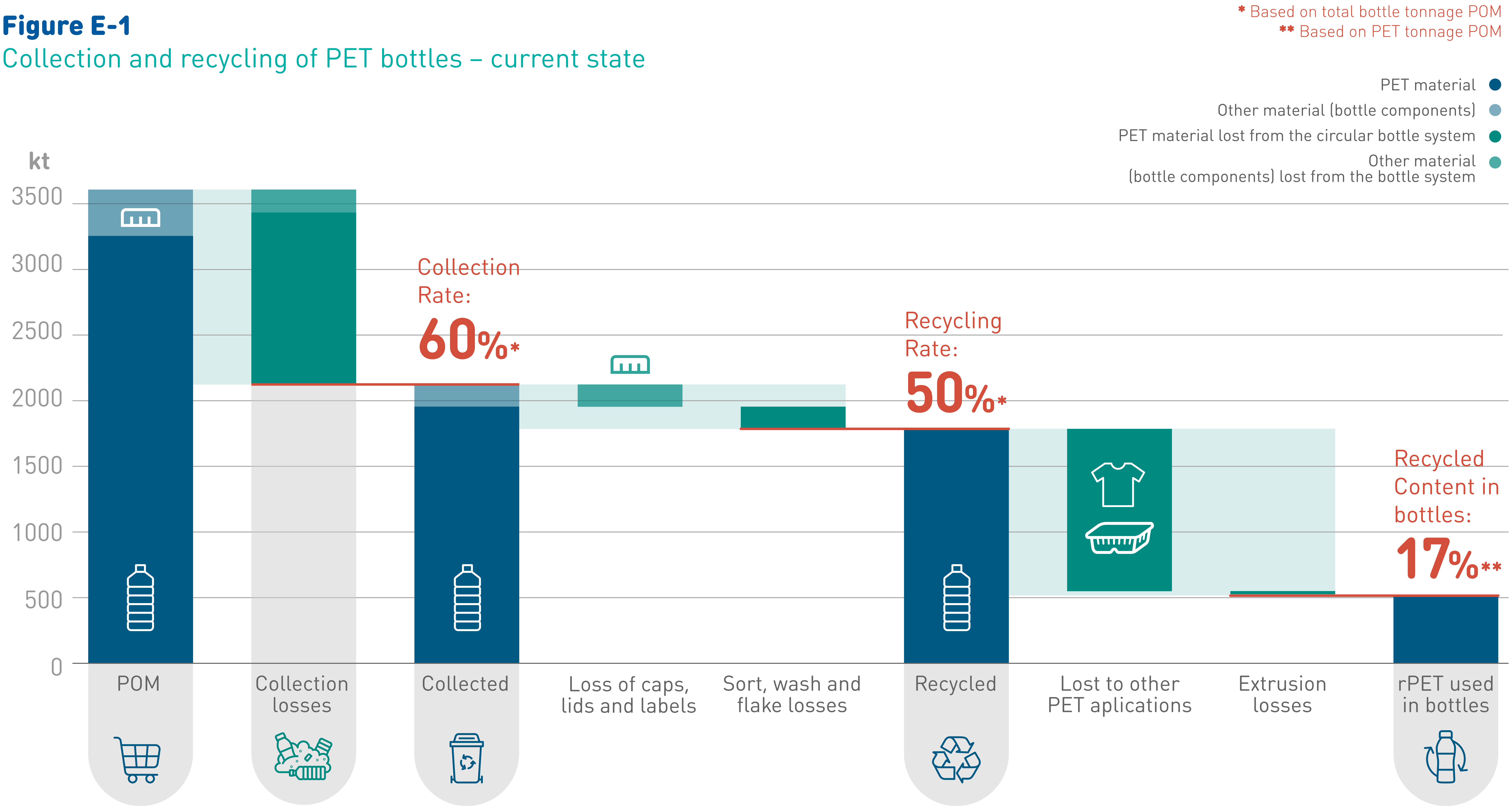
The model of PET circularity is much more complex than one singular circular PET application model. In fact, there are many different PET products with different manufacturing requirements of recycled PET (rPET) feedstock. It is technically and economically more challenging to deliver manufacturing quality requirements from rPET than virgin PET. As this is especially the case for closed loop applications, rPET can 'cascade' 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.

2.1 **PET bottles**

Of the entire PET family, bottle recycling has the most developed technology and infrastructure. Across Europe, collection schemes for PET bottles vary. Some countries are achieving high recycling rates with beverage deposit refund schemes (DRS), while other countries and regions are achieving lower recycling rates with separate collection schemes. We estimate that PET bottles 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 lids and labels) placed on the market). rPET used in bottle manufacturing has high overall quality criteria and must be derived from bottles. It is estimated that bottles placed on the market (POM) only comprise of an average of 17%[1] rPET , with the remaining rPET downcycled into other, lower grade manufacturing applications and therefore considered a loss from the circular bottle stream.

Figure E-1

Collection and recycling of PET bottles – current state



2.2 The general PET stream

While bottles make up the largest share of PET packaging, PET is used in other PET applications, such as in fibres, single-use tray manufacturing, films, and strapping.

There is no standardised collection and sorting of non-bottle PET applications in Europe. The lack of appropriate sorting and recycling technologies as well as the design of these applications makes them currently difficult to recycle. Although some tray and film recycling does happen on a small scale, the amount is negligible in greater scheme of the PET packaging manufacturing scope currently. Therefore, only bottle recycling has been considered in the current scenario.

Trays use approximately one third (31%)of the total rPET generated from bottle recycling, In total, PET Packaging uses 74% 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.

Approximately 14% of the global polyester market is recycled polyester, the majority of which is produced from PET bottles.[2] Clear/light blue bottle material is typically most desirable for textile production, as this produces fibre with reduced discolouration. Although fibres may have a recycled content (rPET from bottles), there are no known current market scale recycling processes for post-consumer fibres. Therefore, similarly as seen in other non-bottle PET applications, the mass of PET used in fibres will end up as leakage from the circular system.

Figure E-2: PET Mass Flows - current state

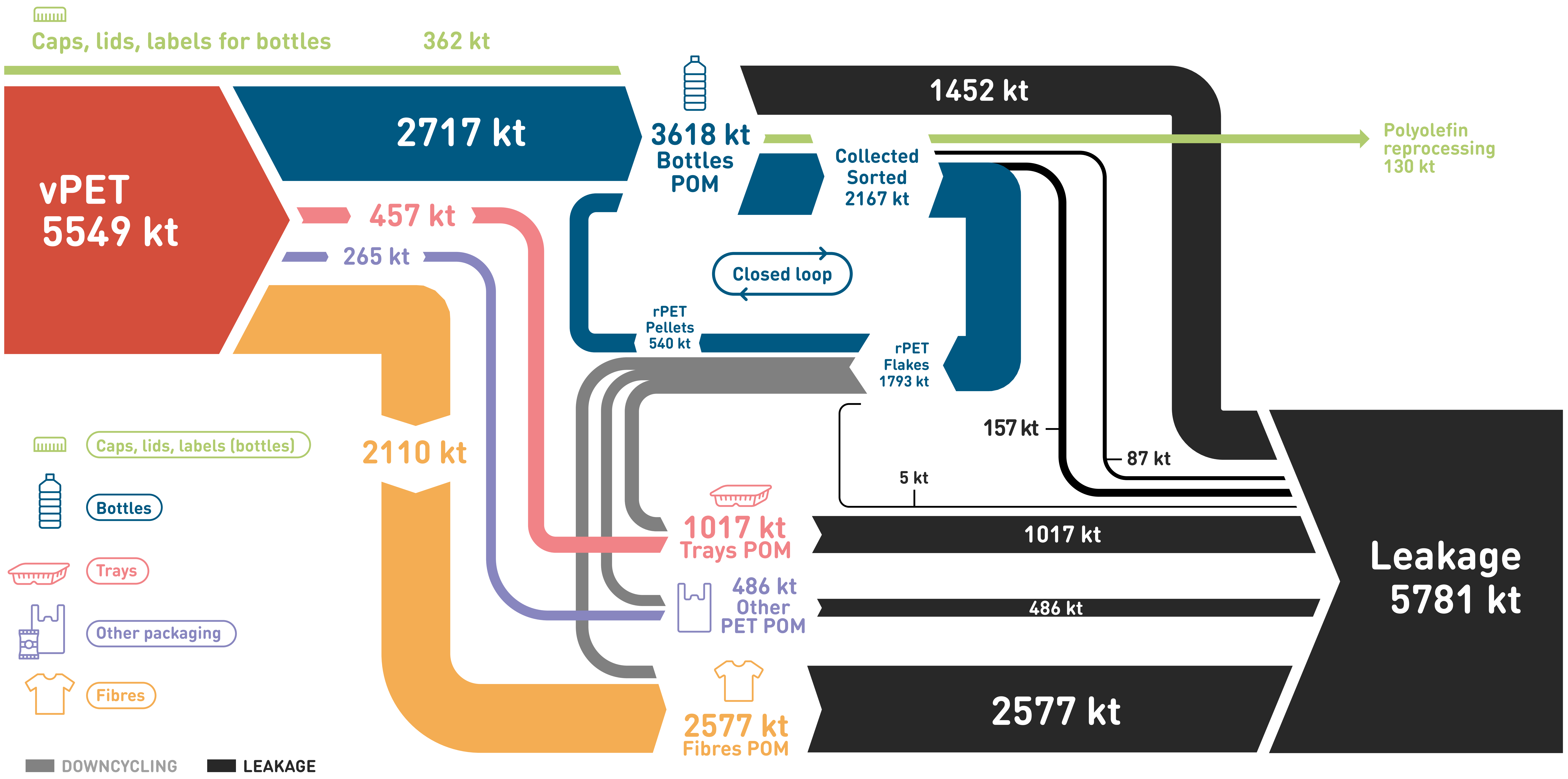
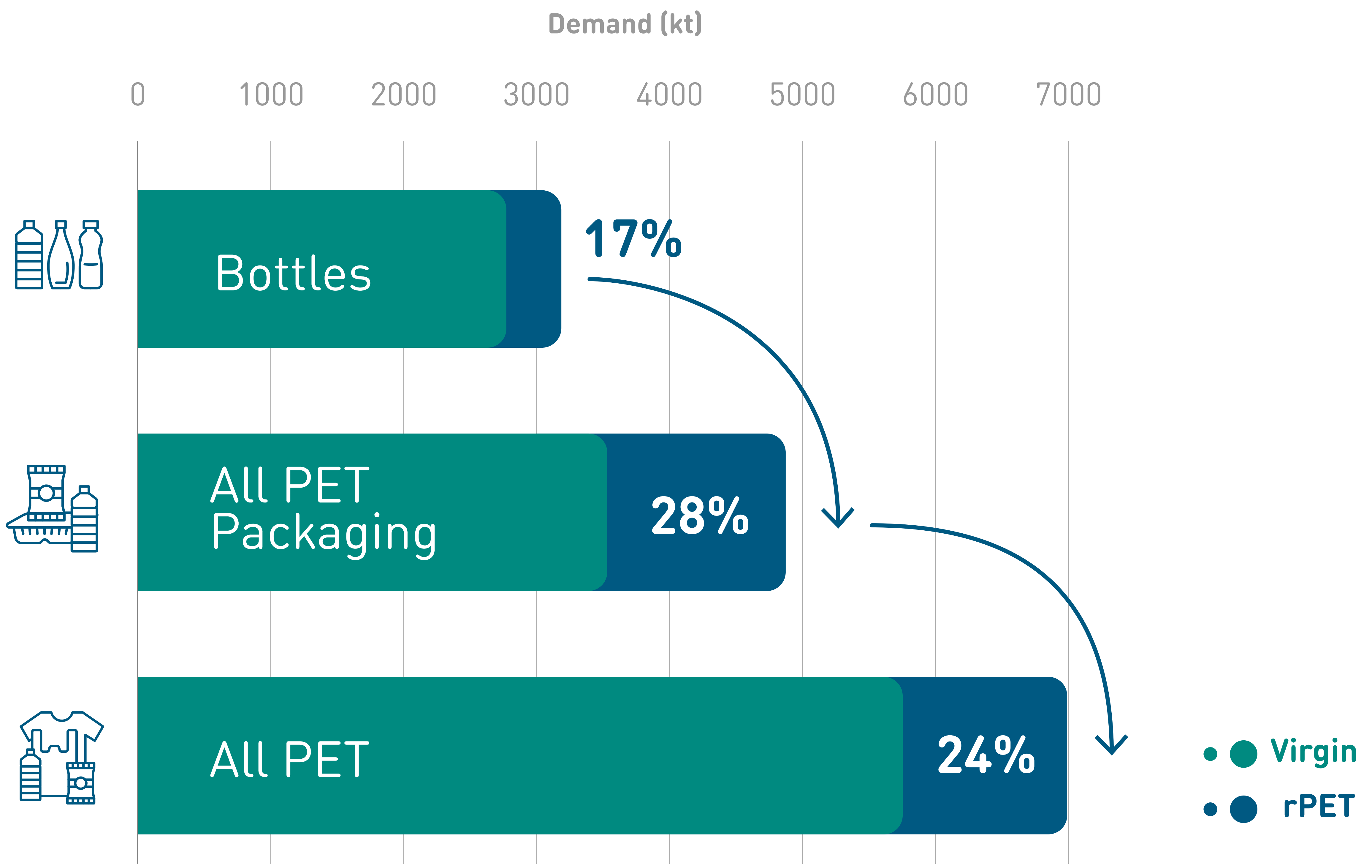


Figure E-2 presents the current PET mass flows for all PET applications assessed in this report. It clearly shows that only bottles are recycled and hence recycled content for all product streams is sourced from bottles. Of the 1.8mt flake output from bottles, only 31% are made into pellets for bottles, with the rest (69%) cascading into other products, such as trays, other packaging or fibres. The lack of recycling in some product streams provides further leakage from the total PET system.

Figure E-3 also shows the lack of circularity of PET by looking at the recycled content of each manufacturing scope in Europe.

Figure E-3:
Recycled content by manufacturing scope (baseline)

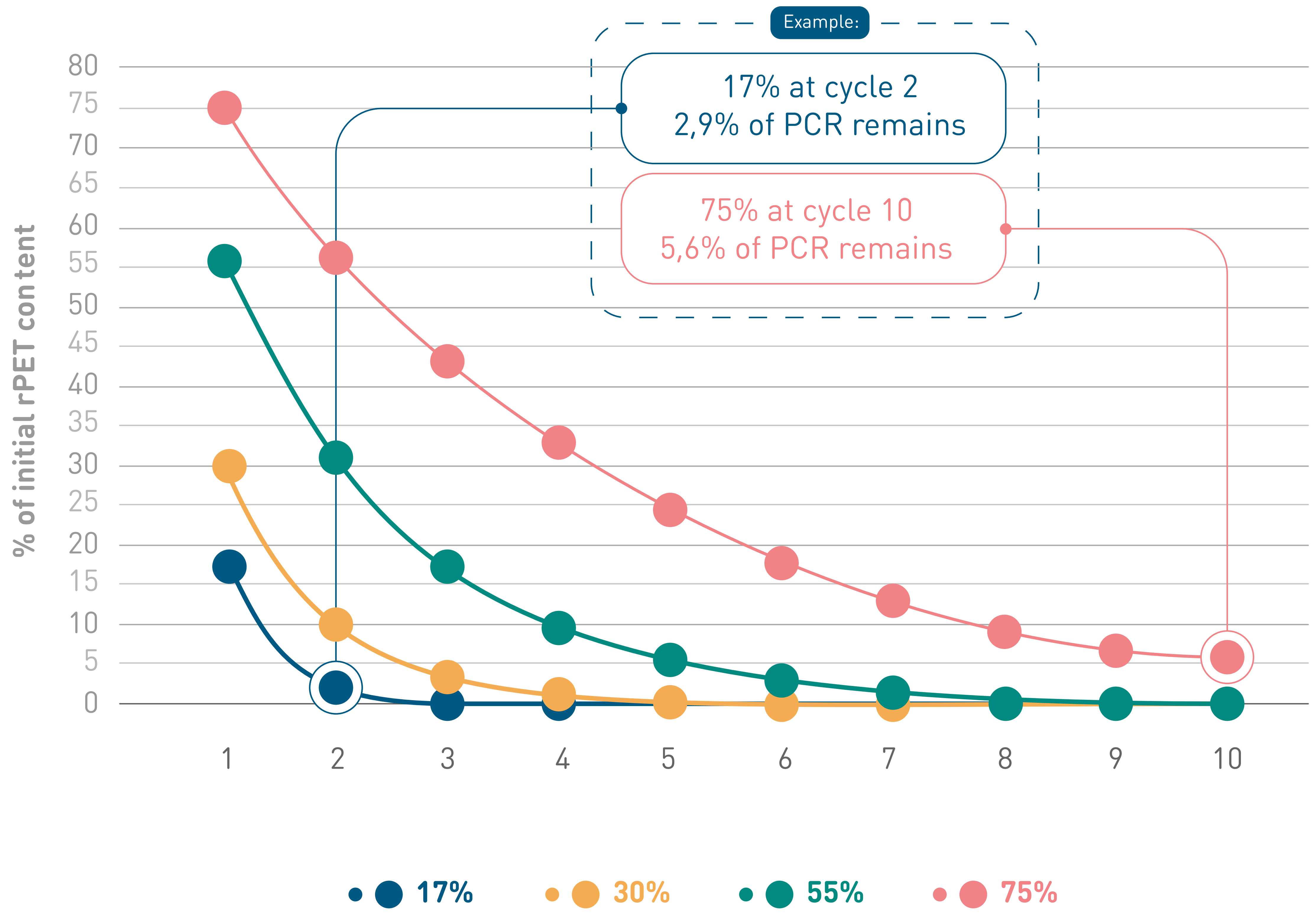


3.0 Upper limits to PET circularity in the future

Upcoming policy is driving increased bottle collections, likely only achievable through the introduction of deposit return systems (DRS) for PET beverage bottles. The widescale of introduction of DRS, coupled with improvements in bottle product design, is also likely to offer advantages in the quality of rPET derived from bottles.

Petcycle, a German DRS closed loop circular system, demonstrates continued circularity can be achieved with 55% rPET content of bottles (recycled content target for members for the past eight years). Recent laboratory test results[3] indicate that bottles can be made from 75% recycled content in a closed loop circular model by adding 25% of vPET at each manufacturing stage, without any significant loss of bottle quality characteristics, other than a grey discolouration in the bottle appearance.

Figure E-4:
Longevity of rPET content within PET bottles



Within the total European PET bottle market this means that bottles POM contain on average 17% rPET, which means only 17% will be carried over from the previous loop and PCR content within the system is swiftly reduced, as seen in Figure E - 4. Taking the upcoming policy changes, the Petcycle case study as well as the experiment results by Pinter et al. into account, we can see that the impact on the longevity of PCR content in each case is significant.

A future scenario will likely see bottles being managed in a much more circular way than currently is the case. 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 cascading into other, lower grade PET applications, as can be seen in Figure E - 5.

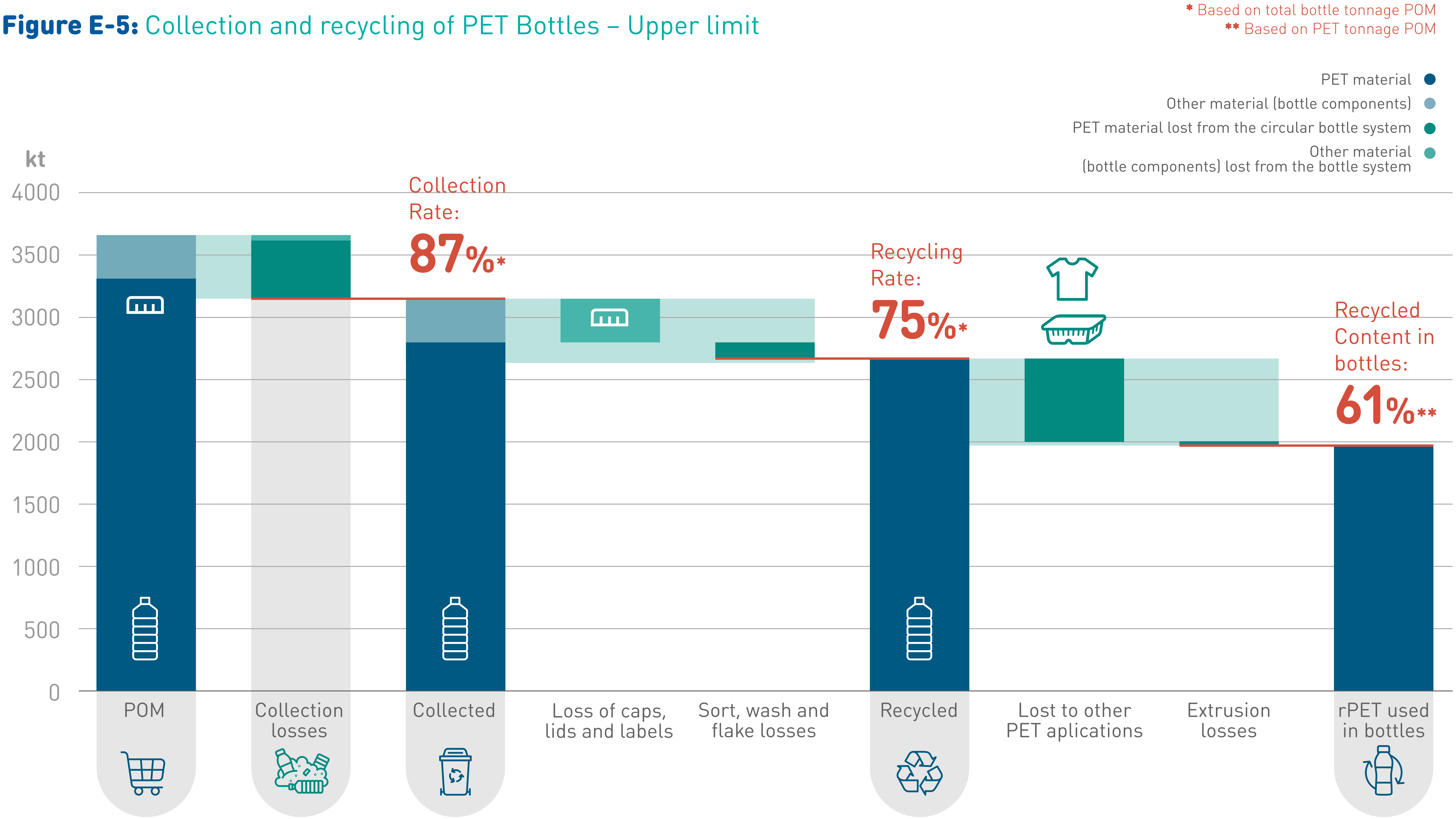
Due to lack of availability of rPET from clear and light blue bottles, in this best-case scenario only 61% instead of 75% recycled content in bottles is possible. Considering only the traditional mechanical recycling market there are two potential scenarios considered in more detail in this report which could increase the recycled content in bottles:

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

To generate 75% recycled content purely with a further increase in the DRS Collection Rate alone, even when assuming that all current and future DRS systems would achieve the current Collection Rate of the highest performing DRS system (i.e., 97% reported in Germany), is not possible. Therefore, manufacturers would need to 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 can be achieved.

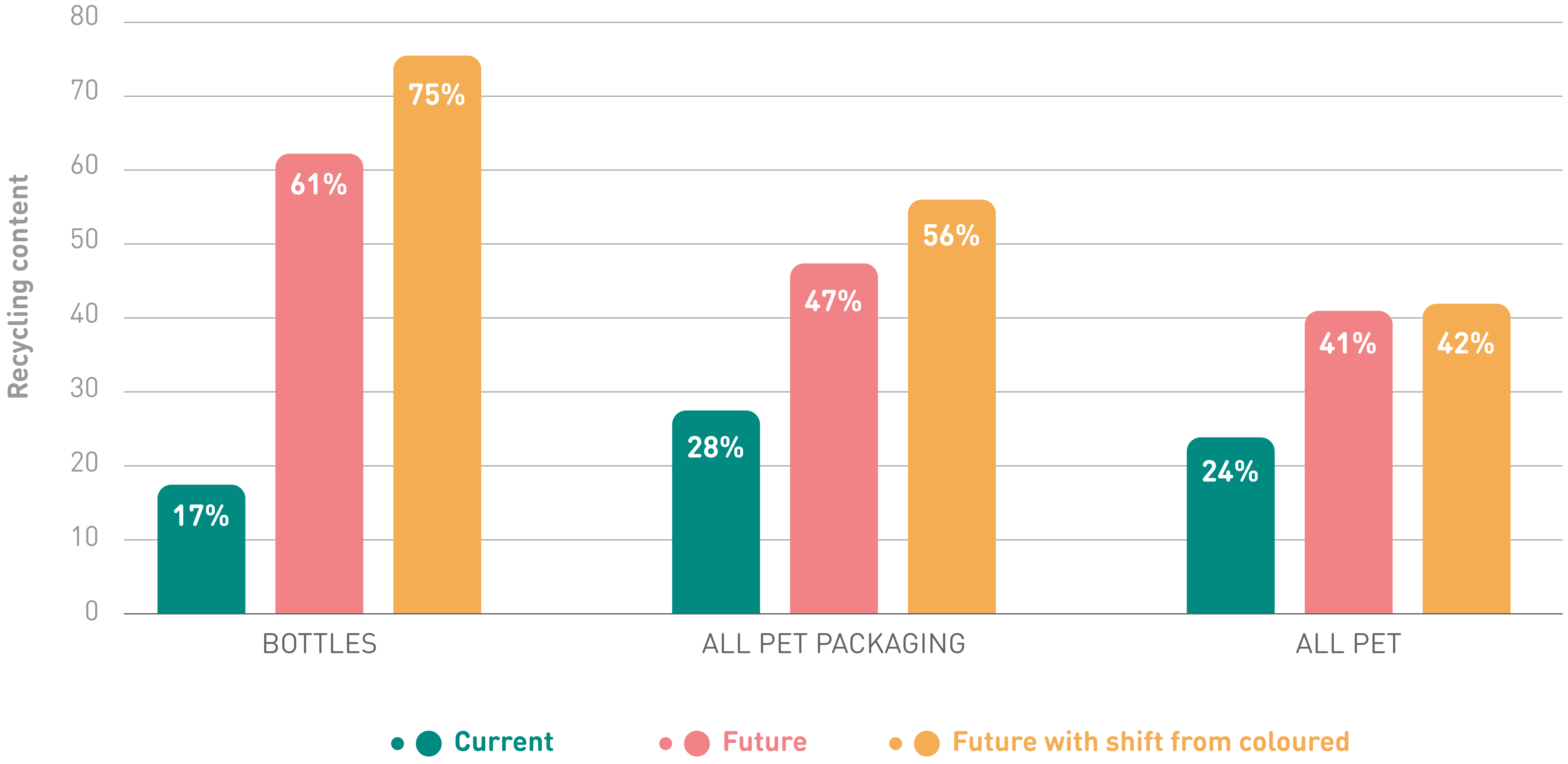
In addition to the two scenarios considered for mechanical recycling there is potential for chemical recycling technologies, such as chemical depolymerisation, to contribute to PET circularity and achieve a 75% recycling content in all bottles. This industry has not reached maturity, however, and its true potential is not fully known at present, but it does appear that there is planned input capacity (sorted and clean post-consumer PET flake) of approximately 350ktpa by 2025[4], that could be sufficient to achieve 75% content in bottles if food contact regulations allow.

Figure E-5: Collection and recycling of PET Bottles – Upper limit



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

Figure E-6: Recycled content by manufacturing scope



This will happen only by...

- Prioritising bottle-to-bottle closed loop recycling instead of using rPET from bottles in other PET applications;
- Increasing the use of Deposit Return Schemes, which will improve collected material quantity and quality; and/or
- Switching from coloured and opaque PET to clear PET.

4.0 Increasing circularity of non-bottle PET applications

The increased demand for rPET in bottle applications is set to reduce the availability of rPET for other PET packaging applications. Given the current lack of viable, large-scale methods of recycling PET thermoform such as trays, manufacturers will require increased volumes of virgin material to meet demand. 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. PET film is suitable for mechanical recycling as it can maintain its physical and optical properties over extrusion cycles. Little is however known about the extent of film recycling taking place currently. 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.

There are two main routes for mechanical recycling (direct fibre-to-fibre and melt extrusion) and one form of physical recycling (solvent purification) of PET fibre, which have seen implementation on an experimental level.

In recent years, manufacturers, recyclers and policy makers have shown interest in the development of chemical recycling technologies as complimentary mechanisms alongside mechanical recycling of plastics.[5] Of particular interest to the PET industry is chemical depolymerisation (often referred to as monomer recycling), a category of recycling processes that breaks 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.

Depolymerisation and repolymerisation techniques have the potential to address some of the circularity limitations detailed in this report as the processes may be able to produce monomers from 'lower' PET cycles (e.g., coloured packaging and non-food contact material) for use in 'higher' PET cycles (e.g., clear beverage bottles) if food contact regulations allow.

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. Currently, an input capacity of 68ktpa is estimated to be available from chemical depolymerisation technology providers who have proven to be at an operational level. This capacity is likely to reach 350ktpa by 2025.[6] However, the performance and costs of these processes are not yet clear. Information on yields of monomers though 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 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.

Currently there is still significant uncertainty surrounding the long-term potential of chemical depolymerisation technologies from a financial and environmental perspective. It is also important to note that typically there is little information concerning the extent to which contamination can be tolerated. However, many of these technologies require significant inputs of chemicals and energy[7] and similarly clean and homogenous waste streams to mechanical recycling, resulting in broadly similar costs and impacts at the collection, sorting and material preparation stages. 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.

Notes

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

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

3) Pinter, E., Welle, F., Mayrhofer, E., et al. (2021) Circularity Study on PET Bottle-To-Bottle Recycling, Sustainability, Vol.13, No.7370

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

5) Crippa, M., De Wilde, B., Koopmans, R., et al. (2019) A circular economy for plastics – Insights from research and innovation to inform policy and funding decisions

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

7) Hann, S., and Connock, T. Chemical Recycling: State of Play (2020)

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