SYSTEMIQ

Circular PET and Polyester

A circular economy blueprint for packaging and textiles in Europe

July 2023

About this report

This report is the second in a series exploring circular economy pathways for PET/polyester in Europe.

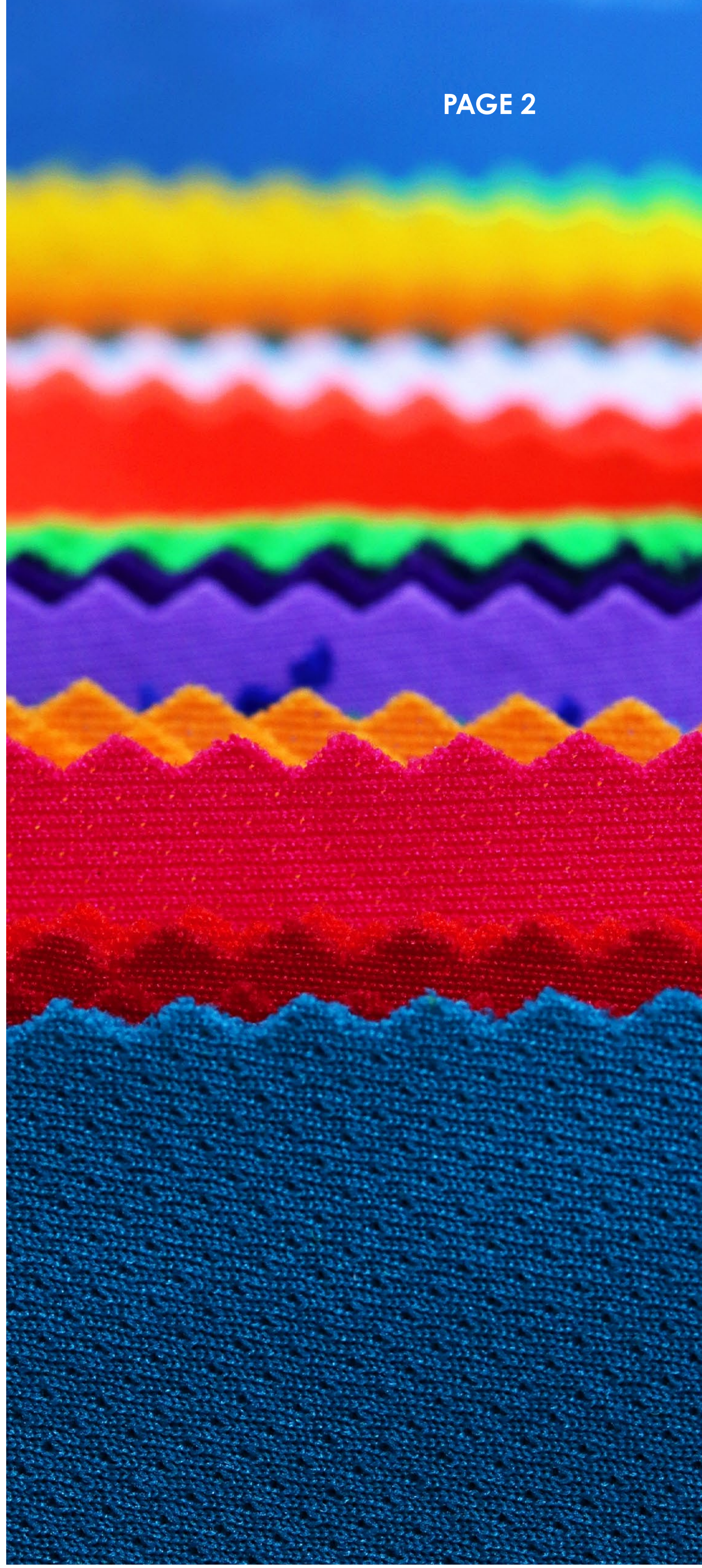
The study was commissioned by Eastman and financed by Eastman and Interzero. It provides a new evidence base, exploring the future potential for complementarity between reuse, mechanical recycling and chemical PET recycling of PET/polyester in Europe under different scenarios, as well as the role that demand reduction strategies could play. It quantifies material flows and environmental impacts of each scenario, and in doing so helps to answer some of the key gaps in existing research, identified in the previous paper in this series. Scenario modelling has been used to chart these possible futures for the system, with data and assumptions drawn from a combination of existing published reports and expert input, validated together with the oversight of the project Steering Group. The study team would welcome questions, challenges, relevant data points and information about published or ongoing studies that are not referenced in this paper. Please contact us at plastic@systemiq.earth.

About Systemiq

Systemiq was founded in 2016 to drive the achievement of the Paris Agreement and the UN Sustainable Development Goals, by transforming markets and business models in four key systems: land use, circular materials, clean energy and sustainable finance. A certified B Corp, Systemiq works to unlock economic opportunities that benefit business, society and the environment; it does so by partnering with industry, financial and government institutions, and civil society. In 2020, Systemiq and The Pew Charitable Trusts published "**Breaking the Plastic Wave: A Comprehensive Assessment of Pathways Towards Stopping Ocean Plastic Pollution**" – a first-of-its-kind model of the global plastics system that describes how to radically reduce ocean plastic pollution. In 2022, Systemiq published "**ReShaping Plastics**", outlining pathways to a circular, climate-neutral plastics system in Europe. Find out more at www.systemiq.earth/.

Disclaimer

This report was prepared by Systemiq with strategic guidance from an independent Steering Group, which provided input on all major project decisions, reviewed all assumptions and provided input into the approach. The steering group had representation from the public sector, civil society and industry, and we are deeply grateful to all the organisations and individuals that contributed their unique perspectives. While the report was financed by Eastman and Interzero, the Steering Group helped ensure its independence and unbiased nature. Responsibility for the information and views set out in this publication lies with the author. Steering Group members or funders endorse the overall project approach and findings, although not all statements in this publication necessarily represent the views of all individuals or the organisations they represent, and they cannot be held responsible for any use which may be made of the information contained or expressed therein.



Preface

The benefits of plastics have made them a key material in many sectors. Achieving circularity requires the engagement of actors from different countries and sectors. This is true for polyethylene terephthalate (PET), the plastic type that is the basis for bottles, trays and other packaging as well as a whole industry outside of packaging, namely polyester textiles. Beverage bottle PET is by far the most collected and recycled plastic, while non-bottle PET packaging and textiles still have a long way to go to achieve circularity. These applications face more difficulties in closing the loop of their products based on current practices in mechanical recycling; and to incorporate recycled content, they typically utilise high-quality recyclates from beverage bottle recycling. So, while it may seem unusual to those in the packaging industry to take polyester from textiles into a single system model together with packaging PET, this inter-change is already happening in reality.

Currently, chemical recycling technologies are emerging and depolymerisation in particular is fit for application to PET, due to its polycondensate nature. One of the main questions today concerns the role that chemical recycling can play as a complementary technology alongside mechanical recycling. The system modelling presented in this report highlights that only a complementarity scenario can truly increase circularity – a scenario in which all solutions are scaled up and all sectors, including the textile industry, contribute to the availability of recyclates. Without this, we face a 'right pocket, left pocket' reality, in which recycling routes change but overall recycling rates stagnate because the same feedstock is envisaged.

The modelling also highlights that recycling is just one part of the solution to achieve sustainability. Revaluing plastics as long-lasting materials with new business models, reuse, and generally longer lifetimes is key. This is valid for packaging (transition from single-use to reusable packaging models where appropriate), but also especially relevant for the textile industry, with its trend of high-consumption fast-fashion business models.

This report is a unique effort that objectively calculates the significant sustainability benefits that could be gained by moving away from fast fashion and from single-use packaging where possible, together with grasping the opportunities of expanding recycling infrastructure and applying chemical PET recycling as a complementary technology. Only by combining these systemic changes can we triple the recycling rate of PET/polyester from 23% to 67% and reduce greenhouse gas emissions by half.

We are grateful for the strong engagement of stakeholders from different industries, research and policy fields for their contribution to this report. Based on this broad input and the diligent work of the system modelling team, this report provides an excellent blueprint to move forwards to PET/polyester circularity in Europe.

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Executive summary

Polyethylene terephthalate (PET) is used extensively across many industries – in particular, consumer packaging and textiles, where it is known as polyester.

The PET plastic molecule is used to manufacture beverage bottles, packaging trays and containers, and synthetic textiles used in the apparel, built environment, automotive, hygiene and industrial sectors. In total, PET/polyester comprises around one-quarter of all plastic packaging and the majority of synthetic textiles sold in Europe.

The PET/polyester system is mostly linear today.

PET bottles benefit from one of the most mature collection, sorting and recycling value chains in Europe, underpinned by an increasingly supportive legislative environment. Although around half of PET bottles are mechanically recycled, the recycling rates for all other PET/polyester product applications are low or non-existent. As a result, only 25% of PET/polyester is recycled, with the remainder largely ending up in landfill or incineration (energy recovery). Of the PET/polyester that is recycled, two-thirds is used to make products which do not have a clear recycling path today, the largest of these being polyester textiles. The lack of recycling paths for most non-bottle PET/polyester applications, combined with demand for recycled PET from multiple industries, puts growing pressure on recycled PET supply.

PET/polyester's abundant circularity potential has not yet been realised.

New technology developments and circular economy innovations are now emerging. These include further scale-up and development of mechanical recycling alongside new solutions such as chemical PET recycling; advanced waste sortation; re-commerce and rental models in the fashion sector; and packaging reuse or new delivery models for products with no or low packaging. The product applications and chemical properties of PET/polyester mean that it can be well suited to different circular economy approaches including reuse, mechanical recycling and chemical recycling via depolymerisation. Chemical PET recycling produces virgin-like recycled PET suitable for contact-sensitive – or 'food-grade' – applications. It also has lower greenhouse gas (GHG) emissions and higher material-to-material yields compared to thermochemical recycling technologies (eg, pyrolysis) typically used for chemical recycling of other plastic types in the municipal waste system.

These new circular economy approaches have not yet been combined in a system model and scenario assessment to evaluate their full potential for system circularity. With support from an independent multi-stakeholder Steering Group, Systemiq has carried out new quantitative system modelling, exploring the material flows and environmental implications of future scenarios for a high-circularity, low-emissions European PET/polyester system. This work has revealed four key insights, outlined in the following pages, on the current trajectory of this system, as well as what is required to achieve a high-circularity, low-emissions future.

Key insights

1

Ambitious application of known circular economy solutions could reduce landfill and incineration by 70% and halve greenhouse gas emissions in 2040.

Modelling shows that all solutions are needed together to achieve the system changes required to hit circularity targets (reduction, reuse, mechanical recycling and chemical PET recycling). This 'complementarity' approach would apply these different circular economy approaches to different product applications based on environmental outcomes and technology suitability. The approach – defined in an 'Ambitious Complementarity Scenario' – has the potential to achieve high levels of circularity by 2040. When compared to a continuation of historical trends, it could:

- **Reduce PET/polyester consumption by one-third**, by expanding the reuse of packaging and textiles and reducing avoidable PET/polyester usage.
- **Reduce PET/polyester sent to landfill and incineration by ~70%** (a reduction of 5.9 million tonnes (Mt) per year), by expanding separate waste collection, sortation, mechanical recycling and chemical PET recycling infrastructure. Average recycling rates could reach 67% across all applications.
- **Halve system-level GHG emissions** (reducing emissions by ~18Mt of carbon dioxide equivalent (CO_2e) per year by 2040).
- **Increase the supply of recycled PET suitable for new PET/polyester packaging and textiles to 4.7Mt/year**, such that proposed requirements for recycled content in the draft EU Packaging and Packaging Waste Regulation (PPWR) can be met and the volume of recycled PET/polyester (rPET) being used for textiles can be maintained or increased (the PPWR requires 2.8Mt/year of recycled content at projected PET packaging consumption rates to meet recycled content targets). The simultaneous application of both mechanical and chemical PET recycling technologies is needed to meet or exceed the proposed targets.

On top of these environmental outcomes, the estimated socio-economic co-benefits of this system change in Europe would include 28,000 net new jobs by 2040 and an additional €5.5 billion per year in revenues for recycling industries, compared to €2.5 billion in 2020.

Further research is needed into the release of micro-plastics during the life cycle of PET/polyester products and the accumulation and migration of substances of concern during reuse and recycling loops (for all materials, not only PET/polyester). These two potential system risks and their impacts on human health and natural ecosystems were not studied in this report and are highlighted as a research priority.

2

To build this high-circularity, low-emissions PET/polyester system, improvements are needed in every part of the system. Six priority actions are identified:

Three 'upstream' actions aim to slow the growth in demand for PET/polyester through business model changes and to design products for circularity:

- **Expand reuse to extend product lifetimes for packaging and textiles, and promote new delivery models for products to reduce packaging demand:**
  Examples include re-commerce in the fashion sector and a transition from single-use food and drink packaging to reusable containers. Scale-up requires a step change in industry investment, building on learnings from pilot initiatives, alongside clarity from policy-makers on important considerations such as safety, hygiene and liability standards; methods for the assessment of the environmental and social impacts of new models; and public financing support.
- **Reverse trends of high-consumption business models in the fashion sector ('fast fashion'):**
  Between 2000 and 2015, the number of times clothes were worn before disposal fell by 36%.[1] Faster turnaround of seasonal collections also contributes to unsold stock, which may be sent to landfill or incineration. The Ambitious Complementarity Scenario[a] presented in this report models a steady slowdown in polyester textile demand growth and stabilisation by 2040. This will require action from industry and consumers, together with new policies such as an ambitious extended producer responsibility scheme for textiles to transfer the cost and responsibility of waste management to producers and provide economic incentives to reduce overconsumption.
- **Standardise product design to improve reuse and recycling economics:**
  In many cases, shifts in bottle designs, such as from coloured/opaque to clear, and a transition from multimaterial to monomaterial packaging[b] and to less complex textiles, may be easy wins to increase recyclability and improve the quality and value of recycled PET. Design for recycling rules that consider chemical PET/polyester recycling are needed, alongside existing rules covering design for mechanical recycling. Some design shifts, such as from coloured/opaque to clear bottles for light-sensitive products, may no longer be required if chemical PET recycling scales up. This would allow for continuation of opaque/coloured PET usage for light-sensitive products and mitigate the risk that design modifications such as shrink sleeves on clear PET bottles interfere with sorting or recycling processes.

a. The Ambitious Complementarity Scenario refers to a PET/polyester system performing at or near the peak, as defined by the current best-in-class for every stage of the system. This includes measures to slow PET consumption, design for recyclability, mechanical and chemical PET recycling, as well as increases in waste collection and sortation rates.

b. Some coloured/opaque and multi-material formats will still be required for specific product applications.

Three ‘downstream’ actions aim to put in place the complementary mechanical recycling and chemical PET recycling systems needed to deliver significant increases in recycling rates and availability of recycled PET/polyester suitable for new packaging and textiles:

- **Secure long-term demand for recycled PET/polyester:**

  In the Ambitious Complementarity Scenario, the supply of recycled PET in 2040 would be three times higher than in 2020. To ensure that demand for recycled PET/polyester drives the system to its full circularity potential, recycled content requirements are recommended across all end-use applications, including textiles. Companies using PET/polyester should enter into long-term offtake agreements with recyclers, ensuring long-term offtake security and de-risking investments for the recycling sector.

  Imports of recycled PET (or PET plastic waste for recycling) into Europe should be carefully assessed to ensure that this trend does not affect confidence in the safety of recycled PET or undermine investment in collection and recycling infrastructure in Europe.

- **Develop sufficient high-quality feedstock flows for recyclers by improving collection and sorting:**

  To achieve a ~75% (2.6Mt) increase in PET/polyester collected for recycling in the Ambitious Complementarity Scenario, effective deposit return schemes for bottles and separate collections for after-use textiles will be needed across Europe. The development of proportionate waste sortation capacity will also be required to ensure this waste is of appropriate quality for recyclers.

  Collection policies should be paired with policies to reduce waste to landfill or incineration (eg, banning the destruction of unsold or returned textiles and the incineration of recyclable packaging). The public and private sectors should collaborate to design and enact principles for the complementarity of mechanical and chemical PET recycling to ensure favourable environmental outcomes and build investor confidence in feedstock supplies.

- **Scale up recycling infrastructure and optimise performance:**

  The Ambitious Complementarity Scenario would see mechanical recycling volumes increase by two-thirds, from 2.0Mt in 2020 to 3.3Mt in 2040. Chemical PET recycling will need to bring 2.1Mt of capacity online by 2040 (including 0.4Mt ‘announced’ capacity that is not yet online in Europe today).[2] Scale-up of chemical PET recycling would enable the conversion of harder-to-recycle PET/polyester waste (eg, textiles, trays, coloured/opaque bottles and waste from mechanical PET recycling) into a contact-sensitive, virgin-like material. This has the effect of ‘recharging’ the system with virgin-like recycled PET without the need for fossil-based feedstocks.

  Complementary development of mechanical and chemical PET recycling could also serve to make the system more resilient – for example, to a failure to reduce overall PET/polyester consumption – or to achieve a large-scale transition from coloured/opaque to clear bottles, as required under design-for-recycling rules.

  The current lack of clarity in the regulatory treatment of recycling technologies (including controlled blending and mass balancing approaches) is a significant barrier to investment in new infrastructure. In the case of chemical PET recycling, the planning and construction timeline can often stretch to many years, putting at risk the achievement of regulatory targets. Recycling capacity will need to scale quickly to achieve targets set out in the EU Single Use Plastics Directive. This includes the provision of enough rPET to meet 2025 and 2030 recycled content targets and enough capacity to process a beverage bottle collection-for-recycling rate requirement of 90% by 2029. The public sector will need to facilitate conditions for investment in both mechanical and chemical PET recycling by providing policy certainty as quickly as possible and accelerating necessary permitting processes for related projects.

3

Further efforts and technology/ system innovations will be required beyond this Ambitious Complementarity Scenario to close the remaining gap on circularity and align with Europe's net-zero commitment by 2050.

Even in the Ambitious Complementarity Scenario, 2.8Mt of non-recycled PET/ polyester waste and 17.5Mt CO_2e of GHG emissions will still be generated per year. Further reductions in the levels of non-recycled waste and GHG emissions could be achieved through greater improvements in textile waste collection and sortation; carbon capture on waste incineration plants; electrification of petrochemicals facilities used for virgin PET/polyester production; and replacement of remaining fossil-based feedstocks with captured carbon, green hydrogen and biomass. These additional levers have not been modelled in this study.

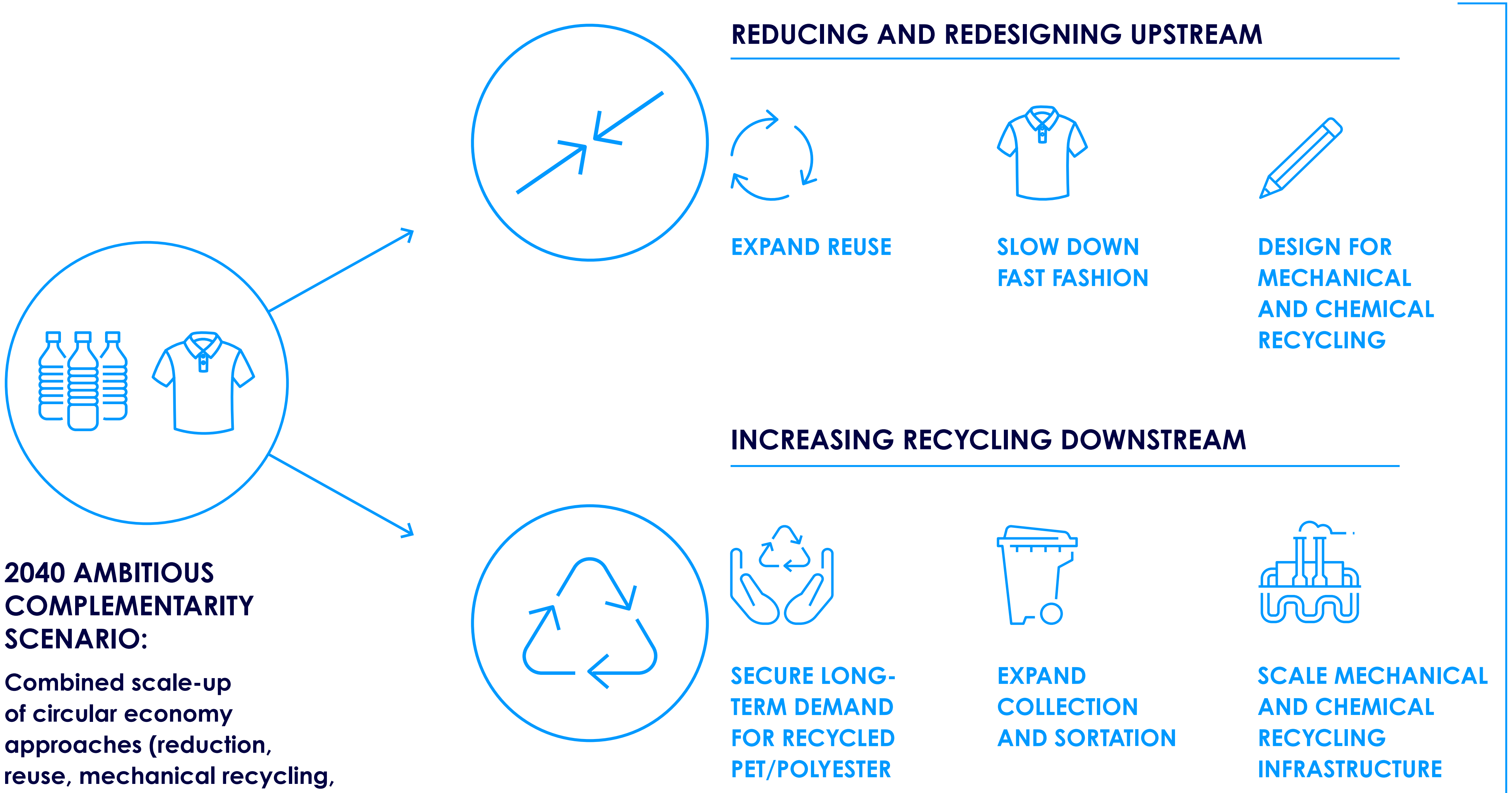
4

Achieving the circularity potential of PET/polyester in Europe requires action from policy-makers and industry.

Additional regulatory clarity is still required to build investor confidence and unlock the multibillion-euro investments that will be required to bring these system changes to life – for example, on recycled content calculations under the Single Use Packaging Directive and Packaging and the PPWR, and on fair and practical principles for feedstock allocations between mechanical and chemical recycling.

With these additions alongside enactment of an ambitious PPWR and EU Textiles Strategy, investors can have confidence that circularity of PET/polyester is an investible business opportunity for the coming decade. Given the timelines for infrastructure developments, there is now great urgency for the new investments, actions, value chain building approaches and public-private collaborations that are required to bring this circular economy vision to life.

Fast facts



2040 AMBITIOUS COMPLEMENTARITY SCENARIO:

Combined scale-up of circular economy approaches (reduction, reuse, mechanical recycling, chemical PET recycling)

THE BENEFITS

Relative to a continuation of historical trends, 2040 could see:

- 1/3 LESS PET/POLYESTER CONSUMPTION
- 70% LESS PET/POLYESTER TO LANDFILL AND INCINERATION
- 50% LOWER GHG EMISSIONS

Socio-economic benefits could also be significant:

- 28,000 NEW JOBS[a]
- €5.5 BILLION ADDITIONAL RECYCLING REVENUES[b]

a. Net new jobs across the PET/polyester value chain compared to 2020. Accounts for job losses in the waste management sector outside recycling.

b. Estimated revenue figures only account for the sale of recycled PET produced by the system. They do not account for other additional revenues in the PET/polyester supply chain or lost revenues – for example, in landfill and incineration.

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Introduction

1.1

About this report: a system model to assess future circularity pathways for PET/polyester in Europe

Report objectives

This report has three main objectives:

1) To produce a data-driven PET/polyester flow model and scenario analysis for the European PET/polyester system, which is well understood and supported by key stakeholders and which explores the role that chemical PET recycling could play alongside reuse, mechanical PET recycling and demand reduction in a circular economy.

2) To use the insights generated from the scenario analysis to prioritise interventions and inform strategies and resource allocation for all stakeholders in the value chain (private and public sector, as well as civil society), and inform policy-making according to desired environmental outcomes.

3) To strengthen the partnership and collaboration between industry, the public sector and civil society by enabling evidence-based conversations between all stakeholders to explore different strategies for achieving a better PET/polyester system in Europe.

System change scenarios

Scenarios have been modelled to establish potential pathways towards system circularity and reduction of greenhouse gas (GHG) emissions. These scenarios are not forecasts; nor are they the only possible scenarios. They provide multiple views from an almost infinite number of potential scenario variations, in order to generate insights on different system change pathways, impacts and trade-offs.

The scenarios were developed by identifying six system change levers (Exhibit 1) and then estimating the maximum plausible efficacy of these levers based on the level of best-in-class performance as of today,[a] over the 2020-2040 time series. A Historical Trends Scenario and an Ambitious Complementarity Scenario provide an assessment of the full potential impact of circularity levers, while the impact of specific sensitivities on the system is also investigated.

- **Historical Trends Scenario:** Historical trends in PET/polyester consumption and collection for recycling continue, with no technological improvement in waste sortation or mechanical recycling and no chemical PET recycling capacity. This scenario does not assume that enacted or draft regulatory targets are met.
- **Ambitious Complementarity Scenario:** This represents the maximum plausible efficacy of all six levers, including reuse, mechanical PET recycling and chemical PET recycling (depolymerisation), with each complementing the system according to environmental outcomes and technology suitability. This is a system performing at or near the peak, as defined by the current best-in-class for every stage of the PET/polyester system.

Measures to slow demand growth are applied only to the Ambitious Complementarity Scenario; while the European electricity grid is assumed to decarbonise in the same way across both scenarios.

a. Best-in-class is based on existing technologies/operating models at scale and commercially available in 2020. Refer to the Technical Appendix for best-in-class system assumptions.

Exhibit 1

System interventions modelled under each scenario

● Reduce ● Substitute ● Recycle

Modelled at the level of historical trends | Maximum foreseeable level

System interventions		Historical Trends Scenario[a]	Ambitious Complementarity Scenario
A	Eliminate avoidable PET/polyester and switch to reusables	Modelled at the level of historical trends	Maximum foreseeable level
B	Substitute PET/polyester for better alternatives	Modelled at the level of historical trends	Maximum foreseeable level
C	Design for recyclability	Modelled at the level of historical trends	Maximum foreseeable level
D	Expand collection for recycling and sortation	Modelled at the level of historical trends	Maximum foreseeable level
E	Scale up and improve mechanical recycling	Modelled at the level of historical trends	Maximum foreseeable level
F	Scale up and improve chemical PET recycling		Maximum foreseeable level

System change levers to improve PET/polyester circularity:

A) **Eliminate avoidable PET/polyester and switch to reusables:** Includes eliminating PET/polyester (eg, product redesign, reduced overpackaging, reduced production waste through better manufacturing), introducing new product delivery models (eg, reuse, refill services and dispensers) and promoting consumer behaviour shifts (eg, switching to refillable water bottles). Together, these measures help to slow PET/polyester consumption growth.

B) **Substitute PET/polyester for better alternatives:**[b] Switching to alternative materials, such as fibre-based trays, where these are suitable for incumbent PET/polyester applications from a functional standpoint. This is also advantageous when considering environmental impacts across their full lifecycle. This helps to slow PET/polyester consumption growth.

C) **Design for recyclability:** Includes a shift to clear and monomaterial formats for packaging,[c] higher polyester purity textiles and other measures that facilitate more effective sortation and recycling.

D) **Expand collection for recycling and sortation:** The scale-up of separate waste collection and sortation systems, such as for textiles.[d]

E) **Scale up and improve mechanical recycling:** Further PET-to-PET yield rate improvements and expansion of acceptable feedstock such as pots, tubs and trays (PTT). Scale up capacity to keep pace with feedstock supply.

F) **Scale up and improve chemical PET recycling:** This technology can recycle some PET/polyester applications which mechanical recycling cannot, while also elevating PET/polyester waste to virgin-like quality in cases where it has deteriorated through successive mechanical recycling loops and product applications. Circularity lever includes significant construction of new plants across Europe, continued widening of feedstock acceptance and improved PET-to-PET yield.

a. This scenario does not assume that enacted draft regulatory targets are met and instead broadly follows trends in system performance seen in recent years.
b. Substitution into PET/polyester from other materials has not been modelled and is considered to be implicit in the consumption growth rates in the Historical Trends Scenario.
c. Some design shifts, such as from coloured/opaque to clear bottles for light-sensitive products, may no longer be required if chemical PET recycling scales up. This would allow for continuation of opaque/coloured PET usage for light-sensitive products and mitigate the risk that design modifications such as shrink sleeves on clear PET bottles interfere with sorting or recycling processes.
d. Improved recovery of PET/polyester from mixed waste has been modelled but is understood to be much more challenging than recovery from pre-sorted, clean waste.

Key definitions

Chemical PET recycling

'Chemical PET recycling' in this report refers specifically to depolymerisation, which is currently the most commercially ready category of chemical recycling available for recycling a variety of PET/polyester waste products into virgin-like PET. The key subcategory technologies used to undertake chemical PET recycling (ie, methanolysis, hydrolysis and glycolysis) are not modelled separately in this study, so environmental parameters are an average between these approaches. Depolymerisation differs from other types of chemical recycling, such as pyrolysis, which are much more challenging to apply to PET/polyester (Exhibit 3).

Complementarity

'Complementarity', as defined in this report, refers to the simultaneous deployment of different circular economy approaches (reduction, reuse, mechanical recycling and chemical PET recycling) to different product applications based on environmental outcomes and technology suitability.

Further details of the allocation approach between mechanical recycling and chemical PET recycling can be found in the Technical Appendix.

1.2

European PET/polyester system today

This work builds on the first synthesis report, "Circularity of PET/polyester packaging and textiles in Europe – Synthesis of published research".

The first report highlighted the benefits of PET/polyester in the packaging and textiles sectors, where PET/polyester accounted for ~20-25% of plastic packaging and ~70-90% of synthetic textiles consumed in Europe as of 2020. It showed that the system is mostly not circular today (around three-quarters of PET/polyester ends up as non-recycled waste), and is reliant on fossil-based feedstocks derived from oil and natural gas (Exhibit 2). The report profiled the successful achievement of high recycling rates in some parts of the system (eg, plastic beverage bottles), and the emergence of new chemical PET recycling technologies suitable for some applications that have low recycling rates today (eg, polyester-rich textiles, opaque PET bottles, some pots, tubs and trays (PTTs), as well as losses from PET mechanical recycling), and which may not be suitable for mechanical recycling (Exhibits 3 and 4).

The PET/polyester system is mostly not circular today and reliant on fossil-based feedstocks derived from oil and natural gas

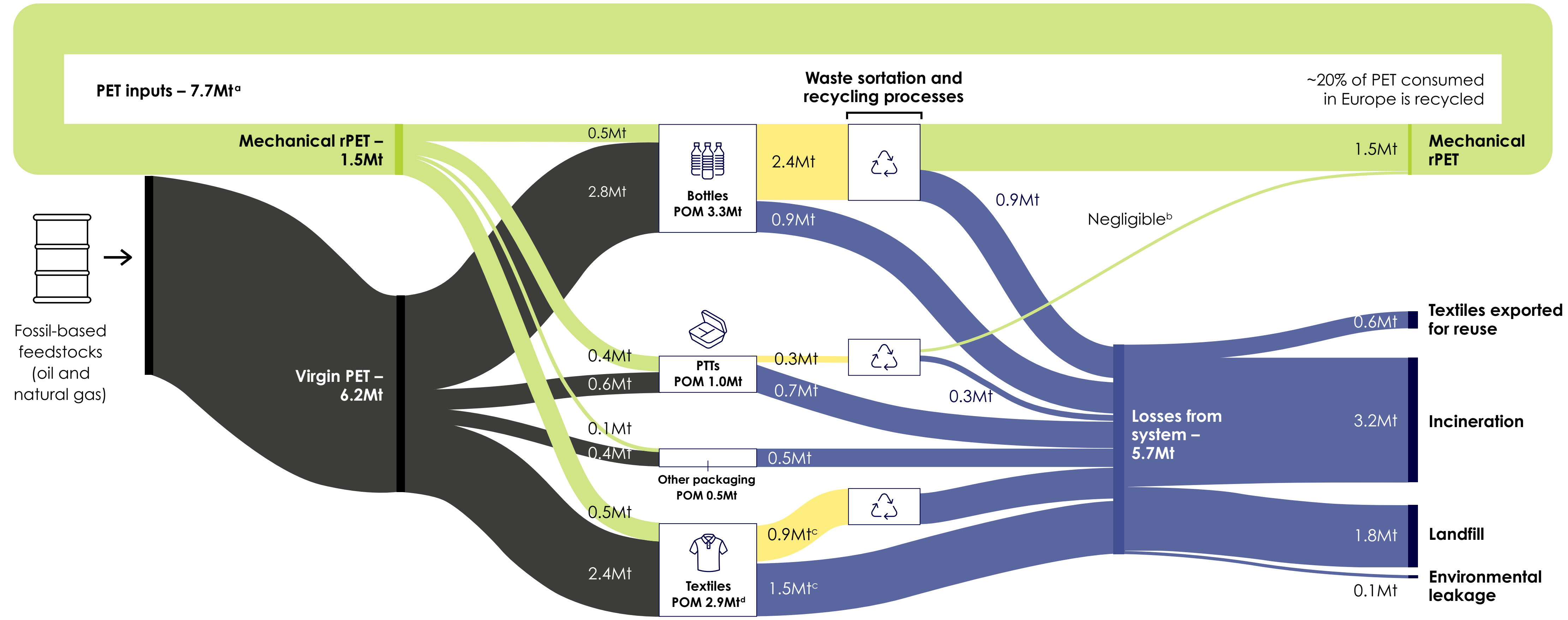
Exhibit 2

A PET/polyester flow map for Europe illustrates low circularity, with only 1.5Mt of 7.7Mt total PET demand from recycled sources, and only PET bottles being recycled at scale

European PET/polyester flows, 2020

Million tonnes

- Seperately collected waste
- **POM** – Put on market
- **PTTs** – Pots, tubs and trays
- Waste sortation and recycling processes



a. Represents mid-point of 7.4-8.0Mt range.

b. Although estimates for PET PTTs sorted for recycling in 2020 are around 20% of the mass put on the market in EU27+UK, estimates of the actual amount recycled into rPET are not available. Expert input indicates that this could be as low as 0.05Mt, with a significant degree of uncertainty; as such, here it is considered negligible.

c. Textiles put-on-market (POM) is 2.9Mt. In the same year, textile waste generation (from textiles put-on-market in previous years) is 2.4Mt.

d. Represents the mid-point of a 2.6-3.2Mt range.

Note: There are some differences in the figures shown in this exhibit, compared to the first report in this PET/polyester series at the time of publication (it has subsequently been updated to be consistent with this exhibit). This is due to differences in the estimation methods used at the outset of this study as compared to the results from modelling undertaken since the release of the first report. References to 2020 are based upon the revised estimates taken from the modelling.

Exhibit 3

‘Chemical recycling’ captures a range of technologies, not all of which are applicable to PET/polyester, and which have significant differences

There are three main types of depolymerisation (referred to as ‘chemical PET recycling’ in this report).

● Technologies not available or emerging for PET/polyester material-to-material recycling at scale in Europe and therefore not in-scope for this study and modelling[a]

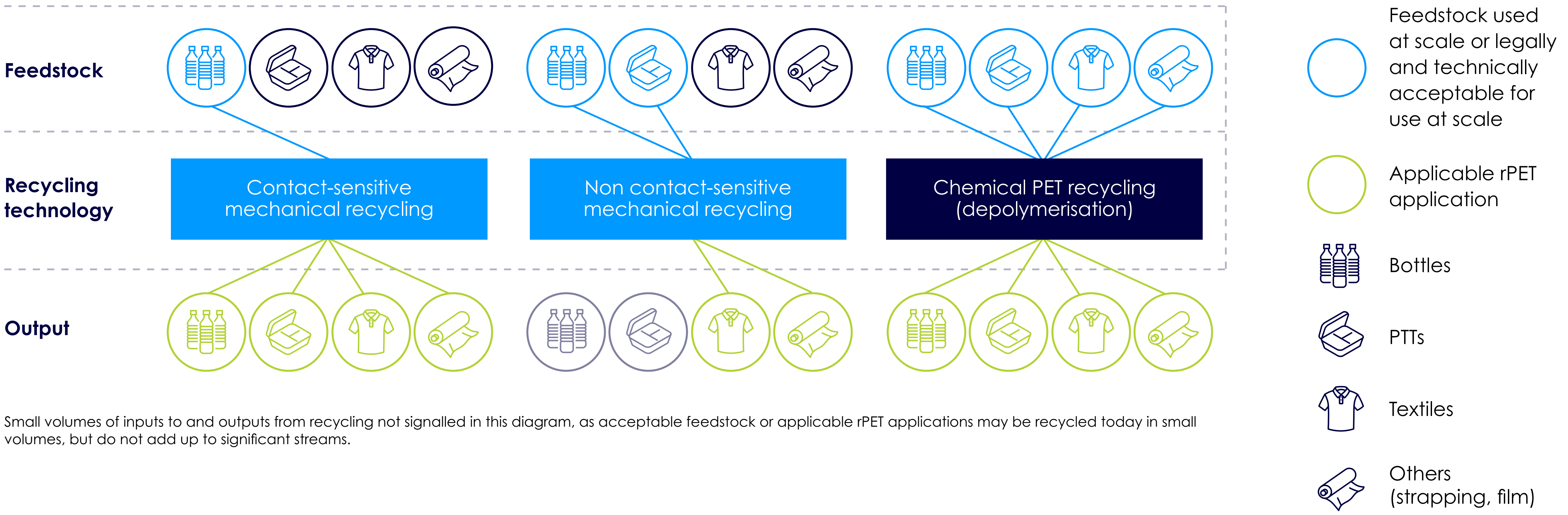
	Mechanical		Chemical recycling				
Recycling method	Mechanical Recycling technologies that do not significantly change the chemical structure of the PET/polyester waste feedstock and leave the polymer chain intact		Depolymerisation (‘chemical PET recycling’) Recycling technologies that break PET/polyester polymers down into smaller molecules (monomers or oligomers) that are reconstituted back into PET/polyester with the same properties as virgin PET			Pyrolysis The breakdown of polymers into hydrocarbons (‘pyrolysis oil’) and other by-products by heating to high temperatures in anaerobic conditions	Gasification The breakdown of polymers into dihydrogen and carbon dioxide (‘syngas’) in a controlled oxygen environment by heating to high temperatures
Sub-types + descriptions	Mechanical recycling Sortation, size reduction, cleaning and extrusion of PET/polyester waste feedstock to produce recycled PET polymers for use in new products[b]	Solvent-based recycling Processes used to dissolve the PET polymer and subsequently precipitate it again by temperature or antisolvent	Methanolysis PET/polyester depolymerisation technology using methanol as a reagent to break down PET/polyester	Hydrolysis PET/polyester depolymerisation technology using water as a reagent to break down PET/polyester	Glycolysis PET/polyester depolymerisation technology using ethylene glycol as a reagent to break down PET/polyester		

a. For justifications on technologies considered to be in and out of scope for this report and modelling, see the Technical Appendix.
b. May also include solid-state polymerisation and the addition of further chemicals such as stabilisers, depending on the required properties of the final material/product.

Exhibit 4

Chemical PET recycling accepts a broader range of feedstock than mechanical recycling and creates rPET that can be used for a wider variety of applications.[a]

Chemical PET recycling generates higher GHG emissions than mechanical recycling, but lower GHG emissions than creating virgin PET/polyester from fossil-based feedstocks. The means that chemical PET recycling can complement mechanical recycling by maximising the waste that can be recycled, while minimising system emissions.



Small volumes of inputs to and outputs from recycling not signalled in this diagram, as acceptable feedstock or applicable rPET applications may be recycled today in small volumes, but do not add up to significant streams.

a. This is because it can process some hard-to-recycle PET waste, such as textiles, into virgin-equivalent PET, suitable for contact-sensitive applications such as beverage bottles and food trays.

Note: Exhibit adapted from Closed Loop Partners, "Transition to a Circular System for Plastics" to PET/polyester applications. See previously published Systemiq report in this PET/polyester series, "Circularity of PET/polyester packaging and textiles in Europe – Synthesis of published research", for analysis of GHG emissions by recycling technology.

1.3

Historical Trends Scenario

If historical trends continue, growth in demand for PET/polyester, combined with stagnated overall recycling rates, will drive waste volumes and emissions upwards, with draft legislative targets missed as a result.

The Historical Trends Scenario follows the trajectory of the system according to rates of development seen across the sector in recent years. This scenario assumes only moderate development of some circularity levers, excludes chemical PET recycling and does not assume that enacted or draft regulatory targets are met.[a]

Impact

In this scenario, consumption of PET/polyester and waste creation rise by almost 50% by 2040. A modest increase in separate collections of PET packaging and polyester textiles waste sees more of this material being made available to waste sorters and mechanical PET/polyester recyclers, which scale up capacity in line with increased demand.[b] However, with significant quantities of PET/polyester waste still lost to mixed waste collections, and without an effective recycling solution in place for polyester textiles or PET PTTs, volumes of non-recycled PET/polyester waste increase. In combination with harder-to-recycle PET/polyester products forming an increasingly large share of consumption by 2040 (eg, textiles and PTTs), PET/polyester's overall recycling rate is 23%, down slightly from 24% in 2020. In parallel, the shift from landfill to incineration continues, resulting in incineration of PET increasing 112%, from 3.2 million tonnes (Mt) in 2020 to 6.8Mt in 2040. The result is that system-wide GHG emissions increase 29%, from 27.0Mt to 34.7Mt, driven by increased production and incineration of PET/polyester. Electricity grid decarbonisation reduces emissions from production, conversion and recycling, but is offset by a reduction in energy generation credits applied to incineration.

a. For example, beverage bottle collection rates of 90% by 2029 under the Single Use Plastic Directive. The Historical Trends Scenario represents a poorly performing future scenario where targets have no influence on trajectory. This may be somewhat unlikey but it serves as a baseline at a time when many targets remain uncertain, given that the Packaging and Packaging Waste Regulation (PPWR) remains in draft form and targets for textiles are still to be developed.

b. Sortation of both separately collected PET packaging and textiles is assumed to scale, while only mechanical recycling of packaging scales as sorted waste increases. In the case of textiles, current exports for reuse and downcycling activities are assumed to be saturated; therefore, additional textiles collected are sent to landfill and incineration. 'Downcycling' in this report specifically refers to the mechanical processes used to recycle polyester-containing textiles into applications which are typically not themselves recycled at end of life – for example, due to a lack of targeted collections, technical difficulties or economic barriers. These include furniture stuffing, automotive uses and building insulation. However, the term 'downcycling' in general has no commonly agreed definition.

Exhibit 5

If historical trends continue, consumption of PET/polyester and non-recycled[a] waste volumes will increase significantly

Historical Trends Scenario

European PET/polyester flows, 2040

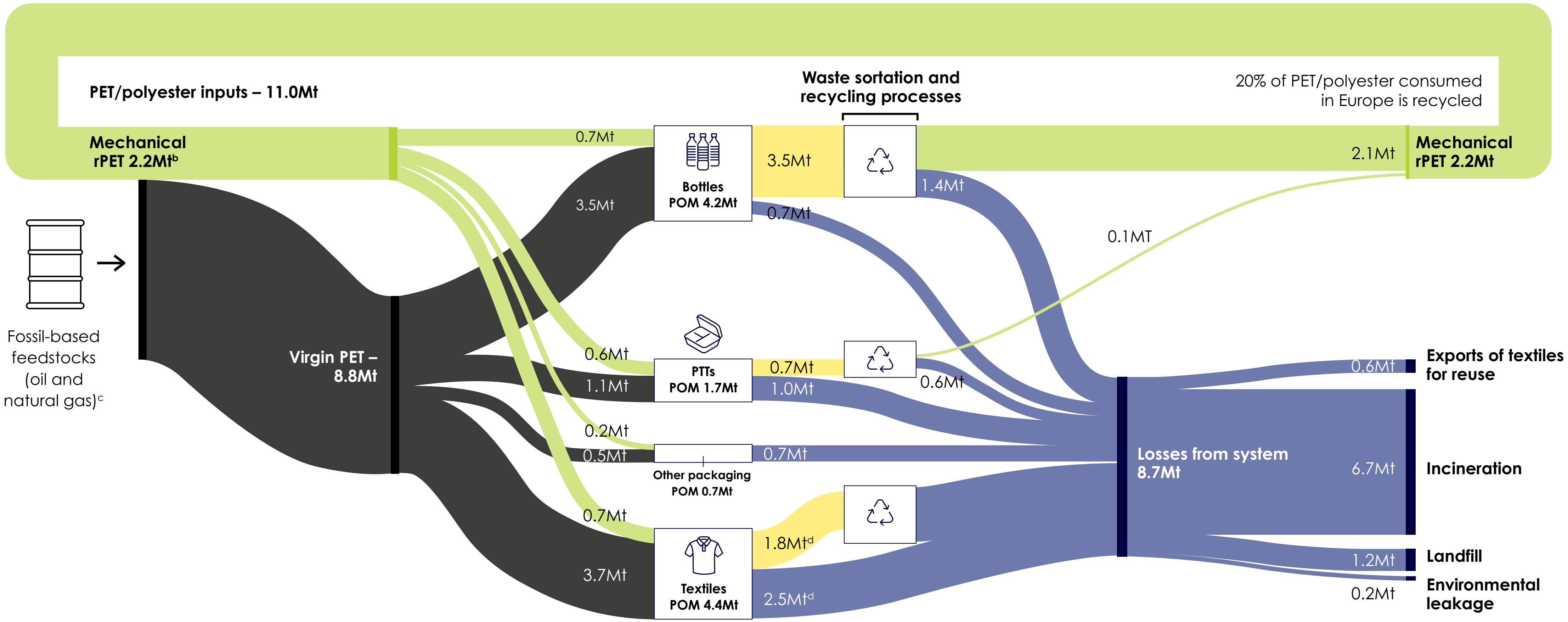
Mt/year

Seperately collected waste

POM – Put on market

PTTs – Pots, tubs and trays

Waste sortation and recycling processes



a. Non-recycled PET/polyester in this report includes losses to mixed waste, losses from sorting facilities, losses from recycling processes and losses of textiles to downcycling (eg, stuffing and insulation). It also includes environmental leakage inside Europe and exports of reusable textiles from Europe (which may not be recycled at end of life).

b. For purposes of this exhibit, rPET has been distributed to product applications in proportion to the total consumption of PET/polyester by each application.

c. Bio-based feedstock has not been considered in this modelling exercise.

d. Textiles POM is 4.4Mt. This volume goes to stock (as it is being used for several years). Textile waste generation (from textiles consumed in previous years) is 4.3Mt.

Future circularity pathways of PET/ polyester in Europe

2.1

Ambitious Complementarity Scenario

A highly circular, lower-emissions PET/polyester system can be achieved with complementary circular economy solutions that exist today.

The **Ambitious Complementarity Scenario** applies known circular economy solutions (measures to slow demand growth, design for recyclability, reuse, mechanical recycling, chemical PET recycling) to different product applications based on environmental outcomes and technology suitability. Each circular economy solution in the scenario is applied in 2040 at the level of best-in-class today. For example, the scenario assumes that the highest bottle collection rate achieved by a European country today can be achieved as a European average in 2040. It is therefore intended to be ambitious, yet also realistic.

Ambitious Complementarity Scenario overview

By 2040, the Ambitious Complementarity Scenario could see the following changes take place across Europe.

- **Demand mitigation measures** – such as the elimination of unnecessary packaging and textile production waste, as well as an increasing focus on reuse – could bring overall PET/polyester consumption and subsequent waste creation to 7.2Mt, one-third lower than projected under the Historical Trends Scenario and slightly lower than in 2020 (Exhibit 10).
- **Design for recyclability** is widely adopted to remove elements that interfere with effective sorting or recycling and to improve the economics of both mechanical and chemical PET recycling.[a]
- **Separate collection for recycling** rates for key PET/polyester product categories could improve significantly in line with best practices found today in Europe: bottles reach ~95% on average[b] (up from 71% in 2020); PTTs reach 92% (up from ~25%); and textiles reach 75% (up from 38%). This also requires PET/polyester waste sorting input capacity to grow to almost 6.2Mt across both packaging and textiles, up from 3.5Mt in 2020.[c]
- **Recycling input capacity** could scale to a total of 5.4Mt[d] (up from 2.0Mt in 2020).[e] Chemical PET recycling could make up ~40% – or 2.1Mt – of this PET/polyester recycling capacity. This would require a rapid growth of the chemical PET recycling industry, so that by 2040 it has grown to approximately the same size as the mechanical PET recycling industry in 2020 (Exhibit 7). Average PET-to-PET recycling yield rates for both processes could reach close to 90%[f] and the system could produce a total of 4.7Mt of recycled PET to use in new products. This creates a system where two-thirds of all PET/polyester demand can be met by recycled PET/polyester.
- **Allocation of rPET:**[g] Modelling outcomes are not affected by the distribution of mechanically and chemically recycled PET/polyester between products. For simplicity, Exhibit 6 shows a scenario where mechanically and chemically recycled PET/polyester are distributed in proportion to demand for each product application (ie, by product category market share). In a hypothetical alternative rPET allocation, if bottle-to-bottle mechanical recycling were maximised, the virgin PET (or virgin equivalent from chemical PET recycling) 'recharge' level in the bottle system would be ~17%. There is currently insufficient evidence to determine whether this is acceptable for product quality and human health, although it is a lower level of virgin 'recharge' than is commonly assumed is required in the long term.

The impact of the Ambitious Complementarity Scenario on flows of PET/polyester is illustrated in Exhibit 6 and on the physical fate of PET/polyester in Exhibit 7.

a. The evolution of design-for-recycling requirements by 2040 will be dependent on material and product innovation as well as developments in chemical and mechanical recycling technologies. The scenario considers a high level of design changes whereby almost 95% of bottles are colourless and transparent by 2040 (up from 75% in 2020); 94% of PTTs are colourless, transparent and monolayered (40% in 2020); and 90% of polyester is contained within textiles that are at least 80% polyester content (up from ~80% in 2020).

b. For bottles, this is enabled by the widespread adoption of deposit return schemes. For PTTs, some innovation may be required to achieve these rates, such as the application of best practices in European countries that are already achieving very high collection rates for similar products (eg, bottles in Belgium). These might include 'pay-as-you-throw' systems to directly disincentivise the creation of mixed waste, as well as effective public behaviour change campaigns to encourage the adoption of new systems. Note that the total collection for recycling rates are even higher than these figures, as this scenario envisions some sortation for recycling of the PET/polyester within mixed waste streams. This means total collection rates are 97% for bottles, 96% for PTTs and 77% for textiles.

c. Note this figure is for PET/polyester sorting only. However, if non-PET recyclate collection rates also increase over the same period, total sortation input capacity may need to be significantly higher. Additionally, this figure does not take into account sortation capacity requirements at mixed waste processing facilities; includes sortation for both reuse and recycling in the case of textiles; and does not include the weight of non-PET material, such as contaminants, caps, lids and labels for packaging and non-PET in textile blends. The sorting capacity for PET/polyester contained within mixed waste amounts to an additional 1.4Mt.

d. Note that these figures are estimated on the basis of both mechanical recycling and chemical PET recycling developing their own end-to-end processing capacity, as opposed to sharing processing capacity, including pre-sortation, washing, size reduction and other feedstock preparation etc. Additionally, as this model has focused on PET/polyester mass flows only, value chain actors will have to plan and build for movements of non-PET materials/components that are typically transported alongside PET/polyester (eg, non-target materials, non-PET/polyester parts of products (lids, labels, non-polyester fibres in blended textiles etc), food and liquid contamination).

e. Note that these figures do not include textile downcycling as this does not produce rPET. It is assumed that the European textile downcycling industry stays at a constant size of 0.3Mt per year.

f. Note that all yield rates are PET-to-PET only and do not include non-PET/polyester. Measured as the weight of recycled PET created divided by the weight of PET/polyester waste entering the recycling facility. Given the lack of data on PET-to-PET only yield rates, these figures may be an underestimate of actual values; however, this is not expected to have a significant impact on the conclusions. Additionally, feedstock-specific yield rates for chemical PET recycling are generally not available and more research is needed in this area.

g. For further information on the specific proportions of each type of collected and sorted PET/polyester waste feedstock allocated to different kinds of recycling in this scenario, see the Technical Appendix.

- **Incineration and landfill** of PET/polyester waste could decrease to 2.2Mt, a reduction of 70% compared to the Historical Trends Scenario.
- **Recycling rates**[h], which represent the proportion of waste that is both successfully collected and sorted for recycling, could reach 67% (up from 23% in the Historical Trends Scenario), with packaging achieving a recycling rate of ~80% and textiles ~45% (Exhibit 8).
- **Draft regulatory targets** for PET packaging could be met or exceeded. By 2040 the system could create 1.9Mt more rPET than needed to meet draft Packaging and Packaging Waste Regulation (PPWR) requirements for minimum recycled content in PET packaging (Exhibit 8). Of the 4.7Mt of total rPET created, this includes 2.0Mt of contact-sensitive PET from bottle-to-bottle mechanical recycling and 1.9Mt of virgin-like PET created through the chemical PET recycling of various feedstocks (Exhibit 8).
- **GHG emissions** could reach 17.5Mt of carbon dioxide equivalent (CO_2e) per year across the full PET/polyester value chain – half that emitted under the Historical Trends Scenario (Exhibit 9).
- **Jobs** could be created across the PET/polyester value chain, in particular in reuse models and recycling infrastructure, totalling 28,000 net new roles.[i]
- **Revenue** could be increased for the PET/polyester recycling industry by €5.5 billion, compared to €2.5 billion in 2020.[j]

h. Recycling rates are based upon the revised European Commission definition as set out under Directive 2008/98/EC (as this definition is used in the November 2022 draft PPWR proposal), and are taken as the weight of homogenous, prepared and sorted recyclate at the input of the recycling process (ie, before any extrusion steps take place in the case of packaging rPET), divided by the total weight of this kind of waste arising (whether separately collected or not).

i. Net new jobs across the PET/polyester value chain compared to 2020. Accounts for job losses in the waste management sector outside recycling.

j. Estimated revenue figures only account for the sale of recycled PET produced by the system. They do not account for other additional revenues in the PET/polyester supply chain or lost revenues – for example, in landfill and incineration.

Exhibit 6

The Ambitious Complementarity Scenario could reduce non-recycled waste volumes and significantly increase the supply of recycled PET/polyester by 2040

Ambitious Complementarity Scenario

European PET/polyester flows, 2040

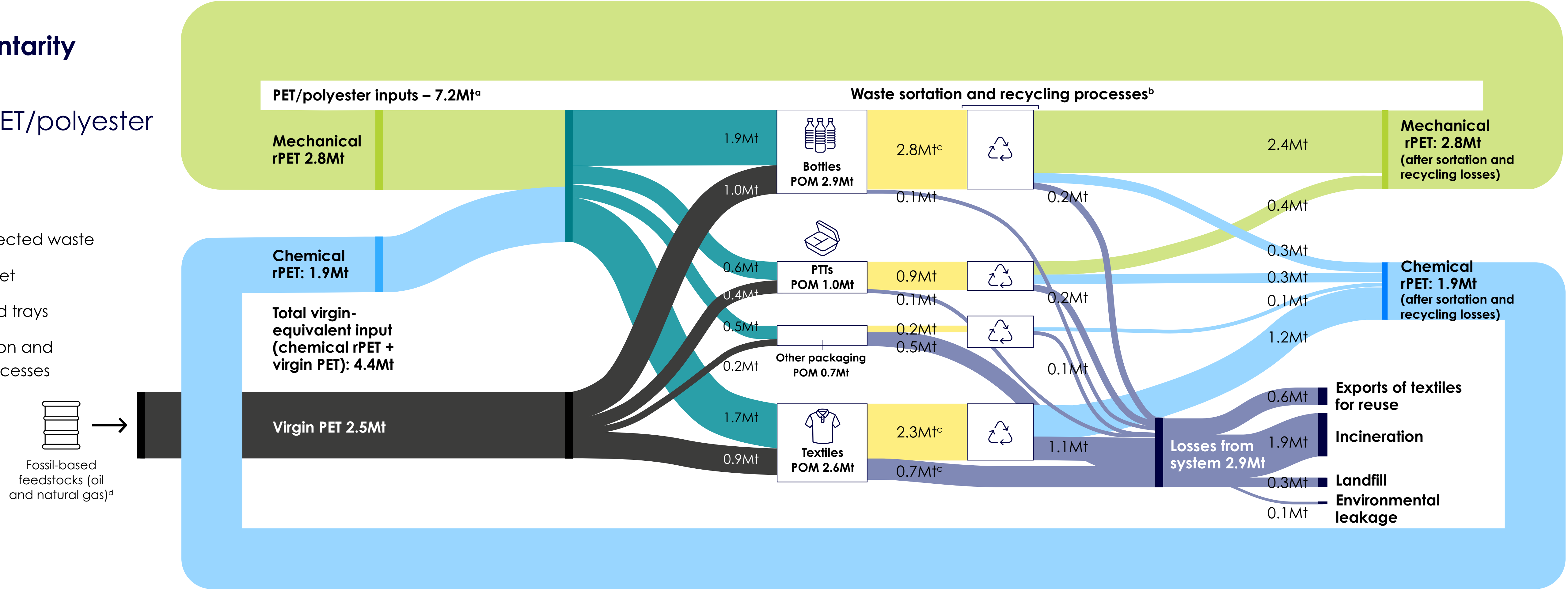
Mt/year

Seperately collected waste

POM – Put on market

PTTs – Pots, tubs and trays

Waste sortation and recycling processes



a. The exact proportions of mechanical versus chemical rPET allocated to any specific new PET/polyester product application will be driven by many factors. These could include rPET prices, rPET grade, the maximum percentage of a given type of rPET that research establishes is appropriate for a given product type (eg, bottles), industry agreements and regulations. Given this uncertainty, rPET has been distributed to product applications in proportion to the total consumption of PET/polyester by each application and no views regarding the most appropriate mix of chemical versus mechanical rPET are put forward.

b. For simplicity, these boxes represent all of the waste sortation, feedstock preparation and recycling processes (including both mechanical and chemical PET recycling) required to generate recycled PET from collected PET/polyester waste. The outputs of these boxes are recycled PET and losses from sortation and recycling processes. Most of the process losses from mechanical recycling are subsequently allocated as feedstock to chemical PET recycling.

c. Textiles put-on-market is 2.6Mt. Textile waste generation (from textiles put-on-market in previous years) is 3.0Mt.

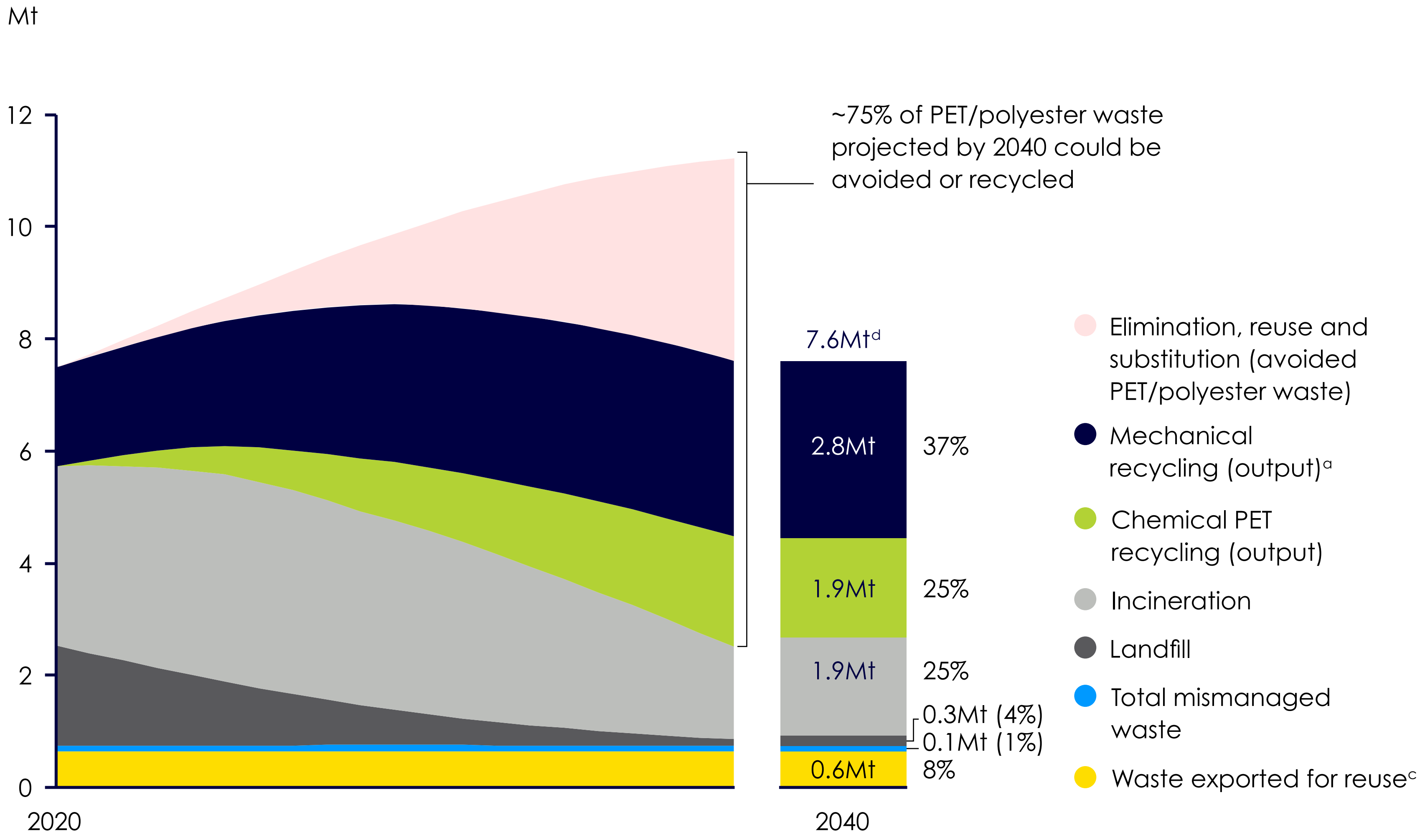
d. Bio-based feedstock has not been considered in this modelling exercise.

Exhibit 7

Circularity solutions could ensure that three-quarters of projected PET/polyester consumption by 2040 is avoided or recycled

- The Ambitious Complementarity Scenario avoids ~one-third (3.9Mt) of PET/polyester consumption projected by 2040 in the Historical Trends Scenario through reuse, reduction and substitution measures. Together with mechanical recycling and chemical PET recycling, this could ensure that a total of ~75% of projected PET/polyester waste is avoided or recycled.
- Of the PET/polyester projected to be consumed in 2040 once reuse, reduction and substitution measures have been applied, the output from mechanical recycling[a] could comprise 37% (2.8Mt), while the output from chemical PET/polyester recycling could comprise 25% (1.9Mt). The result is that landfill and incineration of PET/polyester could fall by ~70% by 2040, from 7.9Mt in the Historical Trends Scenario, to 2.2Mt in the Ambitious Complementarity Scenario.
- Recycling rates of ~45% for polyester textiles would continue to trail PET packaging rates of ~80% in the Ambitious Complementarity Scenario. Both would represent a substantial gain on the 2020 rates of 10% and 32% for textiles and packaging respectively.
- 0.6Mt of polyester textiles have been assumed to continue to be exported outside Europe for reuse. Today, some of these exports are mismanaged.

Physical fate[b] of PET/polyester waste in Europe: Ambitious Complementarity Scenario



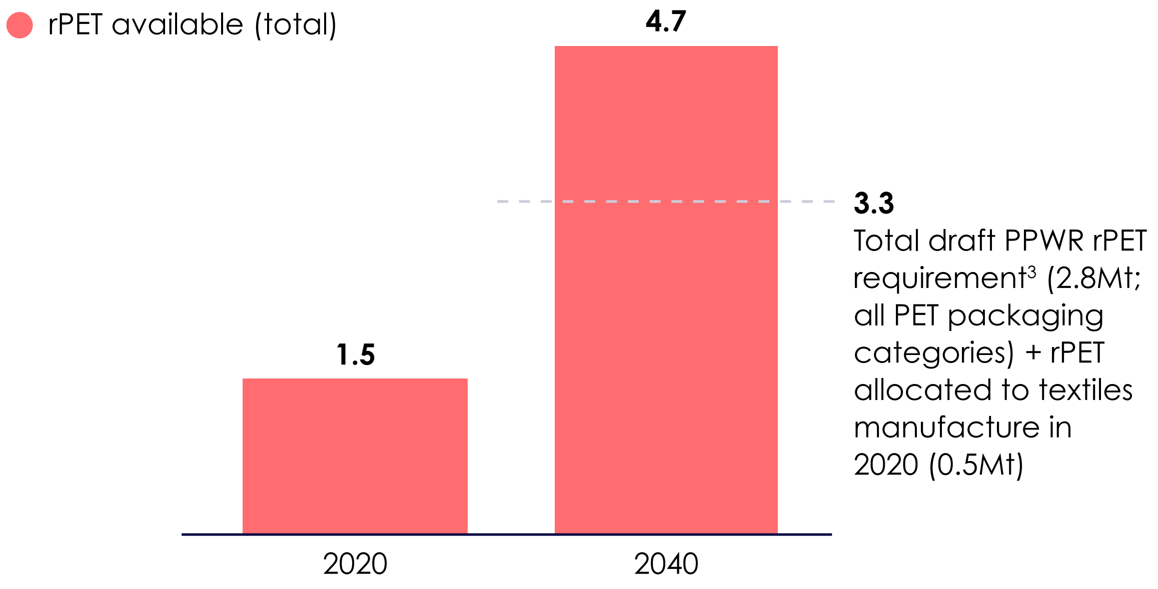
a. Note that this figure excludes the output from textile downcycling activities (0.3Mt).
b. Recycling volumes indicate the amount of recycled content as an output from the process; whereas in the case of mismanaged waste, exports, landfill and incineration, these are the tonnages entering these end-of-life stages.
c. This comprises only polyester textile waste exported outside of Europe for reuse. Exports are modelled as flat in terms of tonnage, due to the opposing forces of increasing separate collections of textiles in Europe (leading to more reusable textiles being made available), in combination with an increasing clampdown on textile exports from Europe of textiles marked as reusable when in fact they are not.
d. Waste in the Ambitious Complementarity Scenario in 2040 is higher than PET/polyester put on market in 2040 due to the time lag between textiles put on market and waste creation.

Exhibit 8

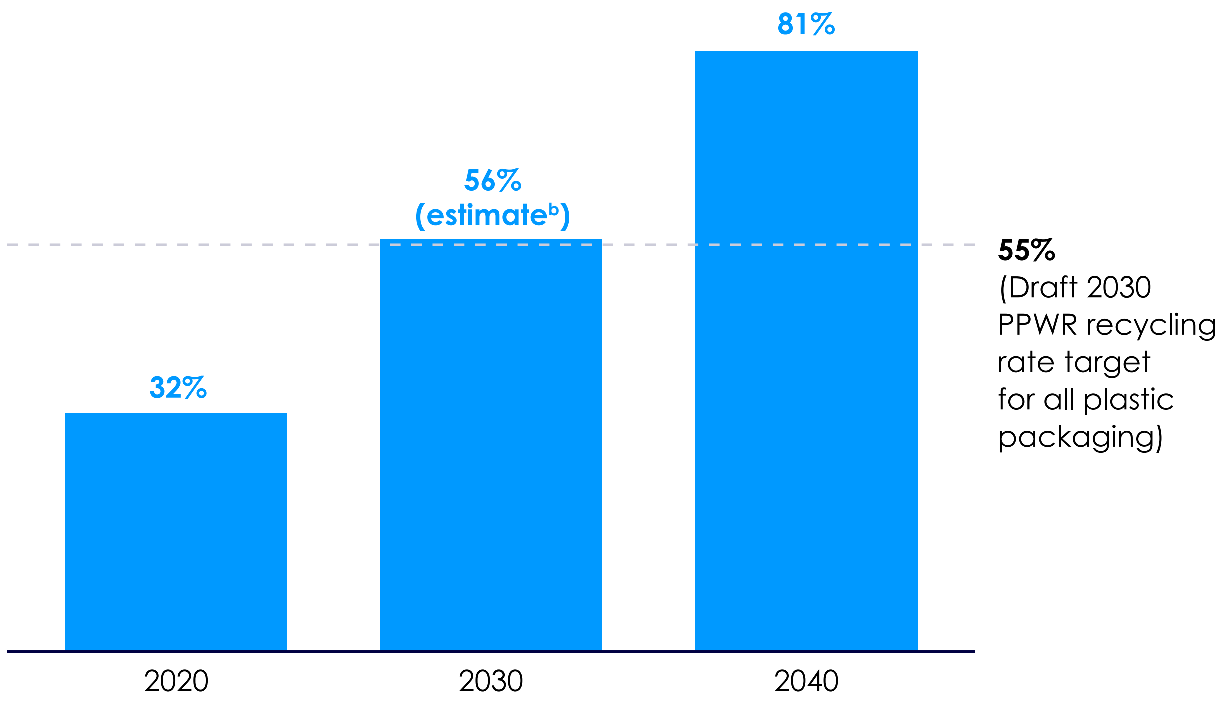
Proposed circularity targets for PET packaging could be met in the Ambitious Complementarity Scenario, if infrastructure scales up quickly

rPET generated: Ambitious Complementarity Scenario[a]

Mt/year, 2040



Recycling rate of all PET packaging: Ambitious Complementarity Scenario



a. rPET content targets based upon the draft PPWR at the time of publication (relevant 2040 recycled content requirements: beverage bottles - 65%; contact-sensitive PET packaging - 50%; other packaging - 65%); and projected consumption in 2040 of PET packaging products in-scope, accounting for the impact of ambitious application of measures to slow growth in consumption.

b. Projected recycling rates in 2030 and 2040 are shown against draft 2030 legislative targets for plastic packaging as a whole, in order to illustrate how close PET specifically could come to the target if each plastic packaging material meets its fair share of the overall target. There is a tension between current recycling rate targets, if interpreted in this way and draft recycled content targets under the PPWR. This is because a recycling rate of 55% in 2040 applied, for example, to PET beverage bottles would not deliver the recycled content requirement set out in the draft PPWR (65% by 2040). Therefore, to meet draft recycling content requirements for PET packaging, recycling rates in 2040 will need to be higher than the 2030 target for plastic packaging overall. Note that model outcomes in years between 2020 and 2040 are linearly interpolated between starting 2020 values and final 'best-in-class' values achieved by 2040 (see the Technical Appendix for full details). Therefore, the recycling rate described in 2030 is in essence the outcome of the European PET packaging system reaching halfway towards these ambitious levels of performance in 2040.

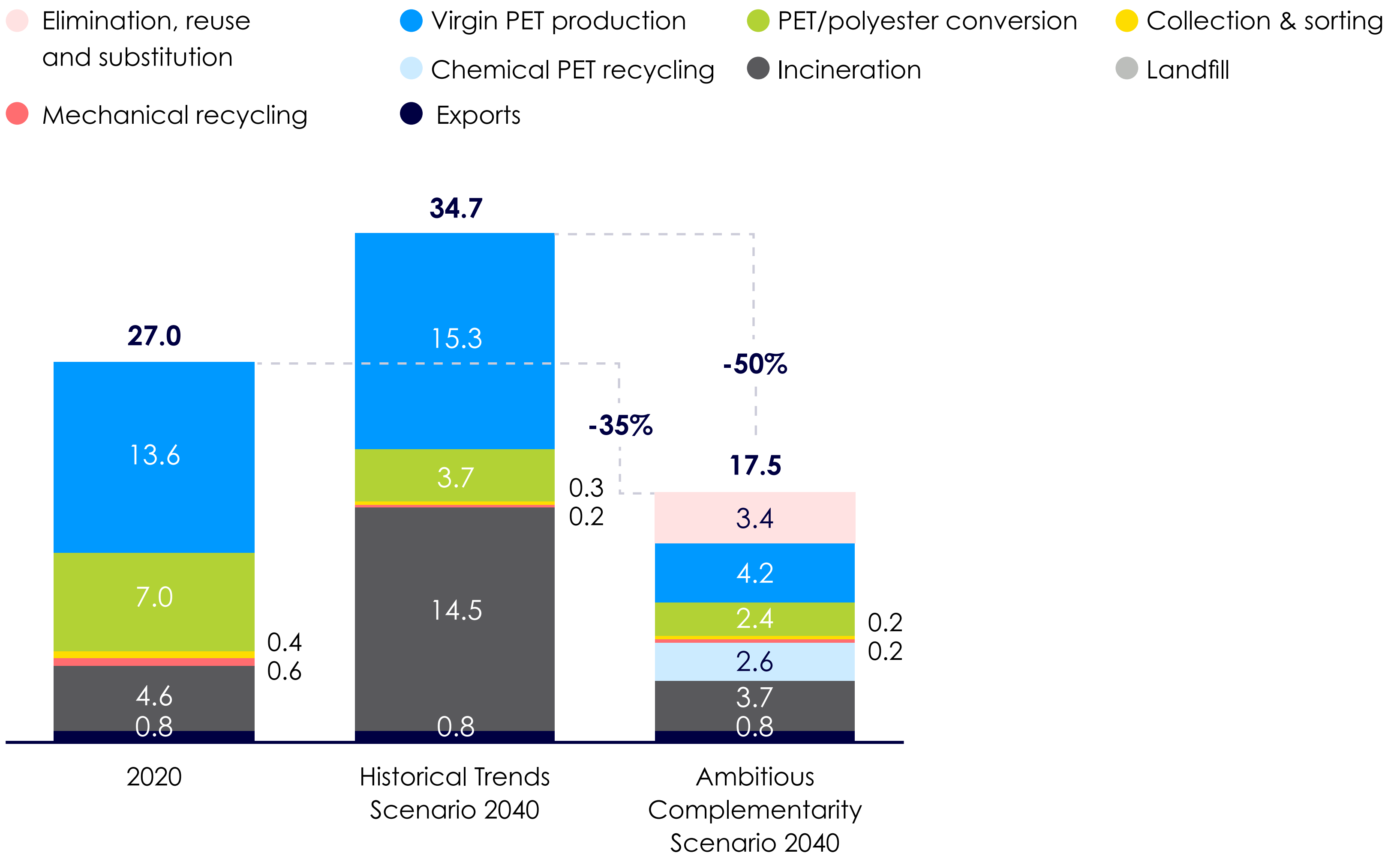
Exhibit 9

Complementary circularity solutions could halve the GHG emissions of the PET/polyester system by 2040, relative to a continuation of historical trends

- GHG emissions increase by ~30% in the Historical Trends Scenario, despite energy grid decarbonisation.
- Emissions from virgin PET production increase as production increases, partially offset by electricity grid decarbonisation.
- Emissions from PET/polyester conversion fall due to electricity grid decarbonisation, despite conversion volumes increasing.
- Emissions from incineration more than triple. This is due to unrecycled PET/polyester volumes increasing, a shift from landfill to incineration and the emissions credits for incineration reducing as the grid decarbonises.
- GHG emissions reduce by half in the Ambitious Complementarity Scenario, relative to the Historical Trends Scenario, and decrease by 35% relative to emissions in 2020.
- The two largest sources of emissions in the Historical Trends Scenario – virgin PET production and incineration (accounting for 44% and 42% of emissions in this scenario respectively) – are cut significantly through avoided consumption, increased mechanical recycling and the build-out of chemical PET/polyester recycling.
- Reuse and substitution solutions also carry a footprint, accounting for 19% of GHG emissions in the Ambitious Complementarity Scenario. However, this is in exchange for avoiding approximately one-third of total PET/polyester consumption, with emissions benefits as described above.

GHG emissions of European PET/polyester system in future scenarios

Mt CO_2e/year



How can we start to reverse the consumption trajectory?[a]

Relative to PET/polyester demand growth projected by 2040 under the Historical Trends Scenario, the Ambitious Complementarity Scenario assumes the following demand shifts:

- **Bottles:** By 2040, 10% of bottle consumption eliminated, for example due to refilling at home and from public fountains. A further 22% reduction in consumption is assumed in line with the draft PPWR, mandating a 25% market switch to consumer-owned reusable bottles and new beverage delivery models based upon returnable, reusable bottles. Overall this could result in a 32% reduction in bottle consumption.
- **PTTs:** A 47% total reduction in consumption by 2040, for example through a combination of elimination (eg, via packaging-free fresh produce aisles and enhanced food shelf life by using coatings directly on produce), reuse (eg, switches to returnable packaging and refill dispensers) and substitution with paper and cardboard where functionally and environmentally advantageous.
- **Other PET packaging:** Replacing strapping with reusable alternatives could result in a 26% reduction in its consumption by 2040. Strapping accounts for 30% of this category, resulting in an 8% overall category reduction.
- **Textiles:** By 2040, consumption of textiles reduced by 40% via a combination of levers: (1) improved resource efficiency can reduce consumption by 15% and includes minimising pre-consumer waste in fibre, garment and finished product manufacturing, and reducing overproduction and seasonal collections; (2) the scale-up of circular business models, which has already started and is expected to continue to grow, reduces demand by 20% and includes rental models, re-commerce, refurbished and/or upcycled products; (3) substitution to new fibres (eg, man-made natural fibres) where the alternative is functionally and environmentally beneficial yields a further 5% reduction in PET/polyester demand.

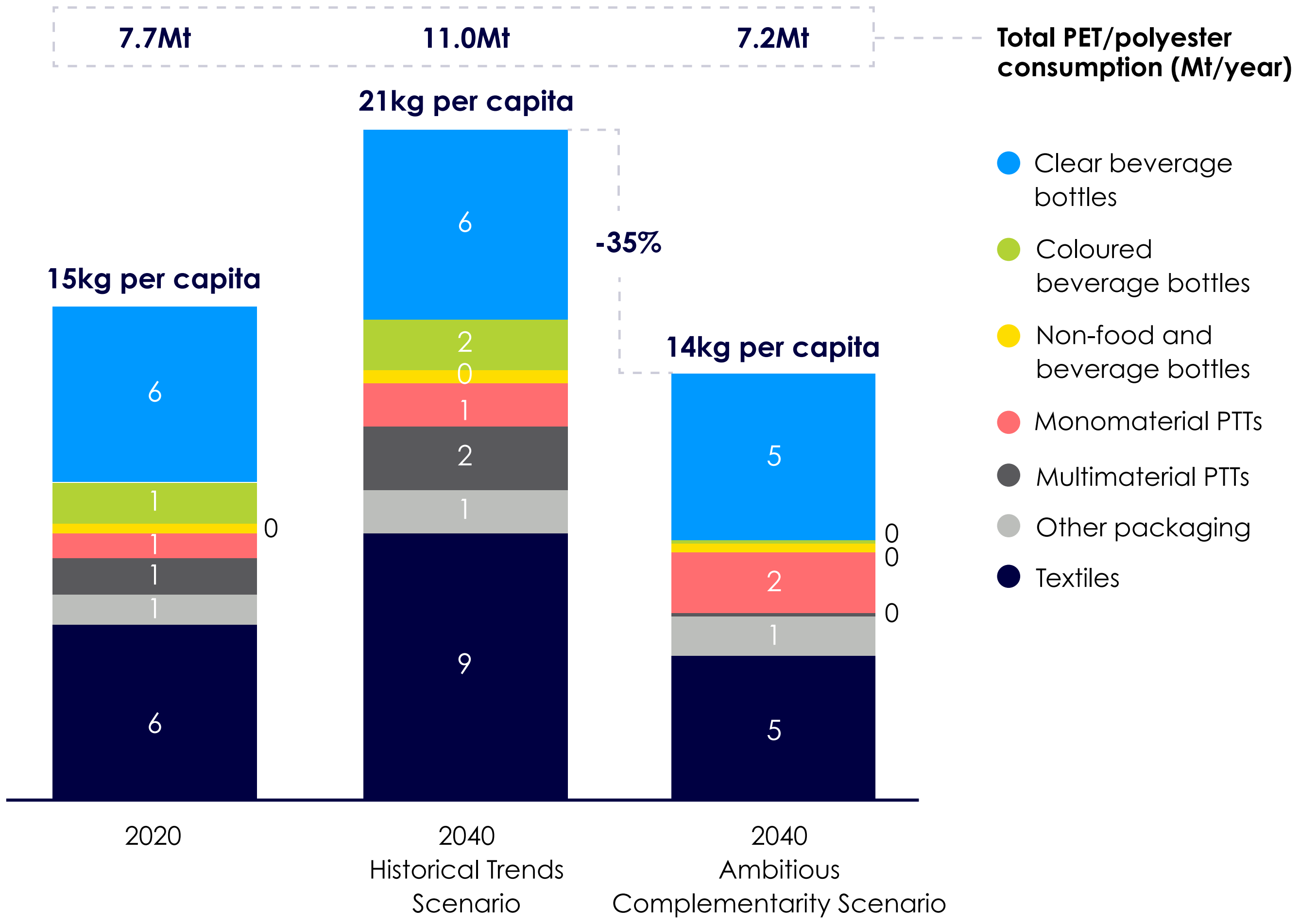
a. The impact of reduction, reuse and substitution assumptions is based on a Systemiq evidence-based methodology, detailed in the Technical Appendix. Shifts in consumer behaviour will also be be required to enable a slowdown in consumption growth. In addition, future PET/polyester consumption could be higher than projected if, for example, there is a significant shift away from existing materials and towards PET/polyester, due to improved environmental outcomes. Any substitution to PET/polyester from other materials has been considered to be implicit in the consumption growth rates in the Historical Trends Scenario. Finally, more work is needed to develop real-world reusability data (eg, average number of reuse cycles possible and lifecycle GHG emissions) for PET-specific product types.

Exhibit 10

PET/polyester consumption growth can be slowed through reduction and substitution measures

PET/polyester consumption per capita

Kg/year



2.2

Expansion of collection, sorting, mechanical recycling and chemical PET recycling systems in the Ambitious Complementarity Scenario

As noted earlier in this chapter, PET/polyester waste collected for recycling could increase by 74%, from 3.5Mt in 2020 to 6.2Mt in total, by 2040 through the application of best-in-class collection rates seen in Europe today across the different product categories.

Sortation capacity for separately collected PET/polyester waste could grow to accommodate the 6.2Mt of PET waste collected by 2040 with technology development, significantly increasing sorting efficiencies; while sortation capacity for PET/polyester within mixed waste could grow to over 1Mt of PET annually. The widespread adoption and scale-up of current best-in-class waste sortation technologies could allow much more separately collected PET/polyester waste to be successfully sorted for recycling. Sortation rates[a] could improve to 97% for bottles and 89% for PTTs; while textiles sortation rates could remain at around 95%.[b] Additionally, rates of sortation for recycling of PET/polyester from mixed waste could improve considerably, with 60% of bottles and PTTs and 10% of textiles contained within mixed waste extracted for recycling.[c] This means that the majority (70%) of PET/polyester waste created could be successfully sorted for recycling.[d]

The growth of mechanical recycling could be complemented by a new at-scale chemical PET recycling industry to create a recycling system that produces 4.7Mt of rPET, around three times that generated in 2020. Recycling input capacity could scale to a total of 5.4Mt (up from 2.0Mt in 2020)[e], with chemical PET/polyester recycling now processing 2.1Mt of feedstock annually (39% of the total available PET/polyester feedstock). The adoption of current best-in-class technologies could result in average PET-to-PET recycling yield rates for both processes reaching up to 90%,[f] with Europe's complementary recycling system producing 4.7Mt of recycled PET to use in new products. This could result in a system where 66% of all PET/polyester demand can be met by recycled PET. Most PET bottles could continue to be mechanically recycled, as well as some trays. Polyester textiles with a high polyester purity (>80% polyester), some trays, losses from mechanical recyclers and strapping could be the major feedstocks for chemical PET/polyester recycling. A small textiles mechanical recycling (downcycling) industry could remain for lower-purity, non-reusable textiles going into lower-value applications such as industrial rags, insulation and padding – processing just over 0.1Mt per year.[g]

The Ambitious Complementarity Scenario enables draft PPWR recycled content targets for PET packaging to be met. The Ambitious Complementarity Scenario generates enough rPET to meet draft PPWR recycled content targets in 2040, while ensuring that a supply of highly versatile rPET remains available for other end uses, such as textiles. The total recycling rate for PET packaging could be as high as 81% in 2040, compared to 32% in 2020, meaning that PET/polyester could contribute significantly towards overall plastic packaging recycling rate targets under the draft PPWR (Exhibit 8).

a. Measured as the percentage of collected PET/polyester waste successfully sorted for recycling; and including the weight of PET/polyester material only, and not including non-PET components, non-target materials, contaminants, moisture etc.
b. Note that although a significant scale-up in the (semi-)automated identification and sortation of textiles by fibre type is envisaged to support recycling, this will need to be complemented by a major scale-up in pre-sorting via hand. This is because commercially ready technologies to sort by textile item type and condition (reuse versus recycling) are not yet available.
c. Note that this material is assumed to be subsequently passed onto sortation facilities receiving separately collected PET/polyester, in order to achieve acceptable quality/purity levels for recycling.
d. It is important to note that sortation rates are much higher when waste is collected separately due to reduced contamination and waste variety arriving at sorting facilities.
e. Note that these figures do not include textiles downcycling as this does not produce rPET, where the European textiles downcycling industry is assumed to stay at a constant size of 0.3Mt per year.
f. Measured as the weight of recycled PET created divided by the weight of PET/polyester waste (not including the weight of non-PET parts or other non-PET materials) entering the recycling facility. Note that the yield rate for PTT mechanical recycling is expected to be closer to 75% by 2040; therefore, the average yield rate is closer to 83%.
g. Although not considered to be proven at significant enough scales to be considered in this report, it is possible that solvent-based recycling technologies could play a part in recycling <80% polyester content textiles by 2040.

2.3

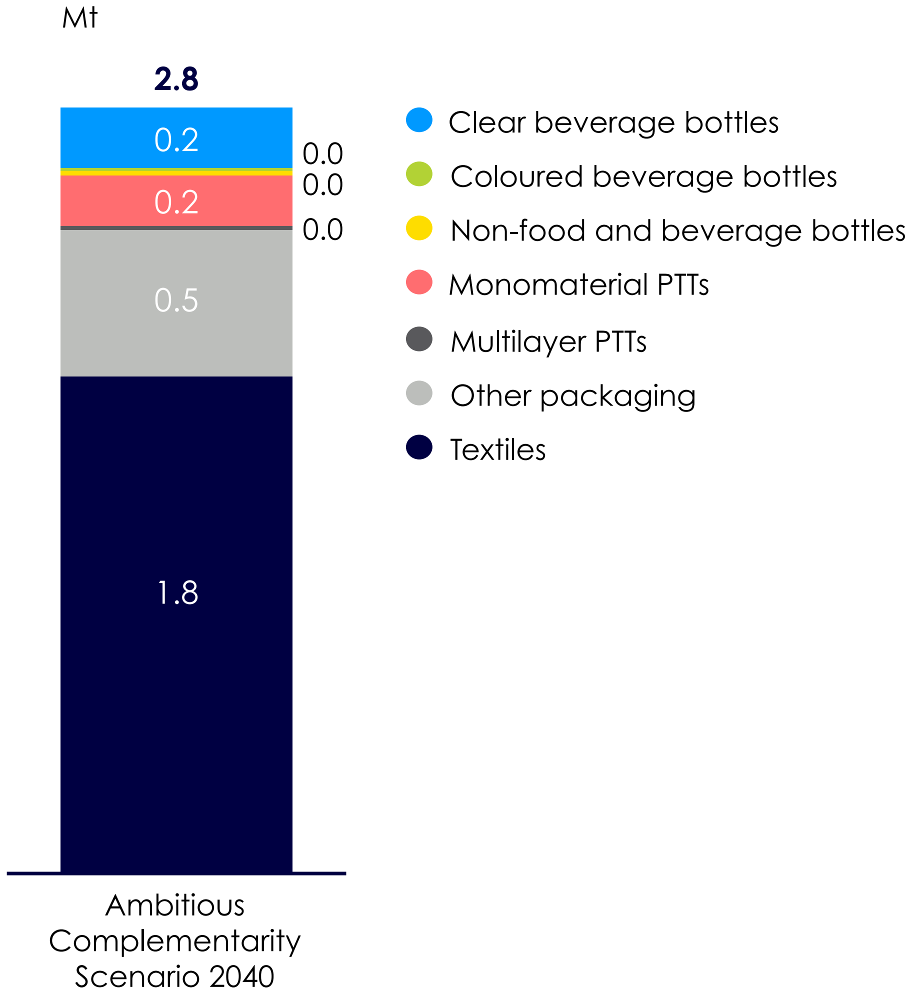
Further efforts and innovations will be required to close the remaining circularity gap and align with Europe's net-zero commitment by 2050.

- **The analysis in this report suggests that the application of known circularity solutions could ensure that three-quarters of projected PET/polyester waste produced by 2040 is avoided or recycled, and that emissions are cut by 35% compared to 2020.** However, this scenario still relies on virgin feedstock inputs of 2.5Mt in 2040 and incineration of 1.8Mt of non-recycled PET/polyester waste, contributing to system GHG emissions of 17.5Mt CO_2e.
- **Increasing circularity further will require system innovation – especially in the textiles sector, which could become the largest source of PET/polyester lost from the system (Exhibit 11).** Textile separate collection and sortation could become the primary bottlenecks in improving the PET/polyester system further and will require new infrastructure, operational systems, consumer education and technological advances to achieve parity with the separate collection rates of PET packaging. Remaining losses will also result from packaging and textile products which are resistant to redesign for recycling due to specific functionality requirements that make them more challenging to sort and recycle. Aside from textiles, losses of some packaging (eg, beverage bottles) will also result from waste which is not reaching collection schemes (eg, beverages consumed on the go away from collection-for-recycling options), as well as waste that bypasses sortation technologies (eg, due to the use of small formats or incompatible textile blends), or that relies on specific recycling technologies that may not be widely available (eg, due to small volumes available).
- **Overall, the Ambitious Complementarity Scenario is a useful north star for the PET/polyester system; but it should not be perceived as the final solution from an environmental perspective.** Achieving the EU's net-zero commitment by 2050 will require a wider agenda and ambition level in the coming years, focused on textile circularity and the decarbonisation of the largest remaining sources of emissions: incineration, PET/polyester production and conversion, and chemical PET recycling (Exhibit 11). This will require full electricity grid and transport decarbonisation (impacting multiple parts of the value chain, including mechanical recycling); carbon capture, utilisation and storage at incineration plants; decarbonisation of energy used by the petrochemicals sector (as some virgin PET/polyester is still needed); decarbonisation of chemical PET/polyester recycling (given its scale in a high-circularity system); and the use of captured carbon, green hydrogen and bio-based material as PET polymerisation feedstock.

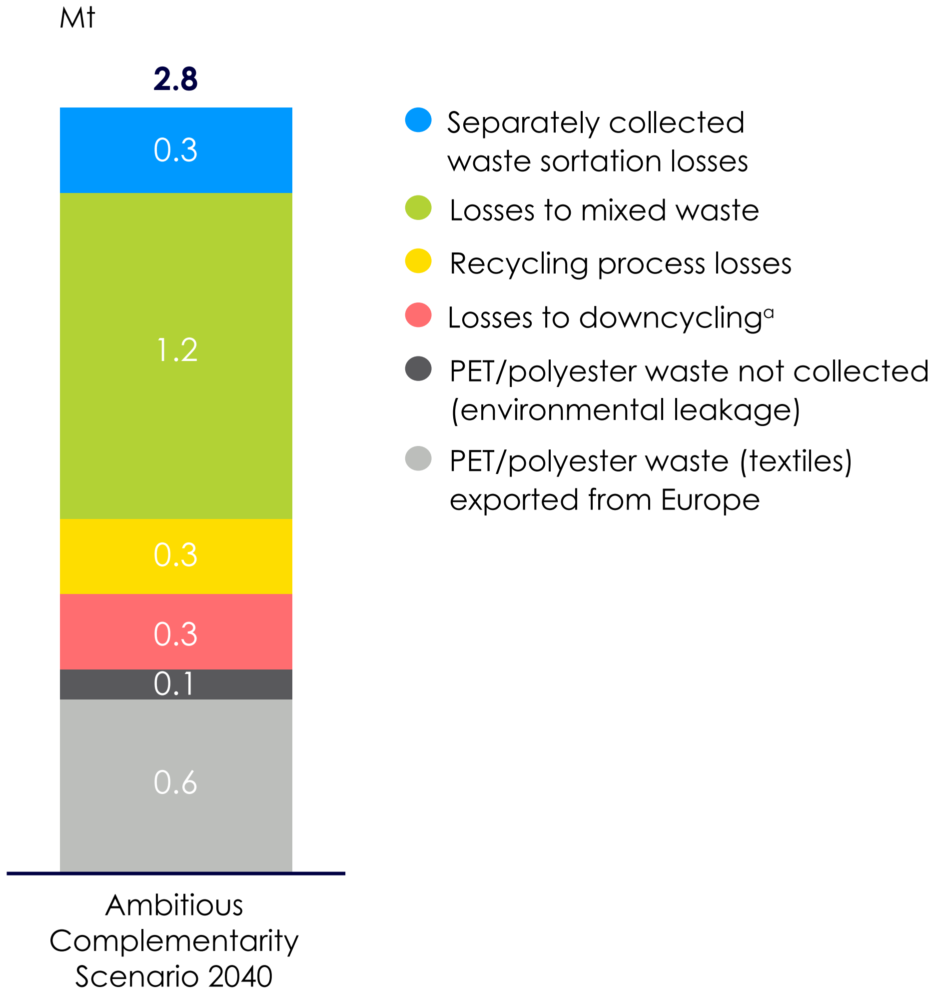
Exhibit 11

Increasing circularity beyond the Ambitious Complementarity Scenario will require system innovation, especially in the textiles sector

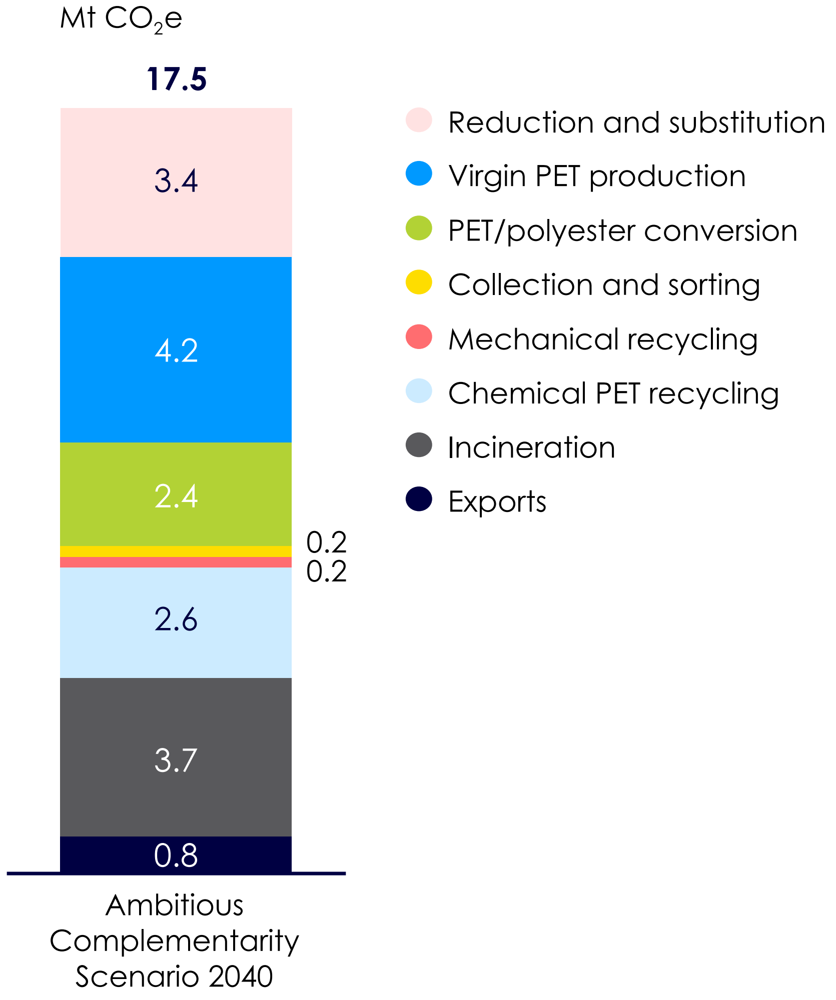
Non-recycled PET/polyester waste in 2040 by product category



Non-recycled PET/polyester waste in 2040 by value chain activity



GHG emissions per system activity in 2040 (all PET/polyester categories)



a. As these product applications are unlikely to themselves be recycled and so will go to landfill and incineration at end of life.

2.4

Sensitivity analysis

Sensitivity analysis was carried out to identify which elements of the system are most important for the achievement or non-achievement of the environmental outcomes in the Ambitious Complementarity Scenario. The results are shown in Exhibit 13. In summary:

System change outcomes are particularly sensitive to the increased collection-for-recycling (including widespread deposit return schemes (DRS)) and sortation-for-recycling rates that are modelled in the Ambitious Complementarity Scenario. If these fail to increase beyond those modelled in the Historical Trends Scenario, then the overall system recycling rate would be 41% and GHG emissions would be 23.0Mt CO_2e (compared to 67%/17.5Mt CO_2e in the Ambitious Complementarity Scenario). This reflects the size of the gap between average rates today and what has already proved to be achievable in leading European countries. It is also because this represents the start of the recycling 'funnel' and material that is not collected for recycling has a very low chance of being recovered from the mixed waste stream.

System change outcomes are sensitive to the scale-up of both mechanical and chemical PET/polyester recycling. Two hypothetical scenarios help to demonstrate this:

- If mechanical recycling capacity grows and chemical PET/polyester recycling capacity is not developed, recycling rates could drop from 67% (Ambitious Complementarity Scenario) to 44% and system-level GHG emissions could increase from 17.5Mt CO_2e to 21.1Mt CO_2e. Supply of rPET could fall from 4.4Mt to 3.0Mt, which would marginally exceed the 2.8Mt of rPET that would be required to meet draft PPWR requirements, without any surplus available for polyester textiles.
- Conversely, if chemical PET/polyester recycling capacity grows to recycle all possible PET/polyester feedstocks and mechanical recycling capacity remains at 2020 levels, system-level GHG emissions would increase from 17.5Mt CO_2e (Ambitious Complementarity Scenario) to 19.6Mt CO_2e, since chemical PET/polyester recycling has a higher emissions footprint than mechanical recycling. The recycling rate and rPET generated in this scenario would be similar to those in the Ambitious Complementarity Scenario, since chemical PET/polyester recycling would theoretically be able to process all of the feedstocks that would have gone to mechanical recycling.

System change outcomes are also highly sensitive to the success of efforts to slow demand growth – for example, by reducing avoidable material use and shifting from single-use or short-lived products to reusable or long-lived durable products. This is especially true if recycling infrastructure fails to increase at the same pace.

It will be important for chemical PET/polyester recycling to utilise polyester textiles as a feedstock. Chemical PET recycling is expected to be able to recycle polyester textiles at large commercial scale, although this is not yet proven at these scales, since major plants are currently in project development phase and not operating. In the Ambitious Complementarity Scenario, polyester textiles account for ~65% of chemical PET/polyester recycling feedstock. If this feedstock is not utilised, the PET/polyester system's recycling rate could reduce from 67% (Ambitous Complementarity Scenario) to 51% and the supply of rPET could reduce from 4.4Mt to 3.5Mt. System-level GHG emissions could increase from 17.5Mt CO_2e to 20.1Mt CO_2e.

Principles and frameworks will be required, for both feedstock allocation to different kinds of recycling and rPET allocation to products. These should be considerate of a wide range of factors, including maintaining PET/rPET at its highest level of utility, environmental impacts, health impacts, the encouragement of certain product groups to build their own collection and recycling value chains, cost and other factors. This is an area that requires further research in order to fully understand the various trade-offs and second-order impacts of different choices.

Exhibit 12

Sensitivity analyses highlight the importance of separate collection and sortation rates, and of building a complementary mechanical and chemical PET/polyester recycling system

All figures as of 2040

- Total rPET produced (Mt) from mechanical recycling
- Total rPET produced (Mt) from chemical PET recycling
- PET/polyester waste to landfill and incineration under the Historical Trends Scenario (2040)

	Scenario	Recycling rate[a] %	Waste to landfill /incineration, Mt	System GHG emissions, Mt CO_2e	rPET generated, Mt
Core scenarios	**Historical Trends Scenario:** As described previously	23%	7.9	34.7	100% – 2.2
Core scenarios	**Ambitious Complementarity Scenario:** As described previously	67%	2.2	17.5	60% / 40% – 4.7
Sensitivity analyses	**Ambitious Complementarity Scenario without chemical PET recycling:** Follows the Ambitious Complementarity Scenario where mechanical recycling grows and develops but without any chemical PET recycling taking place	44%	3.7	21.1	100% – 3.0
Sensitivity analyses	**Ambitious Complementarity Scenario with limited waste collection and sortation:** Follows the Ambitious Complementarity Scenario but waste collection and sortation are limited to those of the Historical Trends Scenario	41%	3.9	23.0	65% / 35% – 2.8

a. These figures are the total PET recycling rates across packaging and textiles, and include the recycling of textiles into lower-grade applications (eg, insulation).

Note: Total PET/polyester consumption in each of the above sensitivity analyses/scenarios is 7.2Mt, except for the Historical Trends Scenario and the sensitivity where measures to slow PET/polyester product demand do not take place, in which consumption amounts to 11.0Mt.

Exhibit 13

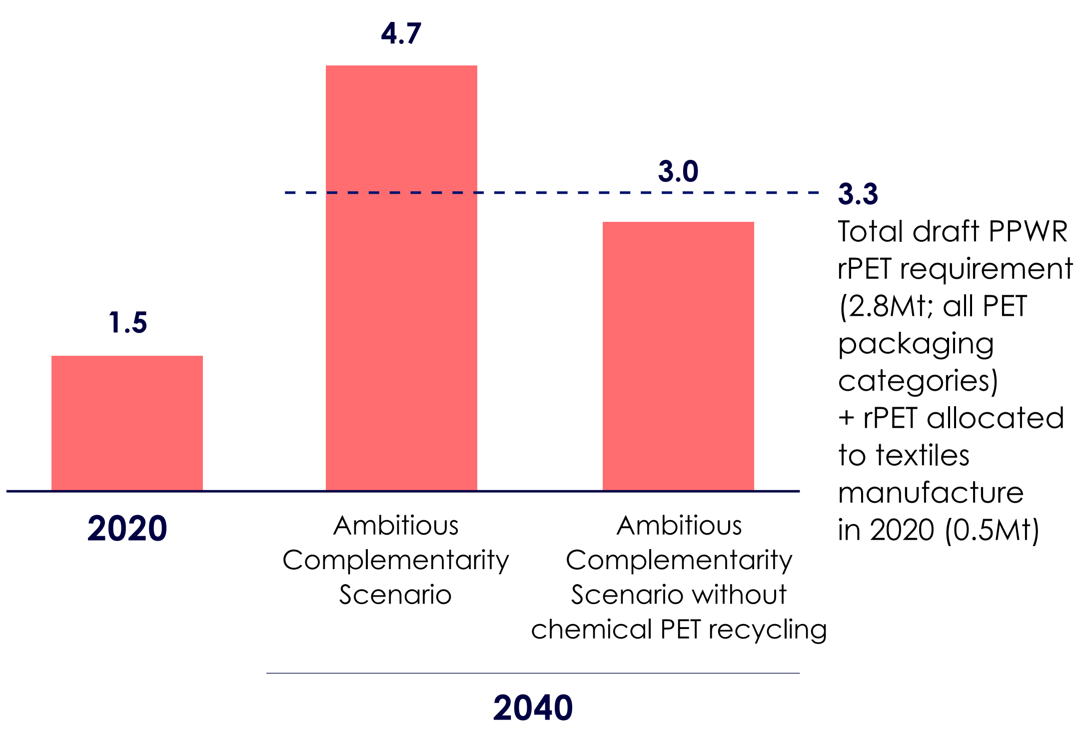
Sensitivity analysis: proposed circularity targets for PET packaging are unlikely to be met without chemical PET recycling

This analysis also sought to understand the impact on the Ambitious Complementarity Scenario if chemical PET recycling does not scale up in Europe, while mechanical recycling and all other elements scale up in line with the Ambitious Complementarity Scenario.

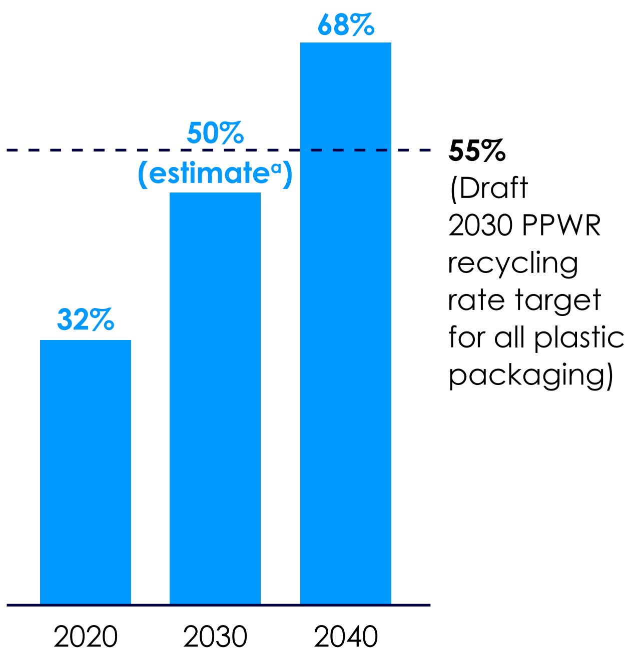
- **rPET generated:** 37% less rPET compared to the Ambitious Complementarity Scenario – if the rPET supply to the textiles sector remains at 0.5Mt/yr (2020 level), then the 2040 PPWR targets for PET packaging cannot be met.
- **Recycling rate:** The projected 50% recycling rate for PET packaging in 2030 is below the draft PPWR target for plastic packaging as a whole.

Recycled PET (rPET) generated

Mt/year, 2040



Recycling rate of all PET packaging: Ambitious Complementarity Scenario without chemical PET recycling



a. Projected recycling rates in 2030 and 2040 are shown against draft 2030 legislative targets. Note that model outcomes in years between 2020 and 2040 are linearly interpolated between starting 2020 values and final 'best-in-class' values achieved by 2040 (see the Technical Appendix for full details). Therefore, the recycling rate described in 2030 is in essence the outcome of the European PET packaging system reaching halfway towards these ambitious levels of performance in 2040.

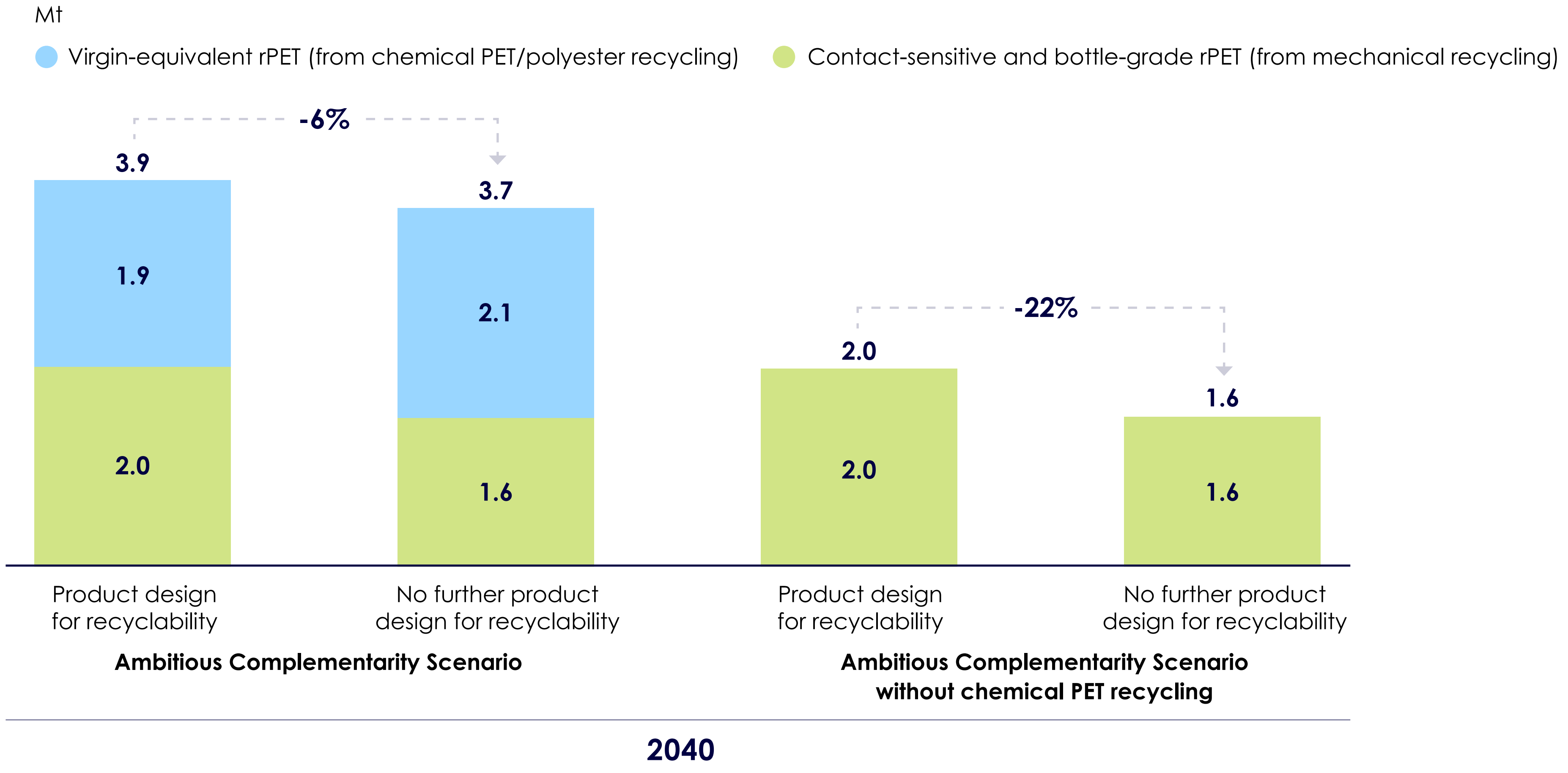
Exhibit 14

Sensitivity analysis: without chemical PET recycling, supply of high-utility rPET is reduced and system outcomes are at risk from slower adoption of design for recycling

If chemical PET recycling is not scaled, the system is less resilient against a failure to scale up design for recycling by 2040. This is because products such as coloured/opaque bottles, trays and textiles are not generally mechanically recyclable into a contact-sensitive and bottle-grade rPET quality, whereas chemical PET/polyester recycling elevates these materials to a virgin-quality rPET.

If changes such as a shift from coloured/opaque to clear beverage bottles, from multimaterial to monomaterial trays, and to less complex textiles do not take place, the supply of contact-sensitive and bottle-grade rPET could reduce by 22%. If chemical PET/polyester recycling scales (ie, the Ambitious Complementarity Scenario), supply only falls by 6% without these design for recycling changes.

Supply of high-utility rPET with and without product design for recyclability[a]



a. Design for recyclability as modelled here means specifically a shift from coloured and opaque towards clear PET bottles, a shift from multimaterial to monomaterial PTTs and a shift from <80% polyester purity textile blends to >80% purity.

Delivering PET/polyester's circularity potential

Transforming the system requires an ambitious action plan

Delivering high circularity ambition for PET/polyester in Europe requires an ambitious action plan that delivers coordinated action and investments

Ambitious and coordinated action from all stakeholders will be required to achieve a high circularity system for PET/polyester similar to the Ambitious Complementarity Scenario described in Chapter 2. This includes new policies and regulatory frameworks, business models, incentives, funding mechanisms, voluntary industry action and consumer behaviour change.

Aligning these elements is particularly challenging for the polyester textiles system, where policy drivers, technology roadmaps and action plans are less well defined than for the PET packaging system.

Six priority actions have the greatest potential to deliver a system transformation in line with the Ambitious Complementarity Scenario.

3.1

Priority actions

Six priority actions have the greatest potential to deliver these transformations

Three 'upstream' actions aim to slow the growth in demand for PET/polyester through business model changes and the design of products for circularity:

(i) Expand reuse to extend product lifetimes for packaging and textiles, and promote new delivery models for products to reduce packaging demand:

Examples include re-commerce in the fashion sector and transition from single-use packaging to reusable containers.

Scale-up requires a step change in industry investment, building on learnings from pilot initiatives, alongside clarity from policy-makers on important considerations such as safety, hygiene and liability standards; methods for the assessment of the environmental and social impacts of new models; and public financing support.

(ii) Reverse trends towards high-consumption business models in the fashion sector ('fast fashion'):

The Ambitious Complementarity Scenario presented in this report models a steady slowdown in demand growth and stabilisation by 2040. Action is required from brands to provide a narrative that runs counter to fast fashion.

New policies will be required – in particular, an ambitious European legislative extended producer responsibility (EPR) framework for textiles. This will transfer the cost and responsibility of waste management to producers and provide an economic incentive to reduce both overproduction and overconsumption.

(iii) Standardise product design to improve reuse and recycling economics:

Design for recycling can, in many cases, be an easy way to increase yield rates of recycling processes as well as the quality and value of recycled PET produced.

This can include shifts in bottle designs, such as from coloured or opaque bottles to clear bottles,[a] and transition from multimaterial to monomaterial PTTs, where possible, and to less complex textiles. Design for mechanical recycling guidelines are relatively well established, and are now needed for chemical PET recycling. Some design shifts, such as from coloured/opaque to clear bottles for light-sensitive products, may no longer be required if chemical PET recycling scales up. This would allow for continuation of opaque/coloured PET usage for light-sensitive products and mitigate the risk that design modifications such as shrink sleeves on clear PET bottles interfere with sorting or recycling processes.

a. Some coloured/opaque and multi-material formats will still be required for specific product applications.

Three 'downstream' actions aim to put in place the complementary mechanical recycling and chemical PET recycling systems needed to deliver significant increases in recycling rates and availability of recycled PET/polyester suitable for new packaging and textile products:

(iv) Secure long-term demand for recycled PET/polyester:

rPET demand and prices are currently strong. However, in the Ambitious Complementarity Scenario, the supply of rPET in 2040 is three times (3.2Mt) higher than in 2020, with 40% of the total generated being highly versatile rPET from chemical PET recycling. To ensure that demand for recycled PET/polyester drives the system to its full circular potential, recycling rate targets and recycled content requirements for textiles are needed.

Brands should enter into long-term offtake agreements with collectors, sorters and recyclers, ensuring long-term offtake security and de-risking investments for the recycling sector. These measures should also improve the economics of textile sortation facilities, which depend mostly upon the sale of reusable/rewearable textiles as opposed to the sale of non-rewearable, recycled textiles.[4]

(v) Develop sufficient feedstock flows to recyclers by improving collection and sorting:

To achieve a ~75% (2.6Mt) increase in PET/polyester collected for recycling in the Ambitious Complementarity Scenario compared to 2020, effective DRS for bottles and separate collections for other forms of PET packaging and textiles will need to be in place and functioning at a high level across Europe.

Collection policies should be paired with policies to reduce waste to landfill or incineration (eg, banning the destruction of unsold or returned textiles or the incineration of 'recyclable' packaging); and the public and private sectors should collaborate to design and enact principles for the complementarity of mechanical and chemical PET recycling in line with the waste management hierarchy. Sorting technologies will need further investment, particularly for collected textiles and packaging that end up in the mixed waste stream.

(vi) Scale up recycling infrastructure and optimising performance:

The Ambitious Complementarity Scenario would require mechanical recycling volumes to grow by 65%, from 2.0Mt in 2020 to 3.3Mt in 2040. Chemical PET/polyester recycling will need to bring 2.1Mt of capacity online (including 0.4Mt 'announced' capacity not yet online in Europe today). This will make it larger than the PET/polyester mechanical recycling industry in 2020 (~2.0Mt).

Chemical PET/polyester recycling has an important complementary role to play in a more circular system. It provides an alternative recycling technology that can elevate PET/polyester waste (eg, textiles, PTTs, coloured/opaque bottles and waste from mechanical PET recycling) into a contact-sensitive and virgin-like material, where mechanical recycling cannot. This also has the effect of 'recharging' the system with virgin-like rPET without the need for fossil-based feedstocks. The public sector will need to facilitate conditions for investment – in particular, by providing policy certainty as quickly as possible. Fast-track permitting of related projects will also be needed to accelerate development.

Exhibit 15

Industry has an important role to play in all six priority actions

<table>
<tr><th></th><th></th><th colspan="2">Examples of future industry actions needed on PET/polyester packaging and textiles</th></tr>
<tr><th></th><th>Priority actions</th><th>Brand owners, retailers and product manufacturers/packaging converters</th><th>PET/polyester production, recycling, sorting and logistics</th></tr>
<tr><td rowspan="2">Upstream</td><td rowspan="2">1) Expand reuse and new delivery models for packaging applications
2) Introduce incentives to shift fast fashion to more sustainable business models and slow growth in demand for polyester textiles
3) Standardise product design to improve recycling economics</td><td>• Transition from single-use or high-consumption/high-waste business models to scale up reuse and refill models for packaging and subscription, rental, resale and repair models for fashion
• Design products for reuse, durability and repairability
• Follow design for recycling guidance across all products and actively engage with sorters, recyclers, regulators and wider industry to improve and spread consistent design for recycling rules</td><td>• PET resin producers ensure that product formulations and additives are suitable for reuse or recycling
• The sorting and logistics industry supports the expansion of safe and efficient reuse of textiles and reusable packaging, wherever suitable
• PET/polyester value chain and policy-makers provide clear design for recycling guidance specifically for chemical PET recycling</td></tr>
<tr><td colspan="2">• Engage with policy-makers on policy changes that can slow growth in PET/polyester consumption through coordinated approaches between the public and private sectors that provide business opportunities and minimise negative impacts and disruptions for industry</td></tr>
<tr><td rowspan="2">Downstream</td><td rowspan="2">4) Ensure long-term demand for recycled PET
5) Secure sufficient feedstock flows to recyclers and ensure complementarity between different recycling technologies
6) Scale up recycling infrastructure and optimise performance</td><td>• Set ambitious recycled content targets for packaging and textiles, including both mechanical and chemical PET recycling based on suitability
• Enter into long-term contracts to purchase recycled PET/polyester
• Provide industry support for textile collection, sorting and recycling innovations and scale up schemes to build momentum and provide models for policy change
• Promote industry engagement with government and packaging EPR schemes, particularly to improve packaging collection and recycling (especially for PTTs)
• Promote industry investment in recycling infrastructure – bilateral or via pooled industry funds
• Strengthen product labelling requirements, including recycling instructions and trusted eco-claims for recycled content</td><td>• Promote continued investment in new technology development and deployment by sorters and recyclers to improve technologies, increase the quality of recycled PET and achieve higher yield rates from processes
• Scale up sorting and recycling facilities for both packaging and textiles
• Enter into long-term contracts to sell recycled PET/polyester and long-term contracts for feedstock supply from waste collectors/ sorters or EPR organisations</td></tr>
<tr><td colspan="2">• Promote cross-industry collaboration to design and enact practical principles for achieving complementarity of mechanical and chemical PET recycling based on environmental and economic considerations and product quality
• Engage with policy-makers on policy changes, public investments and incentives to enable the scale-up of the collection, sorting, reuse and recycling system and the stable long-term supply of feedstocks to recyclers
• Explore new innovations, including material markets, that could increase sortability/traceability of packaging and textiles</td></tr>
</table>

3.2
Policy landscape

Ambitious policies have been enacted in Europe that lay the groundwork for a circular PET/polyester system, although further action is needed to enable a highly circular system.

- **The European Union has launched a series of legislative and non-legislative actions to establish circular economic models, which impact the PET/polyester system.** Since publication in 2020, the new Circular Economy Action Plan (CEAP) has been a key building block of the European Green Deal. It sets out the actions needed to adopt circular systems for resource-intensive sectors including the packaging, plastic and textile sectors.

- **Packaging regulation is significantly more developed than textiles, with mature and ambitious regulations for bottles in particular.** Several legal mechanisms reduce the linearity and negative impacts of the PET packaging system. These include the Waste Framework Directive (WFD), the Single-Use Plastics Directive (SUPD), the Packaging and Packaging Waste Directive (PPWD) and the Plastic Packaging Levy. These mechanisms will increasingly integrate principles of circularity from the CEAP as updates of these laws come into force. The draft PPWR will replace the PPWD and will complete a robust regulatory framework if enacted in current form and with supporting definitions that enable mechanical and chemical PET/polyester recycling to complement each other.

- **Polyester textiles need a robust and ambitious regulatory framework.** The Strategy for Sustainable and Circular Textiles has set the foundation for the development of a regulatory framework to shift the sector towards circularity.

  Although ambitious, translation into binding policies is mostly still needed. The first wave of new legislation will be delivered by the Ecodesign for Sustainable Products Regulation (ESPR), covering product durability, repairability and recycling, as well as updates to the WFD, mandating separate collection for textiles and inclusion of EPR guidelines for member states.

  The ambition level, pace of development and clarity of the broader regulatory framework for textiles will have a material impact on the actions of national and sub-national governments and the private sector.

Exhibit 16

The EU has built the foundations for developing a circular PET/polyester system. Robust and relatively ambitious packaging regulation is on course to be established, while textile regulation is now needed as a priority

- ✓ Within scope. Without direct mention or targets for PET/polyester application
- ✓ Within scope. Direct mention and/or specific targets for PET/polyester application
- ✓ Within scope. Direct mention and high-level definitions for PET/polyester application

			PET/polyester system		
		Scope & status	Beverage bottles	Other PET packaging[a]	Textiles
Overarching ambition	European Green Deal	• Overarching goals to achieve climate neutrality by 2050 • Enacted	✓	✓	✓
Policy initiatives and revisions	Circular Economy Action Plan	• Measures to enable sustainable products, consumption and resource use • Enacted	✓	✓	✓
	Waste Framework Directive	• Principles for the adequate management of waste • Enacted. Revision update in course	✓	✓	✓
	Single-Use Plastic Directive	• Measures to prevent and reduce the impact of single-use plastics on the environment • Enacted	✓	✓	
	Plastic Packaging Waste Levy	• National contributions towards non-recycled plastic packaging waste • Enacted	✓	✓	
	Packaging and Packaging Waste Directive/Regulation	• Rules on packaging and packaging waste management and prevention • In revision	✓	✓	
	EU Strategy for Circular and Sustainable Textiles	• Roadmap to develop a climate-neutral and circular textile sector • Published			✓
	Eco-design for Sustainable Products	• Eco-design requirements for sustainable & circular products • Under construction			✓

a. Includes pots, tubs and trays, strapping and film.

Exhibit 17

Six identified priority actions are well supported by the current regulatory framework for PET packaging, in particular beverage bottles. Regulation supporting these actions for polyester textiles is needed

- SUPD
- WFD
- PPWR – draft
- ESPR

- PET beverage bottles were targeted first by circularity policies, and the draft PPWR suggests they will now carry the highest ambition of PET/polyester product applications.
- Textile regulation is still under development without mandatory targets enforced in the sector. The integration of eco-design principles will be one of the first concrete public policy measures in terms of circularity impacting the sector. Possible definitions could be included in the recent WFD and Registration, Evaluation, Authorisation and Restriction of Chemicals reviews.

		Metrics	Beverage bottles	Other packaging[a]	Textiles
Upstream	1) Expand reuse and new delivery models for packaging applications	Reuse	Bottles: 10% by 2030; 25% 2040	Takeaway and pre-prepared food packaging (PTTs) 10% (2030); 40% (2040)	
	2) Introduce incentives to shift fast fashion to more sustainable business models and slow growth in demand for polyester textiles	Reuse			
	3) Standardise product design to improve recycling economics	Design for recycling	Packaging to be 'recyclable' (comply with the design for recyclability criteria) by 2030 + recyclability grades introduced (support EPR eco-modulated fee)		Define eco-design guidelines
		Label and traceability	Harmonised labelling requirements for packaging and waste receptacles by 2028 + labelling on material composition and end-of-life/segregation information		
			Digital product passport and green claim initiative		
Downstream	4) Ensure long-term demand for recycled PET	Recycled content targets	PET bottles: 25% by 2025; 30% by 2030 (all bottles)[b] Bottles: 30% by 2030; and 65% by 2040	Contact-sensitive PET (PTTs): 30% by 2030; and 50% by 2040	
	5) Secure sufficient feedstock flows to recyclers and ensure complementarity between different recycling technologies	Collection	77% by 2026; 90% by 2029	Separate collection	Separate collection
		Sorting	DRS to be established		
		EPR	All packaging covered by EPR by 2024 Eco-modulation to be introduced by 2030		EPR eco-modulation to be introduced based on ESPR
	6) Scale up recycling infrastructure and optimise performance	Recycling targets	Plastic packaging: 50% by 2025; 55% by 2030		

a. Includes PTTs,strapping and film.
b. Note that SUPD recycled content targets are due to be superseded by recycled content targets within the draft PPWR.

Exhibit 18

To meet 2030 targets, second-level EU policy definitions and member state development plans will be needed to implement PPWR swiftly once it is enacted

Complementary policy requirements for PET packaging, once PPWR is enacted

	Priority actions	Guidelines from PPWR (draft)	Second-level level policy definitions (EU level)	Member state development plans
Upstream	1) Expand reuse and new delivery models for packaging applications	• Criteria to classify as reusable packaging • Reuse targets: bottles: 10% by 2030; 25% 2040; takeaway and pre-prepared food packaging (eg, some PTTs): 10% by 2030; 40% by 2040	• Clarity on methods to assess environmental and social impact of reuse versus conventional models and any implications on compliance • Food safety laws adapted for reuse	• Member states must develop plans to meet PPWR requirements. Resources obtained from EPR schemes are intended to finance the development of PPWR-aligned national circular packaging systems. • Investments and economic measures will need to be put in place to finance infrastructure adaptations including: - Establishing reuse at scale (eg, store layouts, logistics) - Deploying DRS systems and harmonised collection of PTTs across Europe - Installing recycling infrastructure and facilitating investments from private sector (eg, fast-track permitting for development of related infrastructure)
Upstream	2) Introduce incentives to shift fast fashion to more sustainable business models and slow growth in demand for polyester textiles	Not applicable to polyester textiles	Not applicable to polyester textiles	
Upstream	3) Standardise product design to improve recycling economics	• Packaging to be 'recyclable' (comply with the design for recycling criteria) by 2030; recyclable at scale by 2035 • Recyclability grades introduced (support EPR eco-modulated fee)(A to E; 70%-95% recyclability per by unit, by weight) • Harmonise labelling requirements by 2028; material composition and end-of-life information	• Clarity on how innovations could be incorporated into requirements over time (eg, whether design for recycling principles are fixed between the publication and implementation deadlines)	
Downstream	4) Ensure long-term demand for recycled PET	• Recycled content targets: - Beverage bottles: 30% by 2030; and 65% by 2040 - Contact-sensitive PET (PTTs): 30% by 2030; 50% by 2040	• Unambiguous calculation methodology for recycled content with clarity on inclusion of chemical PET recycling technologies • Accelerate calculation methodology (to be published in 2026) to provide clarity that supports investment/R&D[a] • Specify calculation methodology for as many products possible	
Downstream	5) Secure sufficient feedstock flows to recyclers and ensure complementarity between different recycling technologies	• Set up systems to provide for the return and separate collection of packaging waste • Deposit return schemes to be in place for beverage bottles with a capacity of up to 3 litres	• Align sorting and collection ambition: implement incentives to drive collected waste to sorting. Set guidelines for cases when sorting is not a viable alternative due to limited infrastructure to reflect regional disparities.	
Downstream	6) Scale up recycling infrastructure and optimise performance	• Recycling target – plastic: 50% by 2025; 55% by 2030		

a. Clarity that recycled content calculations include chemical PET recycling is also needed in the SUPD Implementing Act as soon as practically possible.

A comprehensive regulatory framework is needed to deploy a range of possible policy mechanisms that will drive a rapid transformation of the polyester textile system (Exhibit 19):

- **Ambitious policy mechanisms are needed that go beyond current proposals to reduce consumer demand**. In line with the waste hierarchy,[5] policies that deliver a reduction in overall consumption and extend clothing lifetime should be prioritised. Existing mechanisms include voluntary industry agreements (eg, Textiles 2030 launched by WRAP)[6] and grants to finance the development and scaling of technologies to promote sustainable models (eg, WRAP,[7] CirCoAX).[8] These will need to be complemented with more rigorous mechanisms. Options include the application of tax subsidies, the establishment of targets on the business models to be incentivised (reuse/repair) and a ban on the destruction of unsold stock, such as that introduced in France.[9]
- **Consistently applied EPR principles and regulations across Europe**. This will harmonise efforts and provide certainty to large industry players operating across borders. Indeed some member states – such as the Netherlands,[10] France[11] and Sweden[12] – are already developing or deploying EPR schemes without regional guidelines to align to. EPR policies will need to cover the net costs of delivering the necessary transformation and incorporate circularity principles through eco-modulation at sufficiently high rates to drive action on the part of brands. Research will be needed to understand movements of reusable textiles across borders (within member states and outside Europe) to operationalise the schemes and fee collection.
- **Policies are needed to create a market for recycled materials in textiles that encourages growth and investment.** This can be achieved through a combination of measures such as eco-design principles, targets on recycled content in new textile products and taxes on products that do not meet minimum levels of recycled content. The integration of these measures must be carried out carefully and in coordination with the packaging system. The inclusion of chemical PET/polyester recycling technologies into recycled content calculation methodologies for textile products will be essential in the development of this market.
- **Public resources (grants, investments and resources obtained via EPR) should support the expansion and improved performance of collection, sortation and recycling infrastructure.** The priorities are: ensuring textiles are easier to recycle (eg, fewer fibre blends, switch to single-layer products and making disruptors such as trimmings and fasteners easier to remove), expanding separate textile collection (by increasing convenience of disposal for consumers and encouraging usage via behaviour change), improving sortation capabilities (eg, automated sorting by fibre type to ensure appropriate feedstock for recyclers) and streamlining the build-out of a new chemical PET recycling ecosystem.

Regulations for polyester textiles should also address:

- The large flows of materials that cross European borders. These include the majority of textiles sold in Europe which are produced outside of Europe; the export of second-hand materials outside Europe; and the import and export of recycled PET/polyester. In general, across both textiles and packaging, Europe should focus on ensuring that its own PET/polyester waste is effectively recycled to produce secondary material. The imbalances between the location of PET/polyester consumption and the manufacture of PET/polyester products may require global redistribution of rPET (eg, to facilitate textile manufacturing in Asia).
- Integration of measures to reduce contamination by microplastics into eco-design principles.
- Measures to address the reality of small and medium-sized enterprises. These constitute the majority of companies operating in the sector and can be particularly impacted by changes to tax schemes and other economic measures.

Exhibit 19

The EU Strategy for Sustainable and Circular Textiles sets out ambitious policy initiatives touching on most priority actions, although it has yet to deliver legally binding guidelines. A broad suite of mechanisms is available to support the sector's transformation

Key public policy mechanisms available to increase circularity of polyester textiles[13,14]

		Economic instruments					Direct regulation			Voluntary mechanisms
	Priority actions	**Taxes/fees**	**Subsidies**	**Grants**	**Investment**	**EPR[a]**	**Standards**	**Bans**	**Targets/mandates**	
Upstream	1. Expand reuse and new delivery models for packaging applications	Not applicable to polyester textiles								
Upstream	2. Introduce incentives to shift fast fashion to more sustainable business models and slow growth in demand for polyester textiles		• Taxes/fees (eg, VAT) reductions on reuse/repair models	• Grants for development and scalability of technologies that enable reuse/ repair models	• Direct investments to scale reuse/ repair models		• Increase product durability[b] • Promote reuse/repair • Clear product eco-labelling and consumer information	• Bans on destruction of unsold or returned textiles	• Targets on textile repair, collection, preparation for reuse and recycling to reduce requirements for new clothing and virgin resources	• Voluntary agreement with industry players with targets to reduce overproduction and increase reuse/repair
Upstream	3. Standardise product design to improve recycling economics					• Eco-modulation of producer fees aligned with recyclability requirements	• Product design changes to improve recyclability (eg, reducing presence of fibre blends) • Labelling to facilitate product recycling		• Requirement to meet certain design for recyclability requirements as for packaging under PPWR	• Voluntary product design changes by brands to improve recyclability (eg, reducing presence of fibre blends)
Downstream	4. Ensure long-term demand for recycled PET	• Taxes/fees on products that do not meet recycled content thresholds				• Eco-modulation of producer fees according to recycled content	• Development of recycled content methodology[c] • Chemical PET recycling to account for recycled content		• Recycled content targets established at a product level, with targets increasing over time	• Brands entering into voluntary long-term offtake agreements for rPET created by the recycling of European polyester textiles
Downstream	5. Secure sufficient feedstock flows to recyclers and ensure complementarity between different recycling technologies			• Grants for development and scalability of tech solutions for traceability and sorting	• Fund scale-up and development of additional infrastructure for separate PET/ polyester waste collection and sorting	• Collected EPR funding is used to finance separate collection and sorting systems (eg, kerbside collection, enhanced collection)			• Targets on the proportion of textile waste arising that must be collected separately and sorted for reuse/recycling	
Downstream	6. Scale up recycling infrastructure and optimise performance			• Grants for development and scalability of recycling technologies	• Fund scale-up and development of chemical PET recycling for polyester textiles	• Collected EPR funding is used to finance development of recycling infrastructure			• Targets on the proportion of polyester waste arising that must be recycled (after reuse potential is first realised)	

a. Although EPR requirements are generally enshrined in regulations, many of which are listed in other columns of this exhibit, this section relates specifically to the direct economic/financial impacts of potential EPR regulations for textiles.
b. For example through the application of standards relating to minimum requirements for textile abrasion resistance, ability to withstand multi-axial tension without tearing and colour fastness.
c. Targets on recycled content in textiles must be carefully established to consider the system-level impacts if contact-sensitive rPET (eg, from bottles) is permitted to be used in textile manufacturing in the long term.

Conclusions

The analysis in this report shows that PET/polyester is well suited to a 'complementarity' approach where measures to slow demand growth, mechanical recycling and chemical PET recycling are applied together to build a circular system. With ambitious application of these known circular economy interventions, the PET/polyester system in Europe could be transformed. Relative to a continuation of historical trends, it could:

- Reduce PET/polyester consumption by one-third
- Reduce PET/polyester sent to landfill and incineration by ~70%
- Halve system-level GHG emissions
- Increase the supply of recycled PET suitable for new PET/polyester packaging and textiles to 4.7Mt/year

A transformed PET/polyester system by 2040 will require ambition, speed, clarity and collaborative mindsets from policy-makers, industry, national and regional government authorities and investors across Europe.

The European packaging system is already going through a major policy upgrade that will support this system transition if fully enacted. The textile system requires similarly urgent and significant transformation to slow demand growth through circular business models and radically increase recycling rates. Innovation and R&D are still needed to develop and deploy new solutions in different parts of the system, and must be enabled and not stifled by policies.

Overall, policy changes and strong demand for recycled content in end-user industries are creating a positive backdrop for investment in a more circular PET/polyester system. Large-scale capital is required to construct and upgrade collection, sorting, reuse, mechanical recycling and chemical PET recycling infrastructure. Long lead times mean that this investment must start to flow in the 2020s, to build the 2040 circular system envisaged in this study. Value chain participants should now move with conviction to secure a competitive advantage and deliver a circular system that aligns with the vision set out in this report.

A transformed PET/ polyester system will require ambition, speed, clarity and collaborative mindsets from policy-makers, industry, national and regional government authorities and investors across Europe.

Scope

Scope of the report

The model begins with available data for PET/polyester consumption and is therefore thought to account for the vast majority of PET/polyester flows in Europe (eg, waste data is known to be missing a significant volume of plastic waste when compared to consumption data). The analysis covers packaging (split into clear beverage bottles; coloured beverage bottles; non-food-and beverage bottles; clear monomaterial PTTs; multimaterial PTTs; and 'other packaging', thought to comprise mostly strapping and various PET films) and polyester textiles (given as a single category but assumed to cover clothing and household textiles, as well as industrial textiles).

Due to a lack of available data, pre-consumer PET/polyester waste flows (eg, bottle production rejects and textile production offcuts) were not modelled separately; instead, the mass of this material is assumed to be contained within the major flows of each product category. Additionally, PET/polyester used in further product categories (eg, electrical goods or the automotive sector) is excluded due to evidence of market shares for these applications constituting less than 1% of overall European PET/polyester consumption.

Finally, imports and exports of both virgin PET and recycled PET are considered in the system model using simplifying assumptions to ensure that estimated environmental impacts are included for production and disposal of all PET/polyester used in Europe, even if it is produced or disposed outside Europe. Transportation emissions are not included as previous studies have indicated they are not material contributors to system-level GHG emissions.

Scientific rigour and diverse input

This analysis was conducted following a strict evidence-based approach, relying on reliable published data in conjunction with a Steering Group comprising 11 experts, representing diverse geographies and industries from across the value chain, as well as interviews with and additional validation from further experts from across the PET/polyester sector. All assumptions and methodologies have been extensively peer reviewed and are available in the detailed Technical Appendix.

Model limitations and uncertainty

System economics were not analysed due to the lack of publicly available benchmarks for the cost of scaled-up application of key circular economy solutions (eg, reuse and chemical PET recycling). Primary micro-plastic pollution from the PET/polyester system (manufacturing, usage and recycling/disposal stages) were not analysed. Research has highlighted concerns about micro-plastic discharges from recycling facilities. Additionally, the presence, accumulation and migration of substances of concern were not modelled. The extent of this potential risk, and that of micro-plastics release, requires further research.

The analysis assumes that major change is possible with adequate policy, behaviour change, financing, leadership and technology adoption. Given the high level of uncertainty inherent in any exercise that takes a 20-year forward-looking view, significant margins of error must be assumed for the outputs, especially in the later years. This uncertainty has multiple drivers. For example, some levers may run into 'real-world' barriers that are difficult to predict (eg, best-in-class performance may not scale accordingly across Europe for various reasons); the cost of certain technologies may vary significantly, while required investments may not come to fruition; implementation of policies may not happen as expected (eg, widespread adoption of deposit return schemes for bottles); currently unforeseen technologies may grow rapidly to reach mass adoption, disrupting the existing outlook for the system; public discourse and behaviour change may result in completely different PET/polyester consumption patterns emerging in future; the development of international supply chains could change the economics of Europe pursuing high-circularity for all its PET/polyester waste; and potentially other factors.

In addition, a Europe-wide model has, by definition, limited granularity, and our conclusions need to be applied carefully to local contexts. Despite this uncertainty, comparisons among scenarios based upon current and historical evidence can be very informative and help to show both the relative impact of different levers and the necessary pace of change that would be required, compared to the current system trajectory. As well as validating assumptions and methodologies with the Steering Group and other industry experts, a sensitivity assessment was undertaken to investigate the impacts of failing to achieve key aspects of the system transformation by 2040.

System map

At the heart of the analysis is a conceptual mass-based model (Exhibit 20) that highlights the main stocks (represented by boxes in the system map) and flows (represented by arrows) of key PET/polyester product categories within the European system. Importantly, the system map and underlying model track the weight of PET/polyester only. They do not include the weight of non-PET/polyester parts or material, such as the caps, lids and labels of bottles; food, liquid and other contaminants on PTTs; or the weight of non-polyester fibres in blended polyester textiles.

The model follows an input-driven, rather than output-driven, approach. This means that system parameters such as PET/polyester consumption and waste collection rates are specified, resulting in system outcomes, such as recycled PET/polyester content in new products, being generated by the model. These outcomes are then evaluated against current and draft regulatory targets. An input-driven approach therefore allows stakeholders to compare the impacts of specific actions (or inaction) with regulatory target outcomes.

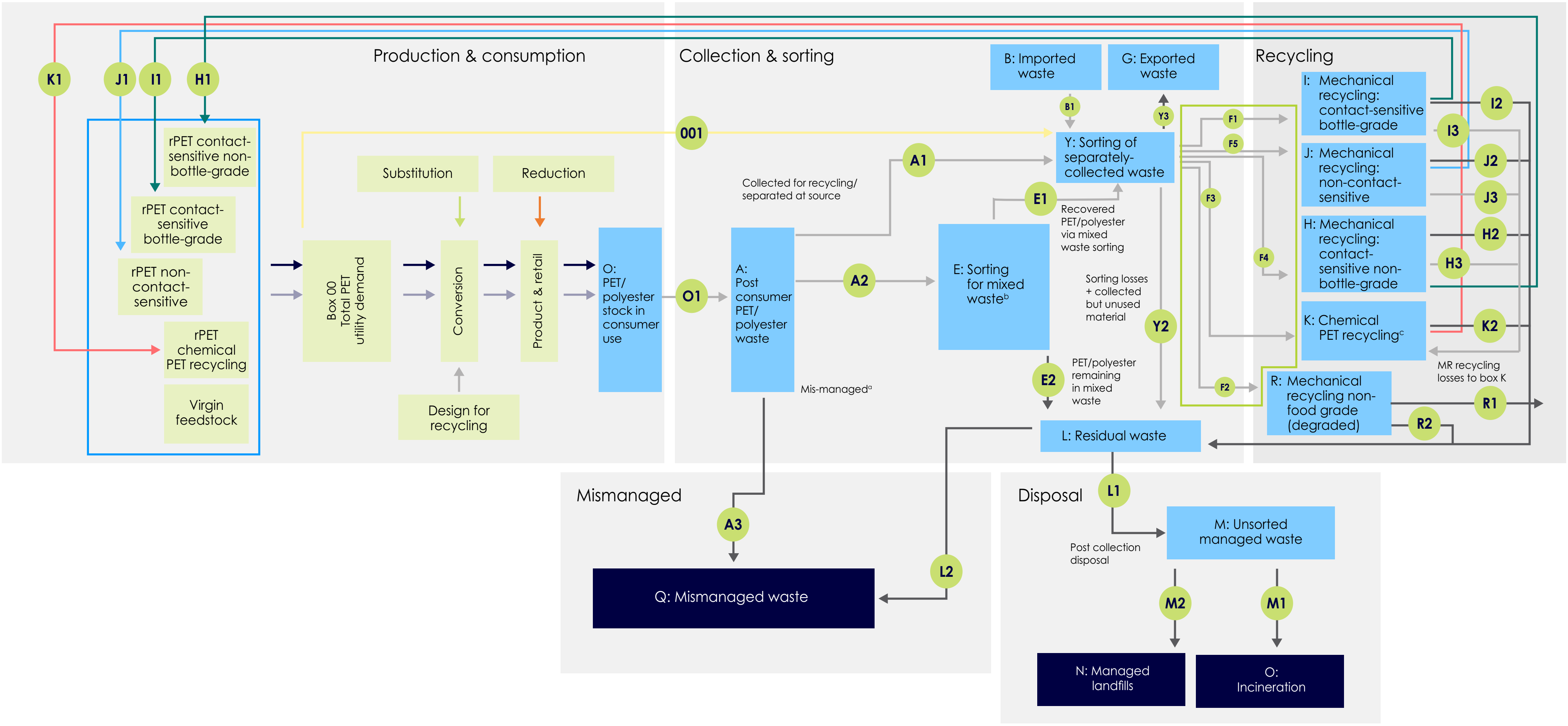
Published data and expert insights are used to set parameters for the current and potential future size of each arrow and box in the system map for each PET/polyester category and for each future scenario. Additionally, GHG emissions data associated with each system activity was collected to calculate the emissions under each scenario, in the context of a decarbonising European electricity grid. Where data was unavailable, expert opinion was collected; otherwise, assumptions were made, the details and rationale for which are outlined in the Technical Appendix.

The geographic boundary of the system map is the EU27+UK, except for the export of polyester textiles for reuse, for which the GHG emission footprint includes a weighted average for the end-of-life fate of these textiles outside of Europe (a mix of landfilling, littering and incineration without energy recovery).
For more details, see the ‘Scope’ section.

Exhibit 20

Mass-based PET/polyester system map

PET/polyester flow
Pre-consumer
Points of mass accumulation
Fossil virgin PET
rPET
Substitution away from PET/polyester
PET/polyester reduction (elimination)
Non-contact-sensitive PET recycling
Contact-sensitive PET recycling
Chemical PET recycling
Production losses
Waste PET/polyester flows
Non-recycled (lost) PET/polyester
Polymers
Feedstock allocation



a. Mismanaged waste stream includes littering and some dumping/burning.

b. Note that PET/polyester waste sorted from mixed waste is unlikely to be used for recycling into contact-sensitive rPET, unless it can be proven that the rPET meets appropriate safety standards. In practice, this waste will not be mixed with waste from separate collections (eg, within sorting facilities receiving separately collected waste.

c. Chemical PET recycling (depolymerisation) is an average of methanolysis, hydrolysis and glycolysis. The model will not have a view on which of the three have the biggest market share. This process box also includes (re)polymerisation to create rPET. For definitions of the other recycling processes, see the Technical Appendix.

Glossary

Chemical recycling
Processes that break down polymers into individual monomers or other hydrocarbon products that can then serve as building blocks or feedstock to produce polymers again.

Circularity
Circularity is a measure of resource efficiency – that is, degree to which (re)used materials replace new virgin materials. In this report, the circularity metric is defined as the share of plastic utility that is either reduced, substituted by circular materials or recycled mechanically or chemically. It excludes plastic disposed of in a linear fashion or plastic entering stock.

Contact-sensitive
Materials subject to specific regulations in the European Union and intended to come into contact with food or skin (eg, cosmetic or pharmaceutical purposes).

Design for recycling
The process by which companies design products and their packaging to be recyclable.

Extended producer responsibility
Schemes that enable producers to contribute to the end-of-life costs of products they place on the market.

Feedstock
Any bulk raw material – virgin or secondary – that is the principal input for an industrial production process.[15] Currently, plastic is largely produced from petrochemical feedstock (ie, from fossil fuels).

Incineration with energy recovery/ waste-to-energy
Waste-to-energy refers to the incineration of (plastic) waste with recovery of generated energy. Waste-to-energy schemes use plastic waste as a fuel to generate power.

Landfill
Specially engineered sites for the disposal of solid waste on land. The waste is generally spread in thin layers which are then covered with soil.[16]

Lever
A specific solution modelled within a system intervention.

Mechanical recycling
Operations that recover after-use plastics via mechanical processes (grinding, washing, separating, drying, re-granulating, compounding), without significantly changing the chemical structure of the material.[15]

Plastic
Material which contains, as an essential ingredient, a high polymer and which at some stage in its processing into finished products can be shaped by flow.[16]

Plastic demand
Plastic demand is defined as the volume of plastic utility minus the volume of plastic utility fulfilled by reduce and substitute levers.

Recyclate
Recyclate is the output material of recycling processes that can be directly used as a secondary raw material for plastic conversion.

Reuse models
Replacement of single-use packages with reusable items owned and managed by the user or by services and businesses which provide the utility (new delivery models).

Sorting
Physical processing techniques and processes to separate materials in waste streams. Sorting is typically performed in material recovery facilities or specific plastic recovery facilities. Sorting can be performed automatically with sorting technologies or manually.

Virgin plastic
Direct resin produced from a petrochemical feedstock, such as natural gas or crude oil, which has never been used or processed before.

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Note: Further details on additional technical references can be found in the Technical Appendix.

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