SYSTEMIQ

TECHNICAL APPENDIX AND DETAILED ASSUMPTIONS

November 2024

This technical appendix compiles the methodology and assumptions underpinning the 'Transforming PET Packaging and Textiles in the U.S.: System change scenarios and recommendations to cut waste, create jobs, and mitigate climate change' report and its modelling. It builds on a similar report that has been published in 2023 by Systemiq for the European PET and Polyester system ('Circular PET and Polyester: A circular economy blueprint for packaging and textiles in Europe'). The focus of the main report is on clearly communicating the findings of the underlying model and analysis, with a deliberate attempt made to minimize explaining the process and assumptions of the analysis. However, in order to provide full transparency, this document provides a more detailed explanation of the approach taken to developing the model, the scenarios, and respective key assumptions.

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1. INTRODUCTION

The report 'Transforming PET Packaging and Textiles in the U.S.: System change scenarios and recommendations to cut waste, create jobs, and mitigate climate change" provides a new evidence base, exploring future scenarios for the US PET[1] [2] sector and the extent to which complementary application of interventions across the entire value chain could contribute towards a circular, lower CO_2 emissions economy from 2022 to 2040. Interventions include circular economy measures to slow consumption growth (PET elimination and product reuse[3]), increases in waste collection and sortation as well as the application of depolymerization recycling alongside mechanical recycling for PET waste.

The findings of the report are based on the 'US PET/Polyester' model. This Technical Appendix transparently highlights the methodology and modelling approach as well as the scenarios constructed and corresponding key assumptions.

The 'US PET/Polyester' model projects stocks and mass flows of PET/polyester (in million metric tonnes, referred to as 'Mt') across 13[4] major PET product categories in the United States (US) for the years 2022-2040. These PET/polyester stocks and flows are quantified at different stages of the value chain in the system. Importantly, where products are typically comprised of PET and non-PET parts (such as the caps, lids and labels of PET bottles and the non-PET fibers in blended textiles that comprise PET as polyester and other fibers), or accumulate non-PET material (e.g., contamination during waste collection process), the weight of this non-PET material is discounted in order to track, as much as possible, pure PET mass flows in the model. This means that, for example, when recycling process yield rates are modelled, this is on the basis of a 'PET-to-PET' yield rate. The product categories modelled (broadly: packaging and textiles) are explained in the section "PET categories". An overview of the modelled flows is shown in the system map in Figure 2.

Two core future scenarios are envisaged: a 'Current Trends' scenario (CTS), which is effectively used as the baseline for comparisons, and an 'Ambitious Circularity' scenario (ACS), which is based on a principle that proven, best-in-class approaches can be widespread across the US by 2040. The aim of the ACS is to understand the impact of these interventions on material circularity and system greenhouse gas (GHG; measured in Mt of CO_2 equivalent) emissions. The projections under the CTS are based on a continuation of recent PET/polyester consumption trends and end-of-life disposal/recycling pathways between 2022 and 2040. In addition to the two core scenarios, a number of sensitivities on the ACS have also been constructed. These are used to investigate which assumptions the model outputs are most affected by. A more complete explanation of the scenarios and sensitivities modelled is provided below in section 'Overview of scenario and sensitivities construction'.

Scenarios have been modelled to establish potential pathways towards system circularity and reduction of 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

[1] Polyethylene Terephthalate
[2] In this report, the PET sector encompasses both PET packaging and polyester textiles.
[3] Substitution into and out of PET into other materials has been considered qualitatively in the report but not been modelled separately due to inconclusive environmental benefits from substitution into and out of PET more broadly for the considered product categories. Rather, substitution is assumed to be inherently factored into the consumption projection and needs to be evaluated on a case-by-case basis.
[4] Note that 13 product categories were modelled, while results shown are aggregated to seven product categories. The reasoning behind this is explained in the section 'PET product categories .

variations, in order to generate insights on different system change pathways, impacts, and trade-offs.

MODEL LIMITATIONS AND UNCERTAINTY

The analysis assumes that major change is possible with adequate policy, behavior change, financing, leadership, and technology adoption. Importantly, the model quantifies the mass-flow and environmental and socio-economic impacts if certain conditions become true in 2040. It is not a forecast or projection. For example, some levers may run into "real-world" barriers that are difficult to predict (e.g., best-in-class performance may not scale accordingly across the US for various reasons); the cost of certain technologies may vary significantly whilst required investments may not come to fruition; implementation of policies may not happen as expected (e.g., widespread adoption of deposit return schemes (DRS) for bottles); currently unforeseen technologies may grow rapidly to reach mass adoption, which disrupt the existing outlook for the system; public discourse and behavior change may result in different PET/polyester consumption patterns developing in future; development of international supply chains could change the economics of the US pursuing high-circularity for all its PET waste; and potentially other factors.

The systems change levers modelled aim to establish the potential impacts of available technologies and operational capabilities to drive change in the PET/polyester system. Modelled scenarios were designed using the best available information to inform mass flows and greenhouse gas (GHG) emissions, yet the model does not fully capture all components and the complexity of the system. Because data gaps exist in all stages of the PET/polyester system (including the amount and type of PET/polyester products placed on the market, amount and sources of waste generation, collection, recycling, disposal, leakage of PET waste, etc.), the model is unable to take into account all system feedbacks. Model design and construction required expert judgment to fill data gaps and estimate current and potential rates of change for the system components, which were then used to generate outputs. As a result, the analyses include inherent assumptions and are unable to determine system sensitivities to some external drivers, such as the price of oil. In addition, a nation-wide model has, by definition, limited granularity, and our conclusions need to be applied carefully to local contexts (e.g., states).

Despite these limitations, the model results are informative as long as they are appropriately contextualized. This means that, rather than providing specific directions for government and industry decision-makers to pursue at individual locations, outputs should be viewed as a system-level assessment of potential futures based on a broad suite of actions and stakeholder priorities. Ultimately, the model and analysis of this report seek to explore the potential to transition to a more circular, lower-emission PET system by analyzing constraints and the potential for scaling different interventions, based on historical trends and current developments. As such, this report seeks to understand what is possible and what factors this system vision depends upon.

SCIENTIFIC RIGOR AND DIVERSE INPUT

This analysis was conducted following a strict evidence-based approach, relying on high-quality, mostly public data in conjunction with three project partner organizations (Closed Loop Partners, The Recycling Partnership, as well as Eunomia Research and Consulting), an independently chaired Steering Group comprising over 15 experts who represent diverse experience from across the value chain, as well as interviews and additional validation with further experts from across the PET sector. All assumptions and methodologies have been shared transparently and extensively peer-reviewed. They are provided in this Technical Appendix.

SCOPE OF STUDY

Our analysis quantifies the mass flows of PET/polyester across both consumer and industrial applications in the time period from 2022 to 2040. On that basis, GHG emissions and job creation are calculated using respective factors. The geographic boundary of the model is the US, except for international trade of virgin PET/polyester, finished textile and packaging goods, recycled PET (rPET), as well as PET/polyester waste, for which global average GHG emission factors were assumed. Job creation only considers domestic jobs, not jobs created beyond the US. Mass flows, GHG emissions, and job creation are quantified on federal level and state-level dynamics were not modelled explicitly. Copolyester, bio-based PET/polyester, system economics, as well as other environmental and health impacts (e.g., biodiversity), including those of (primary) microplastics or substances of concern, are not in-scope. 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 the US. The analysis covers PET packaging and polyester textiles. Import and export of both virgin PET/polyester and rPET are generally considered in the model, but results are agnostic to their exact provenance and use. Post-industrial waste streams (such as bottle production rejects and textile production offcuts) are not modelled separately, the model rather assumes that consumed PET/polyester follows typical post-consumer waste flows.

PET PRODUCT CATEGORIES

The scope of this study covers 9.4 Mt of total US PET/polyester demand, as of 2022. The analysis considers the two largest PET/polyester consuming sectors: packaging (40%) as well as textiles (60%) and models 13 individual product categories across these sectors. More information on these sectors and the specific product categories modelled is provided below:

- **PET packaging:** Given data availability, seven separate packaging categories are modelled. These include clear beverage bottles, colored beverage bottles, clear non-beverage bottles, colored non-beverage bottles, clear thermoforms (also referred to as clear pots, tubs, and trays (PTTs)), colored thermoforms, as well as ‘other packaging’, thought to comprise mostly strapping and various types of PET films.
- **Polyester textiles**: Given the significance of polyester textiles (60% of total PET/polyester mass in 2022) and despite significantly less availability of accurate data compared to packaging, the following six textile product categories were modelled: polyester-rich apparel (>80% polyester share), polyester-poor apparel (<=80% polyester share), non-durable home textiles, durable home textiles, carpet, and technical textiles.

These product categories have been chosen to be able to account for key characteristics of the individual product categories (see Figure 1). Note that to support understanding of the presented results in the report, modelled product categories have been aggregated to three packaging and four textile product categories (see Figure 1).

FIGURE 1. MAPPING OF MODELLED VS. PRESENTED PRODUCT CATEGORIES AND THE RESPECTIVE RATIONALE

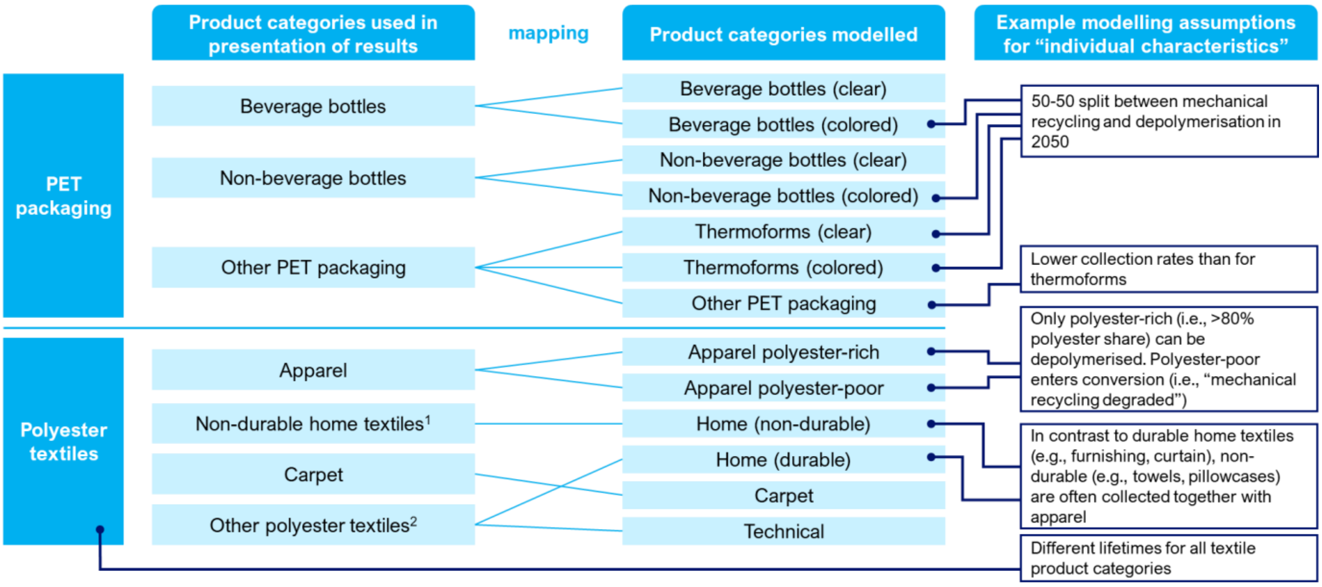


Table 1 provides an overview of the assumed 2022 consumption by product category. PET used in other product categories beyond those modelled is excluded due to their insignificance and lack of data, nor are possible future PET product categories that could gain significant market share in the next ~20 years.

TABLE 1. PRODUCT CATEGORIES AND ASSOCIATED VOLUMES

Product category		Modelled US consumption in 2022 (in Mt)	Share of total consumption in 2022
PET packaging[5]	Beverage bottles (clear)	2.5	27%
	Beverage bottles (colored)	0.3	3%
	Non-beverage bottles (clear)	0.1	1%
	Non-beverage bottles (colored)	<0.1	0%
	Thermoforms (clear)	0.5	5%
	Thermoforms (colored)	0.1	1%
	Other PET packaging	0.2	2%
	Apparel polyester-rich	1.9	21%

[5] All based on NAPCOR (2022): PET Recycling Report (not publicly available). Split into clear/colored bottles and thermoforms is based on unpublished data from The Recycling Partnership. Split into beverage/non-beverage bottles is assumed to be the same as in Systemiq (2023): Circular PET and Polyester. (URL). Split into thermoforms vs. 'other PET packaging' is based on unpublished data from NAPCOR.

Polyester textiles[6]	Apparel polyester-poor	0.9	9%
	Home (non-durable)	0.6	6%
	Home (durable)	0.6	6%
	Carpet	0.6	6%
	Technical	1.1	12%

SYSTEM MAP

At the heart of the analysis is a conceptual mass-based model (Figure 2) that highlights the main process steps and stocks (represented by boxes in the system map) as well as mass flows (represented by arrows) for each of the above-mentioned PET/polyester product categories within the US system.

Effectively, the model is structured such that the mass flows of each product category remain separated. Hence, conceptually, there are 13 separate system maps, one for each product category. The key point at which the product categories (and therefore the maps/model) connect together is when rPET, created through the recycling of PET waste in a given year between 2022-2040, is pooled together and subsequently flows into the production of new products in the next year. Particular allocation shares of rPET to the different product categories are not provided since different rPET grades were not modelled.

Public data and expert insights were used to define the current and model the future mass flow as well as stock of each arrow and box in the system map for each product category and for each core scenario as well as scenario sensitivity analysis. Where data was unavailable, expert opinion was collected, or otherwise assumptions were made. The respective details and rationale are outlined in this document.

Additionally, the following metrics were mapped to the mass flows: Revenue in Dollar per metric ton of recycled PET (rPET) generated per year and GHG emissions in million metric tonnes of CO_2 equivalent ($MtCO_2e$) as well as jobs per 1000 annual metric tonnes of PET/polyester at each stage of the system map. When analyzing GHG emissions, the scope of the study covers the production and end-of-life GHG emissions only. Use-phase emissions (e.g., washing of clothing) or any emissions benefits / avoided emissions (e.g., use of downcycled textiles as insulation for buildings) are not quantified within this study. Jobs associated with activities outside the US (e.g., export of textiles) are not modelled.

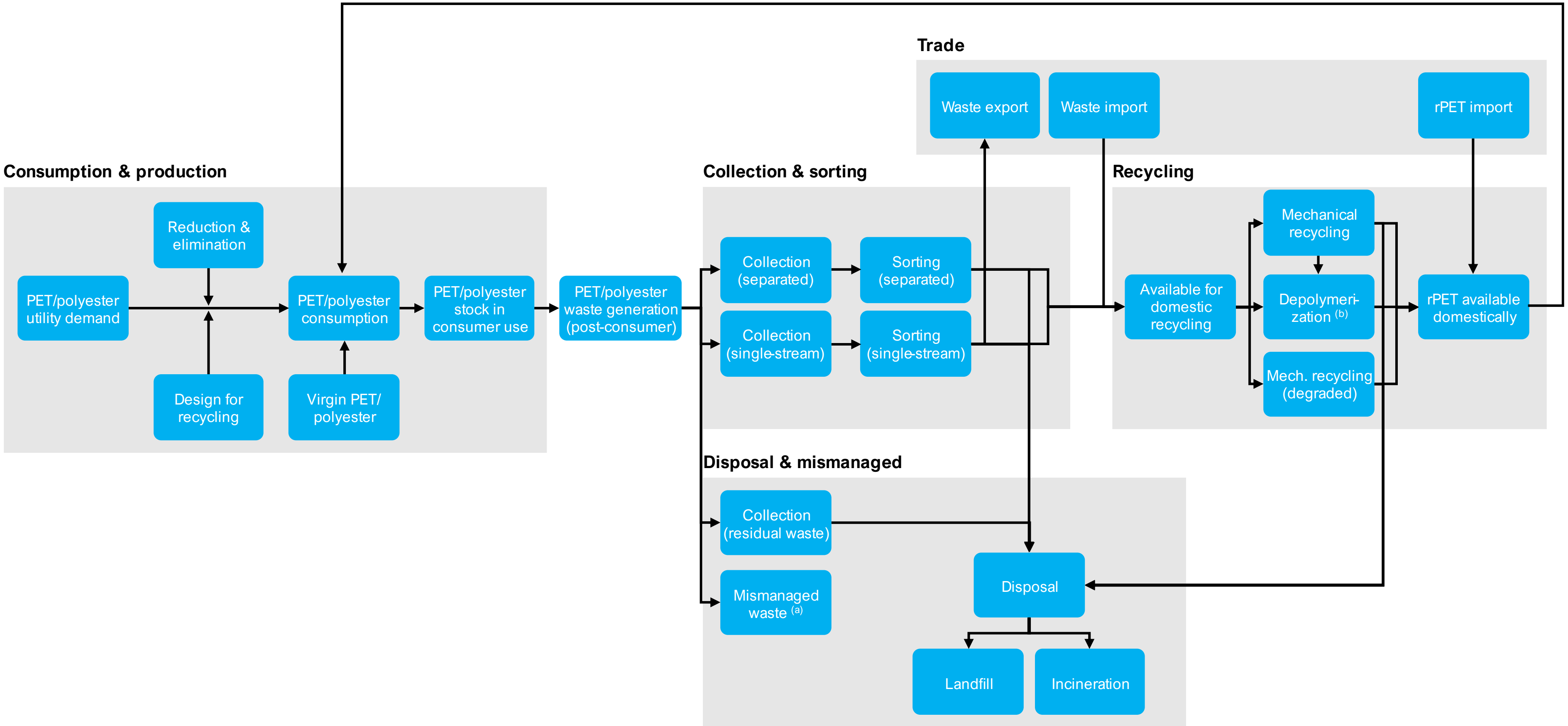
The model follows an input-driven rather than output-driven approach. This means that system parameters, such as PET/polyester consumption per year in Mt, waste collection rates for recycling (as a percentage of waste generation in the same year) and GHG emissions per ton of material passing through each part of the system are specified. This determines downstream system outcomes, such as tons of rPET generated, rPET content share in new products, or GHG emissions. By comparison, an output-driven approach would involve defining a specific system outcome (such as a desired recycling rate for clear beverage

[6] Total volume based on unpublished market information. Source for share of apparel, home, and technical is Systemiq analysis based on Textile Exchange (2023): Materials Market Report 2023. URL. and expert input. Source for share of carpet is Systemiq analysis based on Cunningham and Miller (2022): A material flow analysis of carpet in the United States. URL. and expert input. Split into polyester-rich vs. -poor is based on unpublished data from Resource Recycling Systems (RRS). Split into home durable vs. non-durable is based on Systemiq analysis.

bottles) and then deciding on how a combination of upstream parameters should be defined in order to achieve these outcomes (of which there are a huge number of possible combinations). An input-driven approach is therefore favorable as it allows the use of, e.g., current trends and industry capabilities to set model parameters (instead of an arbitrary mix based on a desired outcome), thus permitting stakeholders to understand the impacts of specific action (or inaction) by specific groups on the resultant outcomes (e.g.. achievement of regulatory targets).

Each part of the system map is defined in the sections that follow in this document, generally listed according to the flow of mass flow within the system from left to right within the system map. In summary, the PET/polyester value chain was categorized into five major components: consumption and production, collection and sorting, recycling, disposal and mismanagement, as well as trade.

FIGURE 2. MODELLED SYSTEM MAP FOR PET/POLYESTER PACKAGING AND TEXTILES.



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

(b) Depolymerization recycling 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)polymerization to create rPET.

2. MODELLING OVERVIEW

MODELLING APPROACHES AND PRINCIPLES

The model aims to provide insights on the level of circularity that can be achieved if proven, best-in-class approaches are widespread across the US by 2040 vs. a continuation of current trends. On that basis, the model quantifies the GHG emissions and job creation implications of that future. Table 2 provides an overview of key overarching modelling assumptions.

TABLE 2. OVERARCHING MODELLING ASSUMPTIONS FOR THE AMBITIOUS CIRCULARITY SCENARIO.

General	• The US PET/polyester recycling system improves, in part due to well-functioning EPR • There is domestic demand for any rPET that the US produces since recycled content commitments and mandates create enough rPET demand to meet ambitious yet realistic supply level • The model produces as much rPET as collection as well as sorting and reclaimer yields allow • No rPET is exported from the US • By 2040, the US PET/Polyester system is not dependent on rPET imports anymore (therefore the model assumes no rPET imports in 2040) • Different grades of rPET are not modelled and therefore no data is provided on the allocation of rPET to different product categories
Collection rates	• Access to recycling services improves, mainly through increasing curbside collection • Participation: Consumer behavior improves
Sorting yields	• Sorting infrastructure meets any supply from collection • Sorting yields improve, also due to advanced sorting technologies becoming widespread, including AI

Reclaimer yields	• Recycling infrastructure meets any supply from sortation
	• Reclaimer yields improve, mainly due to:
	  o High level of Design for recycling
	  o Mechanical recycling receives high-quality feedstock (depends on above)

OVERVIEW OF SCENARIO AND SENSITIVITIES CONSTRUCTION

Two core scenarios are modelled:

- **Current Trends Scenario (CTS):** In this scenario, the model assumes a continuation of recent (over the last few years, depending on data availability) PET/polyester consumption trends and end-of-life disposal/recycling pathways through to 2040. This means that trends in PET/polyester consumption, design for recyclability, collection, and technological improvement (waste sortation and mechanical recycling yield rates). Additionally, since there is no scaled presence of depolymerization recycling capacity (other than Eastman's first plant coming online in Tennessee in 2024), no depolymerization recycling is assumed from 2022-2040.
- **Ambitious Circularity Scenario (ACS):** This scenario assumes that proven, best-in-class approaches are widespread across the US by 2040, including mechanical PET recycling and depolymerization recycling, each complementing the system according to their unique strengths. In terms of levels of performance achieved by the PET system by 2040, the key principles guiding the up- and downstream system parameters/assumptions are applied as below:

- ACS assumptions follow a best-in-class approach, where possible, for defining up- and downstream lever assumptions. In the absence of best-in-class data, a bottom-up approach is used.
- A best-in-class approach is selected based on the best proven example and data in the US. Amongst others, it can be informed by, e.g., the state data for the highest recycling rates by product category or the company/technology data for the most efficient sorting facility.
- A bottom-up approach is used for less established systems where data is not directly available. Here, we rely on technology readiness level or expert input.
- Assumptions have been tested with partners, Steering Group members, and in some cases with external companies.

Note that measures to slow demand growth are applied only to the ACS and the sensitivities on this scenario.

An additional three sensitivity analyses were conducted to understand to what extent the model outcomes in the ACS were sensitive to the key system change levers and underlying assumptions made. These sensitivities include: (1) ACS with no depolymerization recycling, (2) ACS with rPET imports undermining domestic recycling investment, and (3) Only first-mover states achieve ACS level.

Sensitivity modelling has been used to understand the impact of deviations from the ACS and the factors that have the highest impact on the overall system outcomes by 2040. Note that only the parameters that distinguish the scenarios and sensitivities have been adjusted to make the scenarios and sensitivities as comparable as possible, as well as to create clear insights on the key factors that drive outcomes.

Table 3 provides an overview of the key principles of both scenarios and the modelled sensitivities.

TABLE 3. SCENARIO AND SENSITIVITY PRINCIPLES.

Scenarios	**Current Trends (CTS)**	• Projects a continuation of recent PET/polyester consumption trends and end-of-life disposal/recycling pathways
	Ambitious Circularity (ACS)	• Quantifies the impact of applying proven circular economy solutions at scale across the PET/polyester supply chain, in line with best practices in the US today • Based on a principle that proven, best-in-class approaches can be widespread across the US by 2040
Sensitivities	**ACS with no depolymerization recycling**	• If mechanical recycling develops but without any depolymerization
	ACS with rPET imports undermining domestic recycling investment	• If investment in new domestic sorting and recycling were to stall (i.e., capacities available in 2022 for collection, sorting, and recycling remain constant)
	Only progressive states achieve ACS level	• If only the 15 states[7] that have passed or are discussing EPR legislation implement the ACS parameters

[7] State-specific modelling has been approximated by applying the level of the ACS parameters to a share of the PET/polyester mass flows that equals the population share of the below-mentioned states that have passed

A high-level overview of the system change levers enabled across each scenario is shown in Table 3. Chapter 3 will explain the particular assumptions in detail.

TABLE 4. SYSTEM CHANGE LEVERS CONSIDERED.

☑ Modelled at the level of current trends

✅ Modelled at the level of proven, best-in-class approaches

		CTS	ACS
A	Elimination of PET and switch to reusables	☑	✅
B	Design for recyclability	☑	✅
C	Improve and expand collection and sortation for recycling	☑	✅
D	Improve and expand mechanical recycling	☑	✅
E	Improve and expand chemical PET recycling (depolymerization)		✅

The system change levers described in the Figure 3 are:

A. **Elimination of PET and switch to reusables:** Includes eliminating PET/polyester (e.g., product redesign, reduced overpackaging, reduced production waste through better manufacturing), new product delivery models (e.g., reuse, refill services and dispensers) and consumer behavior shifts (e.g., home carbonators and filtration systems).

B. **Design for recyclability:** Includes shifts to clear formats for packaging as well as higher polyester purity levels for textiles that facilitate more effective sortation and recycling.

C. **Improve and expand collection and sortation for recycling:** The scale-up of separate waste collection systems, such as for textiles and systems to sort collected PET from any non-PET it is collected alongside. Improved recovery from mixed waste is modelled also, but is understood to be much more challenging.

packaging EPR bills or have introduced packaging EPR legislation. The level of the CTS parameters is applied to the remaining mass flow share. States that have passed packaging EPR bills (Maine, Oregon, Colorado, California, Minnesota) or have introduced packaging EPR legislation (New York, New Hampshire, Rhode Island, Illinois New Jersey, Massachusetts, Washington, Tennessee, Maryland, Michigan).

D. **Improve and expand mechanical recycling:** Further yield rate improvements and expansion of feedstock such as thermoforms. Scale up of capacity to keep pace with feedstock supply.

E. **Improve and expand chemical PET recycling (depolymerization):** This technology is able to recycle some PET/ polyester applications which mechanical recycling cannot, whilst also elevating PET waste to virgin-like quality, in cases where it has deteriorated through successive mechanical recycling loops and product applications. Significant build out is needed of new plants across the US.

For each of these levers, in the ACS, a proven, best-in-class approach is selected based on the best existing example and data in the US. This can be informed by, e.g., state data for the highest recycling rates by product category or company/technology data for the most efficient sorting facility. A bottom-up approach is used for less established systems where best-in-class data is not available. Here, we rely on technology readiness level or expert input. Figure 3 provides an overview of the approach that has been used for up- and downstream assumptions (note that the exact assumptions are laid out in section '3. Model assumptions by stage of the PET system value chain and scenario'.

FIGURE 3. APPROACH CHOSEN TO DEFINE UP- AND DOWNSTREAM LEVER ASSUMPTIONS.

● Best-in-class geography / facility / technology / company / programme
○ Bottom-up

		Upstream levers			Downstream levers		
		Elimination	Reuse	D4R	Collection rate	Sorting yield	Recycling yield
PET packaging	Beverage bottles (clear)	Technology	Technology	Program	State	Technology (DRS collection); Bottom-up (curb-side collection)	Program
	Beverage bottles (colored)						Program & technology
	Non-beverage bottles (clear)	Technology	Technology	Program	Bottom-up	Bottom-up	Program
	Non-beverage bottles (colored)						Program & technology
	Thermoforms (clear)	Technology	*None assumed*	Program	Bottom-up	Technology	Program & technology
	Thermoforms (colored)						
	Other PET packaging				Programme	Program	Technology
Polyester textiles	Apparel polyester-rich	Bottom-up	Bottom-up	Company (leaders approach)	Geography	Technology (DRS collection); Bottom-up (curb-side collection)	Technology
	Apparel polyester-poor						Technology
	Home (non-durable)	Bottom-up	*None assumed*	*None assumed*			Technology
	Home (durable)				Bottom-up		
	Carpet				State		
	Technical				Bottom-up		

TECHNOLOGY READINESS LEVEL (TRL) AS A FILTER FOR SYSTEM ASSUMPTIONS IN FUTURE SYSTEM

TRL is a method used to assess the maturity of a technology, developed in the US.[8] These are used to filter technologies that could be relevant and widespread in the US PET sector under the ACS in 2040. Technologies below TRL 5 are not considered in this modelling exercise but additional information on technologies included vs excluded and justifications is given in the later sections of this document.

[8] Source: Definition retrieved from Science Direct article; Technology Readiness Level, https://www.sciencedirect.com/topics/engineering/technology-readiness-level

3. MODEL ASSUMPTIONS BY STAGE OF THE PET SYSTEM VALUE CHAIN AND SCENARIO

The following sections provide detailed assumptions, justification and sources for each stage of the US PET value chain across the key product categories modelled, for both the Current Trends and Ambitious Circularity scenario.

US PET/POLYESTER CONSUMPTION IN 2022 AND PROJECTIONS TO 2040

Starting values for PET consumption volume and references are shown in Table 1 above. High-level assumptions about consumption projection to 2040 and factors relevant to consumption are given in Table 5.

TABLE 5 - PET CONSUMPTION ASSUMPTIONS 2022-2040

Parameter	Assumptions (all scenarios)
Baseline PET consumption projection[9]	• Starting consumption values for each product category have been projected to 2030 based on available consumption projections • From 2030 to 2040, per capita consumption growth rates are assumed to trend towards zero by 2040 (linear reduction)
Consumption reduction (elimination, reuse)	• For Current Trends 2040, consumption reduction due to elimination and reuse (incl. new delivery models) are assumed to be implicit in the baseline PET consumption projection • For Ambitious Circularity 2040, consumption reduction due to elimination and reuse (incl. new delivery models) are modelled and applied to the baseline PET consumption projection separately
Consumption reduction (substitution)	• Substitution into and out of PET into other materials has been considered qualitatively in the report but not been modelled separately due to inconclusive environmental benefits from substitution into and out of PET more broadly for the considered product categories. Rather, substitution is assumed to be inherently factored into the consumption projection and needs to be evaluated on a case-by-case basis.
Design for recycling (D4R)	• D4R is modelled as a shift in demand between product categories where applicable, e.g., shift from colored to clear bottles.

To project the future consumption, compound annual growth rates (CAGRs) for the individual product categories were first sourced from the available literature from multiple sources (Table 6). Growth rates for each product category were then calculated based on an average of two to three sources and used for the consumption projection between 2022 and 2030. For consumption growth between 2030 and 2040, it is assumed that per capita consumption growth trends towards 0%, meaning that by 2040, consumption growth solely aligns with population growth in the US[10].

The exception are technical textiles, which already show negative growth (-0.8% CAGR), hence letting per capita growth trend towards 0% in 2040 would translate into an unjustifiable growth of the technical textile category. We therefore made a simplifying assumption that current negative growth of textiles continues through to 2040 at the same rate as 2022-2030.

[9] Refer to Table 6 for sources used for the consumption projection.
[10] Population is expected to grow 0.4% annually between 2030 and 2040. This is based on the projections of population in 2030 (333,288,000 people) and 2040 (355,309,000). US Census Bureau. https://www.census.gov/data/tables/2023/demo/popproj/2023-summary-tables.html, Table 1, accessed on 11th July 2024.

This simplification is justified due to negligible impact on PET/polyester consumption by 2040, as the share of this product category is small compared to the other product categories. Due to automotive being the key driver of technical polyester textiles, growth in the automotive sector serves as proxy for our consumption projection in this product category.

TABLE 6 - COMPOUND ANNUAL GROWTH RATES BY PRODUCT CATEGORY

	Product group	Product category	CAGRs 2022-2030
PET packaging	PET bottles	Beverage bottles (clear)	**3.5%** [11,12,13]
		Beverage bottles (colored)	
		Non-beverage bottles (clear)	
		Non-beverage bottles (colored)	
	PET thermoforms	Thermoforms (clear)	**4.8%** [14,15,16]
		Thermoforms (colored)	
		Other PET packaging	
Polyester textiles	Polyester apparel	Apparel (polyester rich)	**3.0%** [17,18,19]
		Apparel (polyester poor)	
	Polyester home	Home (non-durable)	**5.5%** [20,21,22]
		Home (durable)	
	Polyester carpet	Carpet	**3.6%** [23,24]
	Polyester technical	Technical	**-0.8%** [25,26]

The projection results in an increase of PET consumption by ~50%, reaching 14.0 Mt in 2040 compared to today.

[11] Imarc (2024): North America PET Bottle Market Report. URL, accessed on 11th July 2024.
[12] EMR (2024): North America PET Bottles Market Outlook. URL, accessed on 11th July 2024.
[13] Market Research Update (2024): North America PET Bottles Market. URL, accessed on 11th July 2024.
[14] Grand View Research (2024): North America Thermoformed Plastics Market Size, Share & Trends. URL, accessed on 11th July 2024.
[15] Grand View Research (2024): Thermoformed Plastic Market Size, Share & Trends. URL, accessed on 11th July 2024.
[16] Fundamental Business Insights (2024): United States Thermoform Packaging Market Size & Share. URL, accessed on 11th July 2024.
[17] Statista (2024): Apparel – United States. URL, accessed on 11th July 2024.
[18] Statista (2024): Consumer spending - Clothing. URL, accessed on 11th July 2024.
[19] Oberlo (2024): US Fashion Industry Growth Rate (2019-2028). URL, accessed on 11th July 2024.
[20] Custom Market Insights (2024): US Home Textiles Market 2024-2033. URL, accessed on 11th July 2024.
[21] Mordor Intelligence (2024): US Home Textiles Market Size & Share Analysis – Growth Trends & Forecasts (2024-2029). URL, accessed on 11th July 2024.
[22] Grand View Research (2024): Home Textile Market Size, Share & Trends Analysis. URL, accessed on 11th July 2024.
[23] Statista (2024): Carpets & Rugs – United States. URL, accessed on 11th July 2024.
[24] Imarc (2024): Carpet Market Report. URL, accessed on 11th July 2024.
[25] Statista (2024): Passenger Cars – United States. URL, accessed on 11th July 2024
[26] Report Linker (2024): The United States Automotive Industry Outlook 2024-2028. URL, accessed on 11th July 2024.

EFFECTS OF CIRCULAR ECONOMY MEASURES TO SLOW PET CONSUMPTION GROWTH (ELIMINATION AND REUSE)

To model measures that could slow the trend in increasing PET consumption (e.g., through system interventions), two mutually exclusive levers were considered and applied to annual product category consumption, as relevant: elimination and reuse (Table 7). These levers were applied simultaneously, i.e., the percentage reduction in the weight of annual consumption as a result of each lever is calculated independently, then these reductions are subtracted altogether from the starting annual consumption to get the final annual consumption. All data assumptions and definition of elimination and reuse for textiles are described in Table 7.

TABLE 7 - DEFINITION OF UPSTREAM CONSUMPTION REDUCTION LEVERS (ELIMINATION, REUSE)

Lever	Definition	Examples
Elimination	• Innovations and consumer behavior shifts which lead to reduced plastic material demand for low-utility plastic, that does not require a replacement	• Reduction of over-packaging, e.g. headspace reduction. • Lightweighting of packaging
Reuse (incl. new delivery models)	• Replacement of single-use plastic with reusable items through the following reuse models[27]: o Refill on the go solutions o Refill at home solutions o Return on the go solutions • Shift to concentrated solutions, which often come in the form of refill at home solutions	• Returnable beverage bottles, where packaging is owned and managed by a company • Refill models, where consumers pour products into their own packaging • Refill models, where consumers buy concentrated products, e.g. dishwashing liquid, and dilute the product with water at home

To determine the consumption reduction values for the individual levers per product category, the following approach hierarchy was taken (also see Figure 3):

1. **Approach #1: Best-in-class technology:** use Systemiq approach developed for the '*Breaking the Plastic Wave*' Report (2020), based on 'Maximum Market Penetration Potential' of the specific lever, if applicable to the selected PET product categories.

If approach #1 is not applicable:

2. **Approach #2: Bottom-up:** calculate bottom up, using external sources (expert interviews, reports, and market forecasts) to evaluate the potential of any given lever to slow consumption growth.

The following paragraphs describe approach #1 in more detail. For approach #2, details on approach and sources are provided in Table 8.

[27] Ellen MacArthur Foundation (2019): Reuse – rethinking packaging. https://www.ellenmacarthurfoundation.org/reuse-rethinking-packaging, pp. 12-13, accessed 11th July 2024.

1. Approach #1: Technology

Measures to slow consumption growth (elimination, reuse) have been individually scored to assess their potential market penetration using a 5-test framework developed by Systemiq during the development of Breaking the Plastic Wave report. This is shown in Figure 4.

a Technology test	b Performance test	c Environmental test	d Affordability test	e Convenience test	Limiting factor		
Does a theoretical reduce (1st pass) or substitute (2nd pass) **intervention exist?**	Does the intervention satisfy **performance & health** requirements?	Does the intervention have a better **environmental footprint** (esp. GHG emissivity)?	Are the **cost implications** of the alternative acceptable?	Is the intervention acceptable for **lifestyle and convenience?**	**Overall score**	**2030 %** of serviceable market reached	**2040 %** of serviceable market reached
Yes: TRL 9, available in multiple locations	Yes: meets the minimum performance requirements for sustained utility	Yes: well managed system can outperform reference application	Yes: net savings to society, or broadly acceptable to consumers	Yes: near or better than business as usual	Green	50%	80%
Only at pilot: TRL 5-8	Mostly: does not meet performance requirements for certain applications	Mostly: savings are minimal or on par	Mostly: unacceptable in some consumer segments or products	Mostly: consumers or supply chains would face challenges	Yellow	20%	50%
Only in labs: TRL 1-4	Partially: limited applications only	Partially: externalities small increase of environmental compared to alternative	Partially: eco-conscious consumers only	Partially: eco-conscious consumer only	Orange	1%	10%
No alternative available	Unacceptable health or performance risk	Unacceptable increase in environmental externalities	Unacceptable cost increase	Unacceptable lifestyle change	Red	0%	0%

FIGURE 4 - ELIMINATION AND REUSE SCORING MATRIX

The market penetration potential was then multiplied by the achievable mass reduction for elimination and reuse for the respective PET categories. This is equal to the consumption reduction that can be achieved by 2040. Note that only solutions that currently meet at least technology readiness levels (TRL) 5-8 are considered in this study.

Example: Elimination of PET packaging in beverage bottles through lightweighting (relevant sources are cited in Table 8):

- Mass reduction: best-in-class lightweighting technology of water and carbonated soft drink PET bottles show a mass reduction potential of **~48%** compared to an average water and carbonated soft drink PET bottle of the same size.
- Market penetration potential (i.e. technology readiness): we assume a TRL of 5-8 as the technology is proven by a Canadian manufacturer of injection molding machines in collaboration with a research institute, and therefore assume that this technology can reach **50%** of the market by 2040 (based on Figure 4)
- Therefore, the consumption reduction through lightweighting of PET beverage bottles is **48% * 50% = 24%.**

The consumption reduction for other product categories and levers has been conducted in the same way whenever approach #1 was adopted [28]. A summary of the consumption reduction (as a percentage of annual demand) in 2040 for each product category and for each lever is given in Table 8, as well as a brief description of the information and sources relied upon.

[28] Note that for some PET product categories and levers, an additional layer of calculations was required to arrive at numbers for mass reduction and market penetration potential. These are explained in Table 8.

TABLE 8 - CONSUMPTION REDUCTION 2040 THROUGH ELIMINATION AND REUSE

			Elimination	Reuse

PET packaging	**Beverage bottles (clear)**
	Beverage bottles (colored)
		2040	**24% consumption reduction**, based on
			• Mass reduction: best-in-class lightweighting technology available today (~45% water bottles and ~50% carbonated soft-drinks compared to average bottle weight on the market today[29],[30],[31],[32];
			• Market penetration potential: 50% US-wide adoption by 2040 based on current technology readiness
				30% consumption reduction. This is based on mass reduction by reuse model, market penetration potential by reuse model, and beverage volume sold in PET bottles by reuse model
				• Mass reduction: best-in-class mass reduction assumptions for reuse models
				  o Refill at home (e.g. home soda maker): 85% [33]
				  o Refill on the go (i.e. fountain dispensers): 100% as single-use PET bottle replacement vessel is assumed to be a non-PET, consumer owned vessel (cup, bottle)
				  o Return on the go (i.e. European style deposit return models for reusable bottles): 90%, based on the comparison of the weight of a single-use PET bottle and a reusable PET bottle[34], [35] of the same size and an average number of reuses of 15, which is based evidence from established systems [36];
				• Market penetration potential:
				  o Refill at home: 50% based on TRL by 2040
				  o Refill on the go: 10% for water based on TRL by 2040
				  o Return on the go: 10% based on TRL by 2040
				• Beverage volume: based on current consumption patterns of US consumers for key beverage categories sold in PET bottles

[29] Interpack (2024): The lightest bottle in the world. URL, accessed on 11th July 2024
[30] Petainer (2024): Soda bottles. URL, accessed on 11th July 2024
[31] Wood MacKenzie (2019): Aluminium vs plastic: who'll win the water bottle war? URL, accessed on 11th July 2024
[32] SMF (2022): What to produce? URL, accessed on 11th July 2024
[33] SodaStream (2020): SodaStream Environmental Overview 2020. URL, accessed on 11th July 2024
[34] Alpla (2024): Reusable PET bottles. URL, accessed on 11th July 2024
[35] Petainer (2024): PET plastic bottles. URL, accessed on 11th July 2024
[36] GDB (2024): Flaschen und Kästen. URL, accessed on 11th July 2024

		2040		(water, carbonated soft drinks), assumptions were made on the share of each beverage category that could switch to a particular reuse model. These assumptions are based on confidential expert input and sources and cannot be disclosed. • The calculation done to arrive at the consumption reduction is: PET bottle volume by reuse model x market penetration by reuse model x mass reduction by reuse model. Summing up the PET consumption reduction for each reuse model leads to 30%.
	Non-beverage bottles (clear) **Non-beverage bottles (colored)**	2040	**25% consumption reduction**, based on • Mass reduction: best-in-class lightweighting technology available today of 50% (carbonated soft-drink bottle lightweighting potential assumed as proxy for this packaging category [37,38,39]; • Market penetration potential: 50% US-wide adoption by 2040 based on current technology readiness)	**9% consumption reduction**, based on • Mass reduction: best-in-class mass reduction achievements of ~90% for the switch to concentrated products (mostly applicable to laundry)[40, 41, 42] • Market penetration potential: 50% US wide adoption for a switch from liquid detergents to concentrated products with laundry category representing 50% of the non-beverage bottle segment and liquid laundry representing ~40% of the laundry category by 2040 [43].
	Thermoforms (clear) **Thermoforms (colored)**	2040	**10% consumption reduction**, based on • Mass reduction: best-in-class lightweighting technology available today ~ 20% (e.g. 19% in Berry's Superfos yoghurt pots mass reduction) [44, 45]	• **0% consumption reduction**, as there are no proven solutions of reuse in this packaging category[1]

[37] Petainer (2024): Soda bottles. URL, accessed on 11th July 2024
[38] Wood MacKenzie (2019): Aluminium vs plastic: who'll win the water bottle war? URL, accessed on 11th July 2024
[39] SMF (2022): What to produce? URL, accessed on 11th July 2024
[40] Unilver (2024): Reuse. Refill. Rethink. Our progress towards a packaging revolution. URL, accessed on 11th July 2024
[41] Plastics Today (2022): Dial's refillable handwash reduces single-use plastic packaging. URL, accessed on 11th July 2024
[42] Packaging World (2024): Revolutionary detergent washes away plastic bottles in favour of soap tiles stacked in cartons. URL, accessed on 11th July 2024
[43] Cognitive Market Research (2024): Fabric laundry detergent market report 2024 (global edition). URL, accessed on 11th July 2024
[44] Packaging Europe (2022): Berry reduces weight of Milchwerke Schwaben dairy containers by 19%. URL, accessed on 11th July 2024
[45] Berry Superfos (2022): 19% weight reduction for Weideglück yoghurt and desserts packaging. URL, accessed on 11th July 2024

	Other PET packaging		• 50% US-wide adoption by 2040 based on current technology readiness)	
Polyester textiles	**Apparel (polyester-rich)**	2040	• **16% consumption reduction** over average lifetime of apparel based on wastage reduction along the manufacturing value chain (1% [46, 47]), overproduction (20% [48, 49]), and decreased speed of consumption (by 75% [50]) by 2040.	• **16% reuse adoption,** based on volume-based forecasts of the share of the re-commerce market in the total apparel market (31% by 2040) [51, 52, 53, 54, 55, 56, 57], and an assumption that polyester is half as well represented in secondhand clothing when compared to the average for all fiber types in the resale market (50%)[57]. Waste generation considers a lifetime increase of textiles through reuse[46], following a Weibull distribution in the model.
	Apparel (polyester-poor)			
	Home (non-durable)	2040	• **1% consumption reduction** over average lifetime of durable textiles based on wastage reduction along the manufacturing value chain (1% [46,47]) by 2040. Overproduction and decreased speed of consumption not applicable for this textile category.	• **0% reuse adoption and consumption reduction**, as there are no proven solutions of reuse in this textile category
	Home (durable)			
	Carpet			
	Technical			

46 McKinsey (2020): Fashion on Climate. URL
47 Confidential expert input
48 Fashion United (2018): Infographic: the extent of overproduction in the fashion industry. URL, accessed on 11th July 2024
49 EEA (2024): Many returned and unsold textiles end up destroyed in Europe. URL, accessed on 11th July 2024
50 PIRG (2024): How many clothes are too many? URL, accessed on 11th July 2024
51 Statista (2024): Apparel – United States. URL, accessed on 11th July 2024
52 Global Data (2023): United States apparel market overview and trend analysis by category, and forecasts to 2027. URL, accessed on 11th July 2024
53 Future Market Insights (2023): USA & Canada secondhand apparel market. URL, accessed on 11th July 2024
54 Retail dive (2024): ThredUp: US secondhand market to hit $73B by 2028. URL, accessed on 11th July 2024
55 PYMNTS (2023): Secondhand apparel market surges as consumers seek value. URL, accessed on 11th July 2024
56 Fashion United (2022): Global fashion industry statistics. URL, accessed on 11th July 2024
57 Systemiq analysis

DESIGN FOR RECYCLING (D4R)

Design for recycling/recyclability (D4R) are changes in product design made by manufacturers/ PET converters to facilitate more effective recycling at end of life of the products. These changes could enable both easier sortation of PET products at waste sortation facilities (also known as Material Recovery Facilities; MRFs) and during additional pre-sortation at recyclers. Ultimately it results in higher yield rates from sorting, pre-treatments, as well as recycling - both mechanical and chemical.

In the model, for PET packaging, D4R works by shifting a certain percentage of the annual consumption of product types which are considered to be harder to recycle to similar existing product categories considered to be easier to recycle (e.g. clear beverage bottles) without compromising the product functionality. An 80-90% shift from harder to recycle product types towards more recyclable counterparts is modelled by 2040. In the years 2022-2040, this percentage shift increases linearly from 0-90%.

For textiles, first, the polyester purity distribution of the product category has been determined from external sources. Generally speaking, this is divided into two categories: 80-100% polyester purity (polyester-rich) and below 80% polyester purity (polyester-poor). A 10% shift in the consumption of polyester-poor to polyester-rich textiles is assumed to take place by 2040 and this level is achieved through a linear increase between 2022 – 2040 (Table 9).

TABLE 9 – PRODUCT CATEGORY SHIFTS BY 2040 BASED ON D4R

			D4R
PET packaging	Beverage bottles (clear)	2040	• **80% shift from opaque/colored to clear bottles,** based on increasing momentum for D4R through a variety of efforts, such as the Consumer Goods Forum's Golden Design Rules, APR design for recycling guidelines, and US Plastics Pact efforts to make packaging reusable, recyclable, or compostable by 2025.
	Beverage bottles (colored)		
	Non-beverage bottles (clear)	2040	
	Non-beverage bottles (colored)		
	Thermoforms (clear)	2040	• **90% shift from colored/opaque to clear pots, tubs, and trays** based on expert input that the shift is technically feasible. Some products may require additional preservatives to make them shelf-stable in clear packaging.
	Thermoforms (colored)		

	Other PET packaging		
Polyester textiles	**Apparel (polyester-rich)**	2040	• **10% of polyester-poor switch to polyester-rich textiles**, based on a "leaders" approach, whereby 10% of the market shifts to polyester-rich apparel in the absence of commercial incentives and only early-stage political momentum for D4R.
	Apparel (polyester-poor)		
	Home (non-durable)	2040	• Due to limited visibility on D4R for this segment, we do not make an assumption on a shift to polyester-rich textiles, which is reflected as **0% switch in the model.**
	Home (durable)		
	Carpet		
	Technical		

PET/POLYESTER WASTE GENERATION AND COLLECTION

Following consumption of PET products, this PET eventually ends up arising as waste in the US. For packaging, waste production is assumed to take place in the same year (therefore, e.g., consumption of PET for packaging in 2030 equals waste generation in 2030)[58].

For textiles, products are assumed to have a longer average lifetime (three years for apparel and non-durable home textiles; six years for durable home textiles; 15 years carpet and technical textiles). This means that for textiles consumed in 2030, the probability of these products becoming waste follows a normal distribution with a peak at x + *average lifetime* years and a shape variable of 2.5. The amount of this waste arising in any given year is therefore calculated using an appropriate Weibull distribution table within the model. Hence, for textiles, we model a certain stock in the system such that waste generation lags behind consumption. Once its lifetime ends, generated textile waste enters the collection and sorting or disposal and mismanaged areas in Figure 2 (see Table 10).

TABLE 10. DESCRIPTION OF MODELLED WASTE COLLECTION PATHWAYS.[59]

Area in Figure 2	Box in Figure 2	Description
Collection & sorting	**Collection (separated)**	All collection-for-recycling methods that ensure source-separated collection (e.g., Deposit Return Scheme (DRS), textile charity shops or drop-off boxes)
	Collection (single-stream)	All collection-for-recycling methods that collect waste for recycling without source-separation (e.g., general plastic recycling bin with curbside collection)
Disposal & mismanaged	**Collection (residual waste)**	Mixed residual waste collection that does not enter recycling pathways but will be landfilled or incinerated
	Mismanaged waste[60]	Mismanaged waste is not collected but (uncontrolledly) leaks into the environment (e.g., waterways and oceans)

The share of mismanaged waste is kept constant over time in CTS and ACS. Separated and single-stream recycling are shown in Table 11 (note that the 2040 shares for CTS equal the 2022 assumptions since a continuation of current trends is the underlying principle of that scenario). After calculating the volumes of separated and single-stream collection as well as mismanaged waste, any remaining waste arising is assumed to be collected as mixed waste.

[58] Roland Geyer et al. (2017): Production, use, and fate of all plastics ever made, Sci. Adv.
[59] Due to lack of reliable data on where PET packaging production losses occur exactly and flow to, they have not been modelled. In the case of textiles, losses are known to occur at multiple pre-consumer stages (fibre, yarn and garment production, as well as losses at retailers due to overproduction). However, the vast majority of polyester products are manufactured outside the US (e.g., in Asia) and therefore only retail losses are relevant. Additionally, since polyester estimates currently used are based on fiber consumption figures, they should also include retail losses. However, data availability and quality here is poor so this is an area where more data is needed.
[60] Each PET packaging category is assumed to have a flat mismanagement rate of 1% of the amount of waste created, based on Law et al. (2020): The United States' contribution of plastic waste to land and ocean (URL). The same rate has been used for textile waste leakage based on expert input.

TABLE 11. ASSUMPTIONS FOR COLLECTION RATE.

			Collection rate
PET packaging	**Beverage bottles (clear)**	2022	• **65% for DRS collection (separated):**[61] unweighted average redemption rate across all DRS states • **25% for curbside collection (single-stream):**[62] calculated based on 32% collection rate for bottles overall as well as volumes collected through DRS (0.35 Mt) and curbside (0.61 Mt)
		2040 (ACS)	• **90% (separated):**[63] best-in-class state assumption based on 90% collection rate in Oregon today (redemption rate). Note that the ACS assumes that all beverage bottles are collected through DRS in 2040.
	Beverage bottles (colored)	2022	*Same as beverage bottles (clear)*
		2040 (ACS)	
	Non-beverage bottles (clear)	2022	• **25%:** same as curbside collection for beverage bottles (no DRS for non-beverage bottles assumed)
		2040 (ACS)	• **48%:**[64] bottom-up assumption based on high-performance scenario result of EPR modelling for Colorado (assuming no DRS)
	Non-beverage bottles (colored)	2022	*Same as non-beverage bottles (clear)*
		2040 (ACS)	
	Thermoforms (clear)	2022	• **25%**[65]
		2040 (ACS)	• **48%:** bottom-up assumption that thermoform collection rate increase by the same level as non-beverage bottles do
	Thermoforms (colored)	2022	*Same as thermoforms (clear)*
		2040 (ACS)	
	Other PET packaging	2022	• **0%:** assume no collection of other packaging (e.g., strapping) today
		2040 (ACS)	• **18%:** best-in-class approach based on today's rate for thermoforms
		2022	• **16%**[66]

[61] Calculation based on unpublished TRP data.
[62] Calculation based on unpublished NAPCOR, TRP, and Eunomia data.
[63] Based on unpublished TRP and Eunomia data.
[64] Circular Action Alliance, HDR, Eunomia: Colorado Needs Assessment. URL.
[65] Calculation based on unpublished Eunomia data.
[66] Based on expert input. Note that this share includes textile collection for domestic reuse. As we do not explicitly model domestic textile reuse, we have adjusted the collection rate accordingly in the model: We use 15% for 2022 and 37% in 2040 (assuming that domestic reuse grows with the same CAGR as apparel and home (non-durable) are growing).

Polyester textiles	**Apparel (polyester-rich)**	2040 (ACS)	• **38%:**[67] This is the average collection rate today in Europe. Interviewed experts think that without system-level innovation, 25% is possible in the US. Given that we expect that EPR and depolymerization will change the economics of collection and therefore trigger system-level innovation, we assume a higher rate is feasible and know that 38% is possible as it is today's European rate.
	Apparel (polyester-poor)	2022	*Same as apparel (polyester-rich)*
		2040 (ACS)	
	Home (non-durable)	2022	
		2040 (ACS)	
	Home (durable)	2022	• **0%:** Assume no collection today
		2040 (ACS)	• **5%:** Assume no strong drivers for improvement in collection and therefore only assume 5%
	Carpet	2022	• **5%**[68]
		2040 (ACS)	• **43%:**[69] best-in-class state assumption based on 43% collection rate in California today
	Technical	2022	*Same as home (durable)*
		2040 (ACS)	

SORTATION OF COLLECTED WASTE FOR RECYCLING

Once waste has been collected, either through separate or single-stream collection, it generally needs to undergo sortation to segregate target materials (here PET) from non-PET material or contamination. Note that whether PET/polyester waste has been collected through separated or single-stream collection, the sortation pathway is determined. Table 12 provide an overview of the assumptions for the sortation yield (note that the 2040 shares for CTS equal the 2022 assumptions since a continuation of current trends is the underlying principle of that scenario).

Most sortation that results in the creation of (relatively) clean, sorted and homogenous feedstocks for recycling (and reuse, in the case of textiles) takes place at MRFs (for packaging) and textiles sortation facilities (in the case of textiles). Textiles sortation facilities are generally very labor-intensive operations whereas MRFs can be highly automated.

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[67] JRC (2021): Circular economy perspectives in the EU Textile sector. URL. Note that this share includes textile collection for domestic reuse. As we do not explicitly model domestic textile reuse, we have adjusted the collection rate accordingly in the model: We use 15% for 2022 and 37% in 2040 (assuming that domestic reuse grows with the same CAGR as apparel and home (non-durable) are growing).
[68] As You Sow: Carpet Recycling. URL.
[69] California Carpet Stewardship Program (2023): Annual Report 2022. URL.

TABLE 12. ASSUMPTIONS FOR SORTATION YIELD.

			Sortation yield
PET packaging	Beverage bottles (clear)	2022	• **99% for DRS collection (separated)**[70] • **86% for curbside collection (single-stream)**[71]
		2040 (ACS)	• **99% for DRS collection (separated):** assume no further improvement • **95% for curbside collection (single-stream):**[72] bottom-up assumption based on unpublished TRP modelling
	Beverage bottles (colored)	2022	*Same as beverage bottles (clear)*
		2040 (ACS)	
	Non-beverage bottles (clear)	2022	*Same as curbside collection for beverage bottles (clear)*
		2040 (ACS)	
	Non-beverage bottles (colored)	2022	
		2040 (ACS)	
	Thermoforms (clear)	2022	• **44%**[73]
		2040 (ACS)	• **89%:**[74] best-in-class MRF technology
	Thermoforms (colored)	2022	*Same as thermoforms (clear)*
		2040 (ACS)	
	Other PET packaging	2022	• **0%:** assume no sorting for other PET (e.g., strapping) packaging today
		2040 (ACS)	• **44%:** best-in-class assumption based on today's sorting yield for thermoforms
Polyester textiles	Apparel (polyester-rich)	2022	• **99% for manual sorting:**[75] Assumption that "Unusable due to mildew or other contamination" can be interpreted as sorting yield.

[70] Eunomia (2023): The 50 States of Recycling 2023. URL.
[71] Calculation based on Eunomia (2023): The 50 States of Recycling 2023. URL, TRP (2024): State of Recycling. URL, and unpublished TRP and Container Recycling Institute data.
[72] Calculation based on unpublished TRP data.
[73] Calculation based on Eunomia (2023): The 50 States of Recycling 2023. URL, TRP (2024): State of Recycling. URL, and unpublished TRP and Eunomia data.
[74] Based on unpublished TRP data.
[75] Accelerating Circularity (2020): Research and Mapping Report. URL.

		2040 (ACS)	• **99% for manual sorting (applies to the portion that is not depolymerized):** Assume no further improvement • **90% for optical sorting and removal of disruptors (only applies to the portion that enters depolymerization):**[76] Assume that this includes losses due to removal of disruptors and optical sorting loss
	Apparel (polyester-poor)	2022	*Same as apparel (polyester-rich)*
		2040 (ACS)	
	Home (non-durable)	2022	
		2040 (ACS)	• **99% for manual sorting (applies to the portion that is not depolymerized):**[77] same as apparel (polyester-rich) • **95% for optical sorting and removal of disruptors (only applies to the portion that enters depolymerization):** Similar assumption as for apparel (polyester-rich), but less presence of disruptors
	Home (durable)	2022	*Same as home (non-durable)*
		2040 (ACS)	
	Carpet	2022	*Same as apparel (polyester-rich)*
		2040 (ACS)	• **99% for manual sorting:**[78] Same as apparel (polyester-rich) • **100% for optical sorting and removal of disruptors (only applies to the portion that enters depolymerization):** Assume no optical sorting needed and no disruptors present
	Technical	2022	*Same as home (non-durable)*
		2040 (ACS)	

INTERNATIONAL TRADE OF WASTE AND RPET

The model accounts for imports and exports of sorted PET/Polyester waste as well as imports of rPET. Table 13 summarises the assumptions made for waste trade. The model assumes that ~20% of domestically available rPET is coming from imports in 2022. This volume is kept constant in 2040 in the CTS and is set to zero in the ACS (based on the principle that by 2040, the US PET/Polyester system is not dependent on rPET imports anymore; see Table 2).

TABLE 13. ASSUMPTIONS FOR SORTED WASTE TRADE.

	Waste export (in % of sorted)	Waste import (in Mt)

[76] Based on expert input.
[77] Accelerating Circularity (2020): Research and Mapping Report. URL.
[78] Accelerating Circularity (2020): Research and Mapping Report. URL.

PET packaging	**Beverage bottles (clear)**	2022	• **13%**[79]	• **<0.1 Mt**[80]
		2040 (ACS)	• **0%:** assume no exports as domestic recycling system is assumed to be self-sufficient	• Assume no imports as domestic recycling system is assumed to be self-sufficient
	Beverage bottles (colored)	2022	*Same as beverage bottles (clear)*	*Same as beverage bottles (clear)*
		2040 (ACS)		
	Non-beverage bottles (clear)	2022		
		2040 (ACS)		
	Non-beverage bottles (colored)	2022		
		2040 (ACS)		
	Thermoforms (clear)	2022	• **52%**[81]	• **<0.1 Mt**[82]
		2040 (ACS)	• **0%:** same assumption as beverage bottles (clear)	• Assume no imports as domestic recycling system is assumed to be self-sufficient
	Thermoforms (colored)	2022	*Same as thermoforms (clear)*	*Same as thermoforms (clear)*
		2040 (ACS)		
	Other PET packaging	2022	• **0%:** assume no export today	• Assume no imports as domestic recycling system is assumed to be self-sufficient
		2040 (ACS)	• **0%:** same assumption as beverage bottles (clear)	
Polyester textiles	**Apparel (polyester-rich)**	2022	• **94%**[83]	
		2040 (ACS)	• Assume 2022 volume (not share) is kept constant	
	Apparel (polyester-poor)	2022	*Same as apparel (polyester-rich)*	
		2040 (ACS)		
	Home (non-durable)	2022	• **24%:**[84] assume a quarter of the export share of apparel	

[79] Calculation based on unpublished NAPCOR data.
[80] Based on unpublished NAPCOR data, assumed to be split across all bottle product categories based on their respective consumption volume shares.
[81] Calculation based on unpublished NAPCOR data.
[82] Based on unpublished NAPCOR data, assumed to be split across clear and colored thermoforms based on their respective consumption volume shares.
[83] Based on expert input.
[84] Based on expert input.

		2040 (ACS)	• Assume 2022 volume (not share) is kept constant	
	Home (durable)	2022	• **0%:** Assume no export	
		2040 (ACS)	• **0%:** same assumption as beverage bottles (clear)	
	Carpet	2022	*Same as home (durable)*	
		2040 (ACS)		
	Technical	2022		
		2040 (ACS)		

FEEDSTOCK ALLOCATION TO RECYCLING PROCESSES

Once waste is sorted for recycling, this feedstock must be allocated to different types of recycling processes. Feedstock allocation therefore refers to the specific proportions of a given type of sorted PET waste feedstock flowing to various types of recycling activities. The model differentiates between three types of recycling technologies (i.e., pathways): (1) mechanical recycling, (2) mechanical recycling (degraded), also referred to as 'conversion', as well as (3) depolymerization recycling. Figure 5 provides an overview of the allocation to the three recycling technologies in the ACS in 2040 (in % of sorted feedstock). Note that we assume that clear bottles will be mechanically recycled, whereas colored bottles and thermoforms also partly enter depolymerization pathways (50-50 considered as split to reflect uncertainties for exact allocation). For other PET packaging and all textile product categories except polyester-poor apparel, depolymerization enables a shift from no recycling or conversion to recycling (incl. closed-loop). Only polyester-poor apparel is assumed to remain being mechanically converted since depolymerization cannot process low polyester-purity textiles.

Note that in the CTS in 2040, no depolymerization capacity is assumed, such that all sorted PET packaging volume is allocated to mechanical recycling (note that 'Other PET packaging' has a collection rate of 0% in CTS) and all sorted polyester textiles are allocated to mechanical recycling (degraded).

FIGURE 5. ALLOCATION OF FEEDSTOCK TO DIFFERENT RECYCLING PATHWAYS IN 2040 IN THE ACS.

Mechanical conversion for use in lower-value applications (e.g., insulation or mattress filling)

We assume that in 2040, 90% of the mechanical recycling loss cannot be used otherwise and is therefore fed into depolymerization

	2040: Feedstock allocation to recycling	Sum	Mech. recycling	Mech. recycling (degraded)	Depolymerization
Rel.	Beverage bottles (clear)	100%	100%	0%	0%
	Beverage bottles (colored)	100%	50%	0%	50%
	Non-beverage bottles (clear)	100%	100%	0%	0%
	Non-beverage bottles (colored)	100%	50%	0%	50%
	Thermoforms (clear)	100%	50%	0%	50%
	Thermoforms (colored)	100%	50%	0%	50%
	Other PET packaging	100%	0%	0%	100%
	Apparel (polyester-rich)	100%	0%	0%	100%
	Apparel (polyester-poor)	100%	0%	100%	0%
	Home (non-durable)	100%	0%	0%	100%
	Home (durable)	100%	0%	0%	100%
	Carpet	100%	0%	0%	100%

PET/POLYESTER RECYCLING ASSUMPTIONS

This section and Table 14 in particular provides an overview of the yield rates of the recycling processes in the different scenarios and time points (note that the 2040 shares for CTS equal the 2022 assumptions since a continuation of current trends is the underlying principle of that scenario).

TABLE 14. ASSUMPTIONS FOR RECYCLING YIELDS.

			Recycling yield
PET packaging	**Beverage bottles (clear)**	2022	• **86% for mechanical recycling:**[85] average bottle-only, DRS and curbside collection rate
		2040 (ACS)	• **88% for mechanical recycling:**[86] best-in-class program assumption assuming yield reaches today's DRS collection recycling yield
	Beverage bottles (colored)	2022	*Same as beverage bottles (clear)*
		2040 (ACS)	• **88% for mechanical recycling:** Same as beverage bottles (clear) • **90% for depolymerization**[87]
		2022	*Same as beverage bottles (clear)*

[85] Calculation based on Eunomia (2023): The 50 States of Recycling 2023. URL, unpublished Eunomia data and expert input.
[86] Calculation based on Eunomia (2023): The 50 States of Recycling 2023. URL, unpublished Eunomia data and expert input.
[87] Based on Closed Loop Partners (2021): Transitioning to a Circular System for Plastics. URL, Eunomia: Chemical Recycling: State of Play. URL, and expert input.

	Non-beverage bottles (clear)	2040 (ACS)	
	Non-beverage bottles (colored)	2022	*Same as beverage bottles (colored)*
		2040 (ACS)	
	Thermoforms (clear)	2022	• **60% for mechanical recycling**[88]
		2040 (ACS)	• **86% for mechanical recycling:** best-in-class program assumption assuming yield reaches today's bottle recycling yield • **90% for depolymerization:** same as beverage bottles (colored)
	Thermoforms (colored)	2022	*Same as thermoforms (clear)*
		2040 (ACS)	
	Other PET packaging	2022	• **0%:** assume no recycling today
		2040 (ACS)	• **90% for depolymerization:** same as beverage bottles (colored)
Polyester textiles	**Apparel (polyester-rich)**	2022	• **99% for mechanical recycling (degraded):** assume almost no loss as no high-quality output is needed
		2040 (ACS)	• **90% for depolymerization:** same as beverage bottles (colored)
	Apparel (polyester-poor)	2022	*Same as apparel (polyester-rich)*
		2040 (ACS)	• **99% for mechanical recycling (degraded):** assume almost no loss as no high-quality output is needed and no further improvement to 2022
	Home (non-durable)	2022	*Same as apparel (polyester-rich)*
		2040 (ACS)	
	Home (durable)	2022	
		2040 (ACS)	
	Carpet	2022	
		2040 (ACS)	
	Technical	2022	
		2040 (ACS)	

[88] Calculation based on Eunomia (2023): The 50 States of Recycling 2023. URL and unpublished Eunomia data.

The types of recycling considered to be relevant to PET/polyester, in-scope and therefore modelled are mechanical recycling, mechanical recycling (degraded), and depolymerization. Note that depolymerization corresponds to an average of the three main available technologies that show the greatest potential for commercial expansion by 2040: methanolysis, glycolysis, and enzymatic hydrolysis: The blend of chemical recycling, especially depolymerization, technologies for PET that will scale across the US is an uncertain assumption, and one that should not be used as a basis for investment decisions or seen as a forecast. As a matter of fact, the model is agnostic as to which PET depolymerization will scale (e.g., methanolysis, hydrolysis, glycolysis).

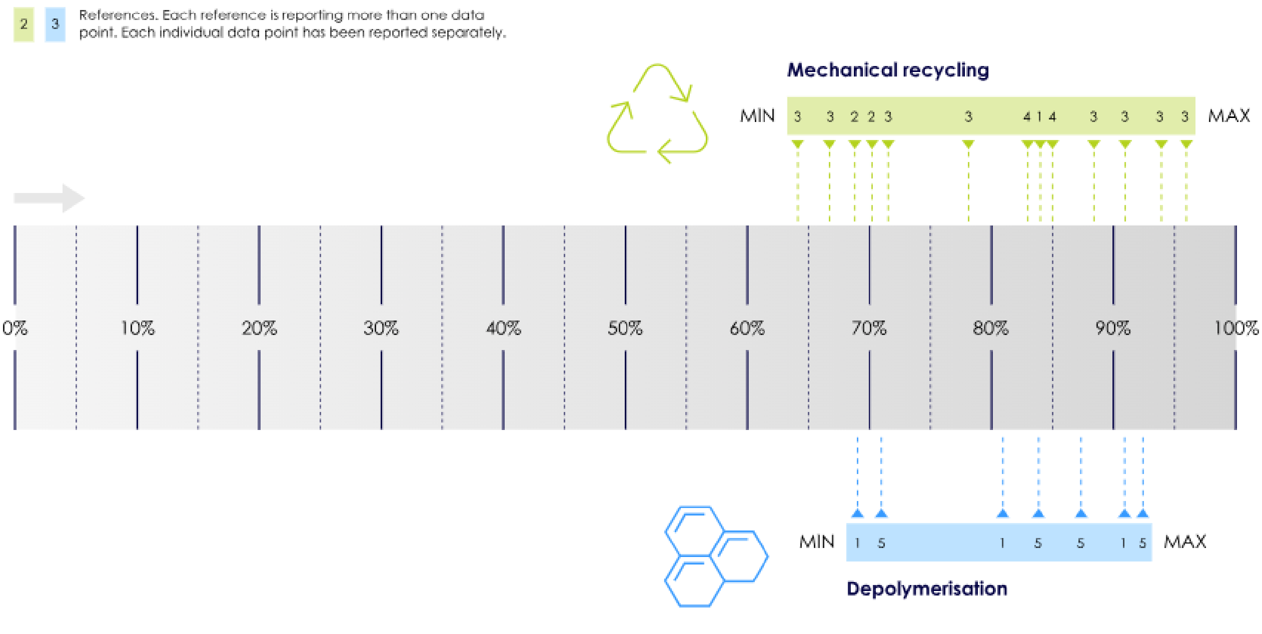
Some recycling technologies have been excluded from the scope due to lack of relevance from a feedstock perspective (e.g., pyrolysis, and gasification where PET is not per se a targeted material and a fraction of the incoming feedstock) or the TRL has been evaluated below 7 (e.g., mechanical recycling of polyester fibers referred to as thermomechanical recycling, solvent-based recycling of PET specifically, thermohydrological separation of polyester from polycotton).

Very limited information was available on the PET/polyester textiles downcycling industry. Generally-speaking, it is understood that polyester-rich clothing is not suitable for certain downcycling applications like industrial wiping rags due to, e.g., worse absorbent properties and higher likelihood of static electricity build-up and discharge than cotton-rich textiles.[89] Instead, they are more likely to be used for example as furniture or automotive stuffing and property insulation filling. However, the specific product types, relative allocations of PET to these, yield rates of manufacturing processes, product lifetimes, disposal pathways and geographic location of final products consumed are not known. Nor is the elasticity of the textiles downcycling industry i.e. how responsive it would be to increased volumes of non-reusable textiles that cannot be chemically-recycled.

Once PET/polyester feedstock has been allocated to recycling processes and subsequently been recycled to produce rPET, this rPET is made available within the model for the production of new PET products in the next year. Particular allocation of rPET to individual product categories is not modelled as it has no implications for the messages of the main report.

[89] Sorting for Circularity Europe, Fashion for Good/Circle Economy (2022)

EXHIBIT **Range of PET material-to-material yield per treatment of recycled plastics**



Note Yield obtained from 1,000 kg of waste plastic together with additives prior to entry into recycling facility (includes in-facility pre-sorting, washing and extrusion steps). Pre-sorting yields have been applied to depolymerisation yields reports by reference (5) according to reference (1).
(1) Closed Loop Partners, Transition to a Circular System for Plastic, 2021, (2) G. Loncaa, et al., Assessing scaling effects of circular economy strategies: A case study on plastic bottle closed loop recycling in the USA PET market, 2020 (3) I. Antonopoulos et al., Recycling of post-consumer plastic packaging waste in the EU: Recovery rates, material flows, and barriers, 2021 (4) Systemiq, Achieving Circularity in Norway, 2021 (5) Eunomia, State of Play: Chemical Recycling, 2020.

RESIDUAL WASTE AND DISPOSAL

The 'Disposal' box in the system map (see Figure 2) aggregates waste from (1) waste collected as residual waste (which is not subsequently sorted for recycling), (2) waste from sorting losses, as well as (3) waste from recycling process losses. This waste is modelled as being sent directly to landfill or incineration (assuming no leakage). The model assumes that 20% of disposed waste flows to incineration and 80% to landfill[90], which is held constant over time.

[90] Systemiq analysis based on expert input and EPA waste generation data (URL).

4. MODEL ASSUMPTIONS FOR GREENHOUSE GAS (GHG) EMISSIONS

To estimate the environmental impacts of the different scenarios, the calculation of GHG emissions (in tonnes of carbon dioxide equivalent; tCO_2e) from each stage of the value chain is integrated throughout the materials' flow model.

This means that for each process along the PET/polyester value chain, an emission factor was assumed. The emission factor was then multiplied by the respective material flow volume of the respective scenario. The total GHG emissions are the sum of the GHG emissions of all relevant processes for the respective PET/polyester category and scenario in a given year.

In order to arrive at this set of GHG emissions factors, assumptions were needed about the system. The first set of assumptions refers to the scope of the analysis and the second one to the calculation methods.

The assumptions made in relation to scope include:

i. Scope 3 GHG emissions associated with the use of PET/Polyester products (e.g., the wearing and washing of polyester textiles by consumers) are not accounted for.
ii. The process 'Design for recycling' does not generate GHG emissions.
iii. The process 'Elimination' does not generate GHG emissions (justification in sub-sections below)
iv. GHG emissions from transportation of exported materials are not considered.[91]
v. 100% of the outputs from PET depolymerization processes are constituted by monomer precursors to produce PET. The production of other by-products or chemicals is not modelled and therefore there are no GHG emissions associated with any non-PET polymer depolymerization process outputs.
vi. Mismanaged waste does not generate GHG emissions. Open burning of waste is not understood to be a significant practice in the US and PET waste that leaks into the environment is not considered to generate GHG emissions.
vii. Each GHG emission factor reported represents the absolute emissions per process, without including any related credits or savings (e.g. savings from energy production or other inputs of substituted materials). Only one exception is made, which is for the incineration of PET. Since the energy produced by this process in the US is used to produce electrical energy, or in some cases for heating energy, this emission factor considers the savings in GHG emissions that would otherwise be generated by conventional means to produce the equivalent energy or heat equivalent derived from the incineration process.

The assumptions made in relation to the calculation methods for the emission factors are:

i. Emission factors were sourced for today (2022-2023) and linearly decreased over time in line with the speed of decarbonization of the US grid between 2022-2040.
ii. The change in emission factors over time (2022-2040) was estimated according to the following considerations:
    a. Emission factors are impacted by decreasing emissivity from the US electricity grid mix due to the anticipated rate of adoption of renewable energy sources.

[91] We acknowledge that excluding transport emissions is a limitation given the US system. Doing so requires further research due to its complexity and uncertainty.

b. Incineration is the only emission factor expected to increase over time given that energy savings due to energy generation from waste-to-energy decrease as the electricity grid decarbonizes and this waste-to-energy becomes less beneficial.
c. Electrification of processes within the system's map is held constant i.e. processes do not become increasingly electrified over time, where they were not before.
d. Carbon capture and storage/utilization is not considered.
e. Emissions factors are applied consistently across all the modelled scenarios.

iii. For emission factors with low certainty or high variability in the literature, several sources were considered and averaged.

Below we present the calculations used to arrive at the GHG emission factors used in the model in greater detail.

Note that compared to Systemiq's study for the European PET and Polyester system ('Circular PET and Polyester: A circular economy blueprint for packaging and textiles in Europe'), emissions in the US study referred to in this document are significantly higher (relative to differences in PET/polyester consumption). This is largely due to the following factors:

- US polyester textile consumption is significantly higher
- EcoInvent has updated its emission factors for virgin production to include fugitive emissions
- GHG emission calculation in the US report considers imports of virgin PET/polyester as well as finished goods (see Table 15). Imports are allocated an average global emission factor, which is higher than US-specific emission factors.

TABLE 15. ASSUMPTIONS FOR IMPORTED VIRGIN PET/POLYESTER AND FINISHED GOODS.

PET packaging[92]	**Import of virgin PET (as share of total US virgin PET consumption for packaging)**	33%
	Import of finished PET packaging goods (as share of total US PET packaging consumption)	2%
Polyester textiles[93]	**Import of virgin polyester (as share of total US virgin polyester fiber consumption)**	88%
	Import of finished polyester textile goods (as share of total US polyester textile consumption)	88%

GHG EMISSIONS FOR VIRGIN PET/POLYESTER PRODUCTION

The GHG emission factors for virgin PET/polyester production correspond to the emissions generated by the production of PET/polyester out of purified terephthalic acid and ethylene glycol. The emission factors adopted are described in Table 16.

TABLE 16 - GHG EMISSION FACTORS FOR VIRGIN PET/POLYESTER PRODUCTION

[92] All based on expert input.
[93] All based on expert input.

Product category	Emission factor (tCO2e/t output)	Explanation
all PET packaging categories and polyester textiles that are domestically produced in the US	3.27	• US specific emission factor, assuming 100% of virgin PET for packaging is produced in the US • Based on European emission factor, which was sourced from Ecoinvent, and adjusted to the US context.
all PET packaging categories and polyester textiles that are imported into the US	3.89	• Global emission factor, which was sourced from Ecoinvent • Adopting a global emission factor accounts for the average emissions associated with virgin PET/polyester production in various geographies globally

GHG EMISSIONS FOR CONVERSION PROCESSES

The GHG emission factors for conversion processes correspond to the emissions generated by the transformation PET/polyester into final products. These processes begin by taking the PET material (usually in pellet form) as input and end with a finished packaging or textile product. Table 17 describes the emission factors used to estimate the conversion of PET into packaging products.

TABLE 17 - GHG EMISSIONS FACTORS FOR CONVERSION OF PET PACKAGING

Product category	Emission factor (tCO_2e/t output)	Explanation
• Beverage bottles (clear) • Beverage bottles (opaque) • Non-beverage bottles (clear) • Non-beverage bottles (opaque)	1.06 [94]	• US specific emission factor, assuming a combined injection molding and stretch blow molding process to manufacture bottles
• Thermoforms (clear) • Thermoforms (colored) • Other PET packaging	0.82	• US specific emission factor, assuming a thermoforming with calendaring process • Based on global emission factor, which was sourced from Ecoinvent, and adjusted to the US context • The same emission factor was assumed for other PET packaging as well due to the variety of processes to manufacture this product category and negligible GHG impact due to small volumes of this product category compared to the overall PET/polyester volume

[94] Franklin Associates (2023): Life cycle assessment of predominant U.S. beverage container systems for carbonated soft drinks and domestic still water. URL, accessed 11th July 2024.

For the case of conversion of polyester into textiles products, several sources were identified, and an average value of 14.3 tCO_2e/t output was selected as the GHG emission factor for this process. This emission factor is global in nature. Note that for textiles converted domestically in the US, we adjusted this factor to account for the difference in grid emission intensity in the US vs. global geographies. The adjusted factor is 13.8 tCO2e/t output.

The emission factor was assumed to be the same across all textile categories. The data and the different sources collected are described in Table 18.

TABLE 18 - GHG EMISSION FACTORS FOR CONVERSION OF TEXTILES

Product category	Emission factor *(tCO_2e/t output)*	Explanation
Textiles conversion Fiber to Fabric Reference #1	12.3 [95]	• Spinning and texturing: 0.55 kg CO_2/ t-shirt • Knitting/Weaving: 0.28 / 3.78 kg CO_2/ t-shirt • Pre-treatment: 0.39 kg CO_2/ t-shirt • Dyeing and Finishings: 1.2 kg CO_2/ t-shirt (emissions from garment production removed) • T-shirts per kg of polyester: 2.9
Textiles conversion Fiber to Fabric Reference #2	13.0 [96]	• Fiber production (without virgin PET production): 2.1 kg CO_2/ kg fiber • Yarn production: 2.7 kg CO_2/ kg fiber • Fabric production: 8.2 kg CO_2/ kg fiber
Textiles conversion Fiber to Fabric Reference #3	17.6 [97]	• Fiber production (without virgin PET production): 8.6 kg CO_2/ kg fiber • Yarn production, dyeing, weaving and knitting (emissions from garment production removed): 9.0 kg CO_2/ kg fabric
Textile conversion average	14.3	• This is a global emission factor • For textiles converted in the US, we adjusted this factor to account for US grid emission intensity. The adjusted factor is 13.8 tCO_2e/t output

GHG EMISSIONS FOR ELIMINATION AND REUSE OF PET MATERIALS

The GHG emission factors for the elimination and reuse correspond to the emissions generated by all those processes required to eliminate or reuse PET/Polyester products. For elimination, we assume 0 emissions as elimination is associated with a mass reduction of the PET/polyester which does not incur emissions.

For reuse, there is a lack of established emission factors due to the lack of scaled reuse systems in the US. Therefore, the estimated GHG emission factors correspond to the emissions generated by a series of real cases already present in the market, which are of special

[95] Massachusetts Institute of Technology (2015): Sustainable Apparel Materials. URL
[96] WRAP (2012): A carbon footprint for UK clothing and opportunities for savings. URL
[97] Ellen MacArthur Foundation (2017): A new textiles economy: redesigning fashion's future. URL

relevance or have a high potential to be expanded as well as previous Systemiq analysis. Table 19 shows the adopted emission factors and an explanation of these in detail.

TABLE 19 - GHG EMISSION FACTORS FOR ELIMINATION AND REUSE

Consumption reduction lever	Product category	Emission factor *(tCO_2e/t output)*	Explanation
Elimination	All PET packaging	0.0 [98]	• Elimination is framed as lightweighting across the packaging categories and additionally headspace reduction for thermoforms (e.g. in yoghurt pots or fruit trays). • The process of elimination does not create emissions.
	All textiles	0.0 [98]	• Elimination is achieved through reduction of manufacturing waste, reduced destruction of unsold stock and decreased speed of consumption (and therefore reduced textile production). • The process of elimination does not create emissions.
Reuse	All PET packaging	1.97 [98]	• Average reduction in emissivity against virgin PET production and conversion is -53% based on an average of four case studies and confidential Systemiq analysis • Reuse emission factor = (virgin PET production emission factor + packaging conversion emission factor) * (1 – GHG reduction) = (3.27 + (1.06 + 0.82) / 2) * (1 – 53%) = 1.97
	All textiles	0.0 [99]	• Emissions for reuse processing (collection, washing) are assumed to be negligible over the lifetime of the textile product

GHG EMISSIONS FOR EXPORTED MATERIALS

This GHG emission factor corresponds to those emissions produced by PET/Polyester products that are exported outside of the US, mainly in the form of waste. Because the destinations for this type of material are diverse, the estimates in GHG emissions correspond to the average distribution of plastic waste treatments. The Breaking the Plastic Wave report (Systemiq & Pew Charitable Trusts, 2020) makes an estimate of these destinations, together with the emission factors associated with each one. Figure 6 shows the calculation of the GHG emissions factor as a weighted average of the various end-of-life destinations for these materials.

[98] Plastic IQ (2021): Plastic IQ methodology document. URL
[99] Systemiq (2023): Circular PET and polyester: a circular economy blueprint for packaging and textiles in Europe – Technical appendix. URL

FIGURE 6 - GHG EMISSION ASSUMPTIONS FOR EXPORTED WASTE

GHG EMISSIONS FOR COLLECTION, SORTING, AND MECHANICAL RECYCLING

This GHG emission factor corresponds to those emissions produced by collecting, sorting, and mechanically recycling PET/polyester products. The emission factors adopted are described in Table 20. GHG emissions of different collection, sorting, and mechanical recycling pathways have not been modelled separately by product category. However, it is acknowledged that collection, sorting, and recycling pathways may differ across product categories.

TABLE 20 - GHG EMISSION FACTORS FOR COLLECTION, SORTING, AND MECHANICAL RECYCLING

Value chain step	Product category	Emission factor *(tCO_2e/t output)*	Explanation
Collection	Same emission factor used across all PET/polyester product categories	0.19	• US specific emission factor, which was derived from Ecoinvent. • The emission factor sourced from Ecoinvent was the emission factor for recycled PET, which combines collection, sorting, and mechanical recycling into one emission factor. • The emissions for collection were then derived based on the breakdown of the recycled PET emission factor
Sorting	Same emission factor used across all PET/polyester product categories	0.12	• US specific emission factor, which was derived from Ecoinvent. • The emission factor sourced from Ecoinvent was the emission factor for recycled PET, which combines collection, sorting, and mechanical recycling into one emission factor.

			• The emissions for sorting were then derived based on the breakdown of the recycled PET emission factor
Mechanical Recycling	Same emission factor used across all PET/polyester product categories	0.91	• US specific emission factor, which was derived from Ecoinvent. • The emission factor sourced from Ecoinvent was the emission factor for recycled PET, which combines collection, sorting, and mechanical recycling into one emission factor. • The emission factor for recycling was derived by subtracting the emissions from collection and sorting from the combined emission factor

GHG EMISSIONS FOR DEPOLYMERIZATION

The GHG emission factor for depolymerization corresponds to an average of the three main available technologies that show the greatest potential for commercial expansion by 2040: methanolysis, glycolysis, and enzymatic hydrolysis.

Various sources with evaluation of the environmental impacts on the depolymerization of PET were identified (see Table 21). Some of the sources adopted needed to be adjusted to account for differences in boundary setting and grid emission intensity:

1. Emissions in JRC report were estimated for a tonne of waste with 84% PET content (weight) as input. The data required was adapted to reflect 100% rPET as output.
2. Emissions in the JRC report were estimated based on European grid emission intensity. Hence adjustments to the emission factors were made to reflect US grid emission intensity.
3. System boundaries for one depolymerization process required complementing measurements for Methanolysis stopped at the production of PET precursors (TPA + EG), emissions for repolymerization and finishing stages (up to the production of rPET pellets) were therefore added in order to align with the process boundaries for other types of chemical PET recycling.

Table 21 shows the results of these calculations, as well as the average of the three technologies that was taken as the GHG emission factor for the PET depolymerization process. The three technologies are averaged without weight assuming that all three have the same potential for expansion in the near future.

TABLE 21 - GHG EMISSION FACTORS FOR DEPOLYMERIZATION

Technology	Product category	Emission factor - published	Explanation	Emission factor - adjusted	Adjustments
Methanolysis	Same emission factor used	0.6 [100] (tCO2e/t input)	- Emission factor per tonne of waste	1.2 (tCO2e/t output)	- Average between the

[100] Confidential expert input

	across all PET/polyester product categories	1.9 [101] (tCO2e/t input)	- Includes processing energy and materials up to PET granulate production		two technologies Only for JRC number:
Glycolysis	Same emission factor used across all PET/polyester product categories	0.6 [102] (tCO2e/t input) 1.3[103] (tCO2e/t input)	- Emission factor per tonne of waste containing 84% PET (weight)(as input) - Includes processing energy and materials up to PET granulate production	1.1 (tCO2e/t output)	- Increase to 100% PET waste linearly - Translate to output assuming 82% yield1assuming 100% output is rPET - No boundary complement. Granulate production assumed same as pellet production - Correction to US grid, assuming ~55% electricity contribution to GHG emissions: +0.26 kgCO2e/kg PET
Enzymatic Hydrolysis	Same emission factor used across all PET/polyester product categories	4.0 [104] (tCO2e/t output) 3.3 Error! Bookmark not defined. (tCO2e/t output)	- Includes processing energy and materials up to PET pellets - Emissions factors produced in USA	3.7 (tCO2e/t output)	- Average between the two technologies
Average depolymerization	Same emission factor used across all PET/polyester product categories			2 (tCO2e/t output)	

[101] JRC (2023): Environmental and economic assessment of plastic waste recycling. URL
[102] JRC (2023): Environmental and economic assessment of plastic waste recycling. URL
[103] Uekert T. et al. (2023): Technical, economic, and environmental comparison of closed-loop recycling technologies for common plastics. *ACS Sustainable Chemistry & Engineering*, 2023, 11, pp. 965-978. URL
[104] Uekert T. et al. (2023): Technical, economic, and environmental comparison of closed-loop recycling technologies for common plastics. *ACS Sustainable Chemistry & Engineering*, 2023, 11, pp. 965-978. URL

GHG EMISSIONS FOR INCINERATION AND LANDFILL

The GHG emission factors for these processes correspond to those emissions produced by landfilling and burning of PET/Polyester waste materials. The emission factors used in this study are described in Table 22.

For incineration, the heat energy produced in this process is assumed to be used to generate electricity or heating, which reflects current practices in the US. The use of this energy for applications is outside the PET/Polyester system and is not modeled in this study. For this reason, the emissions avoided to produce electrical energy or heating that would otherwise have occurred by conventional means (e.g. direct electrical energy production by the US grid, heat generation through natural gas combustion) are incorporated in the GHG emission factor in the form of credits.

TABLE 22 - GHG EMISSION FACTORS FOR INCINERATION AND LANDFILLING

Value chain step	Product category	Emission factor *(tCO_2e/t output)*	Explanation
Incineration	Same emission factor used across all PET/polyester product categories	1.2 [105]	• US specific emission factor • The GHG emission factor for incineration was sourced from Ecoinvent (2.1 tCO2e/t output) • GHG emission credits from waste-to-energy incineration were sourced from the WARM tool (-0.9 tCO2e/ t output).
Landfilling	Same emission factor used across all PET/polyester product categories	0.02 [106]	• US specific emission factor, which was sourced from the Environment Protection Agency.

[105] United States Environmental Protection Agency (2024). WARM tool – Version 16. URL
[106] United States Environmental Protection Agency (2022): PET – Landfilled. URL, accessed on 11th July 2024

5. MODEL ASSUMPTIONS FOR JOB CREATION

This chapter lays out the underlying job creation implications that have been calculated based on the modelled mass flows of PET/polyester in the US. Note that for calculating job creation, only direct job creation within the US has been considered.[107]

The job creation factors, measured in jobs per 1000 annual metric tonnes, are multiplied with the respective mass flows modelled. Table 23 provides an overview of these job creation factors.

TABLE 23. ASSUMPTIONS FOR JOB CREATION FACTORS.

		Job creation factor in jobs per 1000 annual metric tonnes
Production & conversion	Virgin production	0.8[108]
	Conversion (PET packaging)	11.4[109]
	Conversion (Polyester textiles)	2.8[110]
Collection	Formal collection for disposal (residual waste)	1.3[111]
	Formal collection for recycling (curbside and other)	2.5[112]
	Formal collection for recycling (DRS)	4.0[113]
Sorting	Sorting (MRF; packaging)	0.7[114]
	Sorting (manual textile sorting)	5.1[115]
	Sorting (MRF; optical textiles sorting)	0.7[116]
Disposal	Incineration	0.3[117]
	Landfill	0.3[118]
Reuse	Reuse of PET packaging	25.5[119]

[107] Quantifying indirect and induced job creation is subject to significant uncertainties but has significant impact on job creation (up to 2-4 times as much as direct jobs). To ensure that only domestic creation is captured, import and export assumptions for virgin PET/polyester as well as finished goods have been considered (see Table 15).
[108] Container Recycling Institute (2011): Returning to Work (URL).
[109] Tellus Institute (2011): More Jobs, Less Pollution (URL).
[110] Tellus Institute (2011): More Jobs, Less Pollution (URL).
[111] Container Recycling Institute (2011): Returning to Work (URL).
[112] Container Recycling Institute (2011): Returning to Work (URL).
[113] Expert input.
[114] Calculation based on Container Recycling Institute (2011): Returning to Work (URL).
[115] Systemiq analysis based on expert input.
[116] Assume same job creation factor as 'Sorting (MRF; packaging)' based on expert input.
[117] Container Recycling Institute (2011): Returning to Work (URL).
[118] Container Recycling Institute (2011): Returning to Work (URL).
[119] Systemiq analysis and expertise.

	Reuse of polyester textiles	100.0[120]

6. FURTHER INSIGHTS FROM SCENARIO MODELING

This section provides further insights from the scenario modeling, to complement Chapter 3.

Exhibit: 2040 Current Trends Scenario PET/polyester flows

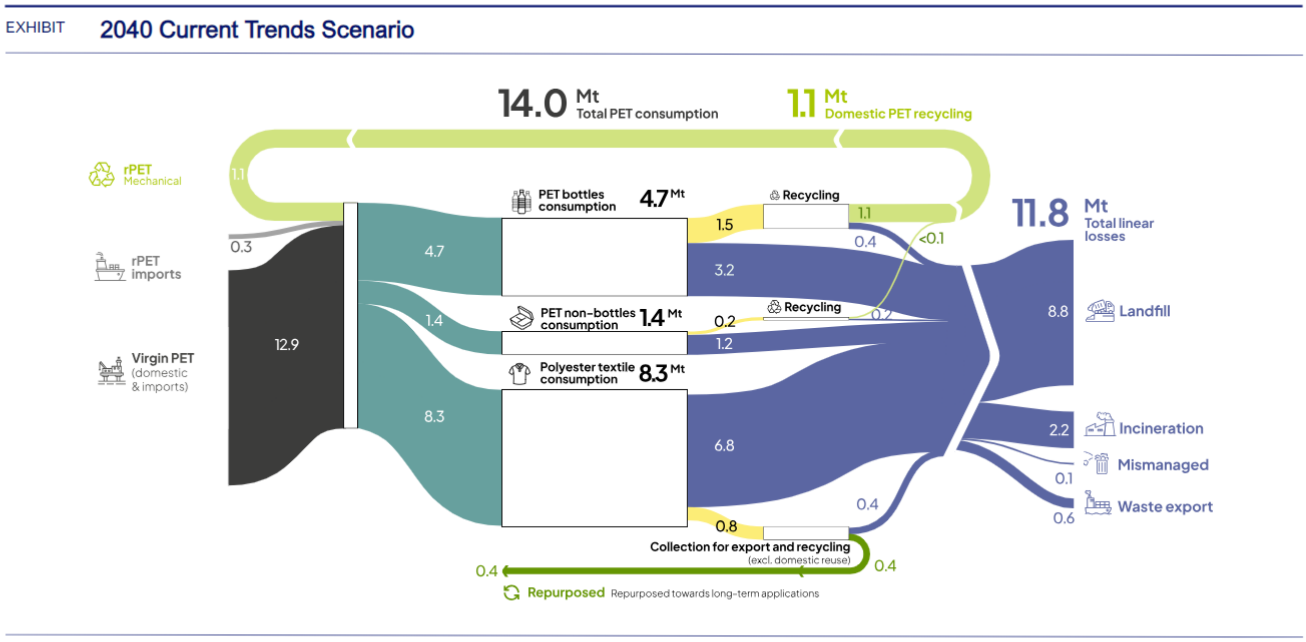


Exhibit: Projected recycling rates in the Ambitious Circularity Scenario varies significantly between PET/polyester applications, with beverage bottles able to achieve high recycling rates in some states with assumption of effective adoption of well-designed Bottle Bills (Deposit Return Systems)

120 Systemiq analysis and expertise.

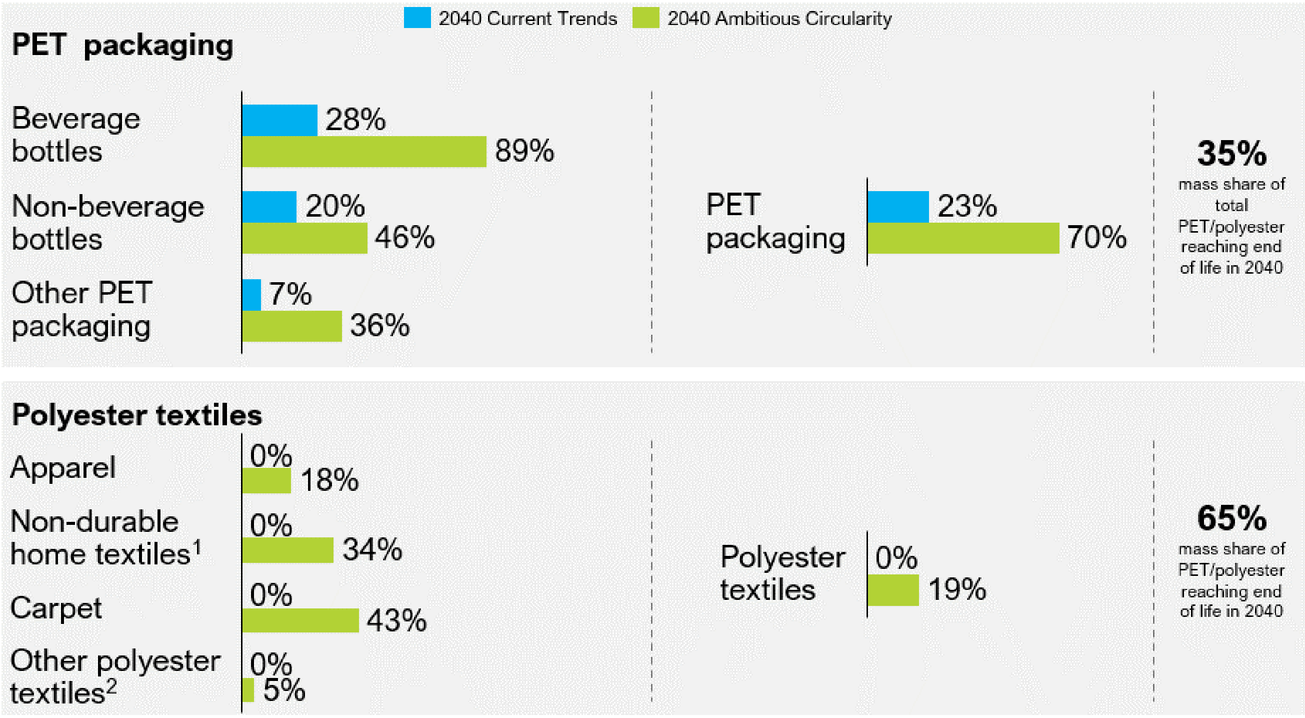
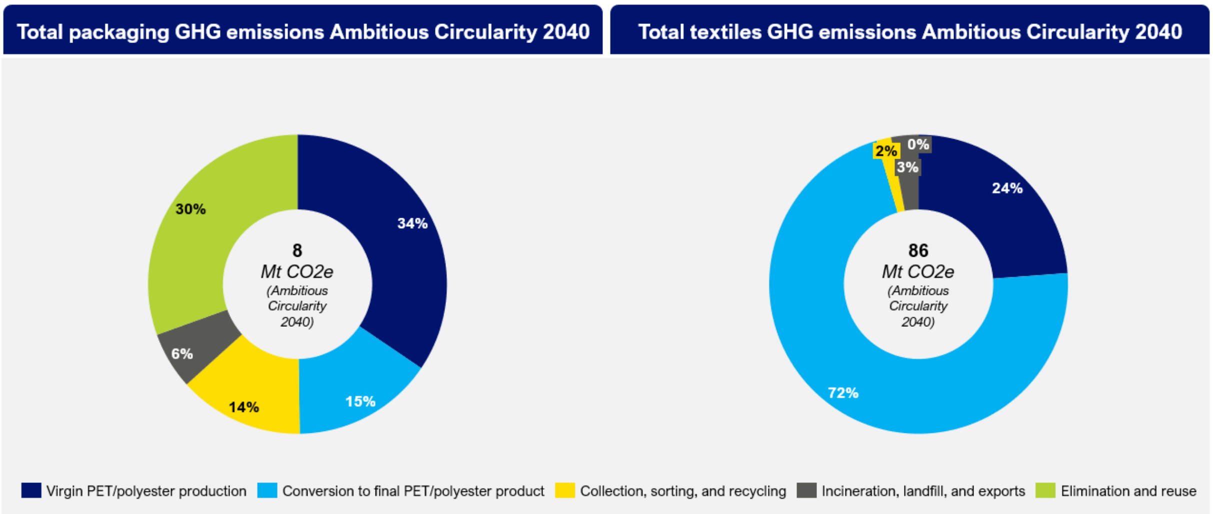


Exhibit: Significant further GHG emissions reductions, beyond the Ambitious Circularity Scenario, are primarily dependent on reducing emissions from the production and conversion of polyester textiles



Key insights:

- GHG impact reductions are driven by Reduced production and conversion volume through elimination and reuse in Ambitious Circularity 2040 as well as decarbonization of production and conversion processes.
- For textiles, annual impact reductions through elimination and reuse are less profound due to longer lifetimes of textiles compared to packaging. Additionally, decarbonization effects in production and conversion of textiles are less pronounced due to global scope of production and conversion operations, where energy grids are expected to decarbonize more slowly than in the US (see technical appendix).